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Unpacking Pandora's Box: Understanding and Categorising Ecosystem Disservices for Environmental Management and Human Wellbeing

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Abstract

Research into the benefits that ecosystems contribute to human wellbeing has multiplied over the last few years following from the seminal contributions of the international Millennium Ecosystem Assessment. In comparison, the fact that some ecosystem goods and services undermine or harm human wellbeing has been seriously overlooked. These negative impacts have become known as ecosystem disservices. The neglect of ecosystem disservices is problematic because investments into the management or reduction of ecosystem disservices may yield better outcomes for human wellbeing, or at a lower investment, than management of ecosystem services. Additionally, management to optimise specific ecosystem services may simultaneously exacerbate associated disservices. We posit that one reason for the neglect of ecosystem disservices from the discourse and policy debates around ecosystems and human wellbeing is because there is no widely accepted definition or typology of ecosystem disservices. Here, we briefly examine current understandings of the term ecosystem disservices and offer a definition and a working typology to help generate debate, policy and management options around ecosystem disservices. We differentiate ecosystem disservices from natural hazards and social hazards, consider some of their inherent properties and then classify them into six categories. A variety of examples are used to illustrate the different types of, and management strategies to, ecosystem disservices.

Key words: definition; ecosystems disservices; management; typology.

Introduction

Since the publication of the Ecosystem Millennium Assessment summary reports in 2005, there has been a surge in research (and funding) into various aspects of ecosystem services (Fisher and others 2009; Shapiro and Báldi 2014). Core areas have included validating and quantifying their links to

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human wellbeing (for example, Santos-Martin and others 2013), management needs and approaches to improve or secure supplies of priority ecosystem services (for example, Banerjee and Bark 2013), and lastly, how to deal with trade-offs between different ecosystem services from the same area of land or under competing management objectives (for example, Chrisholm 2010; van Oudenhoven and de Groot 2013). The number of published research articles has increased exponentially (Fisher and others 2009). This is because the central message embodied in the ecosystem services mantra, that is, that healthy and productive ecosystems underpin all facets of human wellbeing, is an attractive vehicle for advocating for conservation and wise land use (Lyytimäki and others 2008; Lele and others 2013; Villa and others 2014). It has the potential to sway politicians and decision-makers, because if they ignore it, they run the risk of making decisions and implementing policies or programmes that may in fact undermine the wellbeing of their constituents in the medium to long term.

Whilst few would argue that ecosystems do not provide the processes and materials for a healthy and good life, this mantra has eclipsed that the opposite also holds true, particularly for the poorer and more vulnerable societies and peoples in the world. In other words, ecosystems also produce and deliver a variety of goods and services that undermine human wellbeing, or, as succinctly stated by Dunn (2010), ''nature sometimes kill us''. These have become known as ecosystem disservices (Lyytimäki 2014, 2015) (EDS), and have been equated variously to the costs of environmental management, externalities to production systems, negative impacts, ecosystem functions from disturbed or degraded ecosystems or the ''bads'' that ecosystems deliver (Table 1).

Compared to the ever-increasing deluge of research papers on ecosystem services, EDS have scarcely garnered attention (Lyytimäki and others 2008; Ninan and Inoue 2013; Lele and others 2013). The seminal Ecosystem Millennium Assessment (2005) hardly mentions EDS. The number of publications explicitly dealing with EDS is several orders of magnitude lower than those reporting on ecosystem services. Consequently, there is little debate, quantification or understanding of the dynamics and underlying processes of EDS and their ramifications for human wellbeing (Anon 2009; Lyytimäki and Sipilä 2009; Ninan and Inoue 2013). There is a robust literature on natural disasters and risk avoidance or mitigation, as well as environmental diseases and pests but these have rarely been presented or consulted within the ecosystem services or EDS frameworks or the literature on ES. This absence of EDS from relevant environmental management discourses is reflected by there being no universal definition or typology, unlike their positive counterparts (that is, ecosystem services). Indeed, it may be the very absence of a definition and functional typology that underlies the absence of EDS from relevant debates and policies. Other reasons may include a feeling of helplessness against certain EDS as well as their variable nature in both frequency and magnitude (Lyytimäki and Sipilä 2009). Some may be present at low background levels for long periods, to suddenly flare up with significant negative impacts (for example, outbreaks of pests). This unpredictability in timing or magnitude presents substantial modelling and management challenges. But EDS cannot be addressed by simply ignoring them or by post hoc management of their often severe impacts on human wellbeing.

This neglect for EDS from the research and policy discourses around ecosystem services and their management is problematic for several reasons. Firstly, they are real and so environmental management systems need to take them into account; if they do not, then there is a tangible risk that the management objectives and outcomes will not be attained, or to only a lesser degree. Secondly, many EDS significantly undermine human wellbeing. Thus, failing to recognise and address them in policies and programmes will mean that the positive links between ecosystem services, biodiversity and human wellbeing will be constrained or suboptimal. Thirdly, the hoped for outcome of improved human wellbeing through conservation and management of ecosystem services may be better or more cost-effectively achieved through the reduction or mitigation of EDS rather than promoting ES (for example, pest control programmes). Lastly, policies and management interventions to promote or secure a particular ecosystem service, or bundle of services, may also simultaneously increase (or decrease) the number or magnitude of some EDS, resulting in either no improvement, or a decline, in human wellbeing even though the supply or quality of the target ES and benefits have improved. A one-sided focus on ecosystem services is insufficient, because optimisation of a particular ES may also increase an associated EDS; in other words, there must be wider recognition of the inherent complexity of ecosystem management and the connectivity between ES, biodiversity and EDS at multiple scales (Gómez-Baggethun and Barton 2013; Lyytimäki

Table 1. Illustrative Descriptions of Ecosystem Disservices (in Chronological Order)

Description	Source
Ecosystem disservices as economic externalities	Ayres and Kneese (1969)
The absence or diminishment of a valued ecosystem service or biodiversity	Chapin and others (2000)
Negative effects of ecosystem change	Balmford and Bond (2005)
Environments do not act for the benefit of any single species (Nature sometimes kills us)	McCauley (2006)
Agriculture receives an array of ecosystem disservices that reduce productivity or increase costs (for example: herbivory and competition for water)	Zhang and others (2007)
Ecosystem disservices are functions of ecosystems that are perceived as negative for human well-being	Lyytimäki and Sipilä (2009)
The apparently unmentionable negative economic impacts of nature—ecosystem disservices	Dunn (2010)
Management practices also influence the potential for disservices from agriculture, including loss of habitat for conserving biodiversity, nutrient run off, sedimentation of waterways, and pesticide poisoning of humans and non-target species	Power (2010)
Although a few birds cause economic damage, at the ecosystem level the services provided by birds are overwhelmingly positive	Wenny and others (2011)
Functions and structures of an ecosystem that have negative consequences on human life are referred to as ecosystem disservices (but later in the paper they also mention financial costs of management as disservices)	Dobbs and others (2011)
Ecosystem disservices are defined as costs and end-products (incl. management costs such as irrigation or pruning of trees)	Escobedo and others (2011)
Although focus is on the benefits produced, it includes also negative social or economic effects of ecosystems to human well-being, so-called 'disservices'	Bastian and others (2012)
Harmful ecological impacts such as excessive drainage or eutrophication	Swain and others (2013)
Ecosystem disservices are functions or properties of ecosystems that cause effects that are perceived as harmful, unpleasant or unwanted	Lyytimäki (2015)

2015). For example, planting trees in cities has benefits regarding the provision of numerous ES [such as carbon sequestration, pollution abatement, aesthetic enhancement (Roy and others 2012)], but it also provides EDS, such as allergens from the pollen, leaves blocking stormwater drains, roots cracking pavement and residents' fears of increased crime. Similarly, restoring wetlands provides many ES for human wellbeing, but in some parts of the world it also promotes the incidence of diseases such as bilharzia or malaria (Malan and others 2009). Clearing more land for agriculture potentially improves food supply, but it may also increase EDS such as pests, weeds and increased leaching of soil nutrients (Zhang and others 2007). It is intriguing that the bulk of the few papers dealing explicitly with EDS focus on significantly transformed ecosystems, notably agricultural (Dale and Polasky 2007; Zhang and others 2007; Power 2010) and urban (Lyytimäki and others 2008; Lyytimäki and Sipilä 2009; Dobbs and others 2011; Escobedo and others 2011; Gómez-Baggethun and Barton 2013), with little examination of EDS in more natural or less transformed ecosystems.

Paradoxically, although EDS are rarely mentioned in research and management programmes around ES, knowledge of their impacts amongst ordinary citizens is probably more widespread and appreciated, due to significant media attention to negative news (Lyytimäki 2015), than the positive, but frequently unrecognised benefits of many ecosystem services (Shapiro and Báldi 2014). For example, when considering snakes within an ecosystem, most lay people will immediately express the danger of being bitten; few will immediately identify their roles in regulating potential pests such as rodents. Similarly, if mentioning floods, most respondents will conjure up images or stories of the loss of bridges, houses and other infrastructure, and very few will instantly consider the deposition of nutrient-rich sediments useful for arable agriculture. It is thus taken for granted that EDS need to be controlled because of their undesirable impacts, but many are a downside of a desirable ES.

With due examination it might be revealed that the benefits of ES management do outweigh the costs or negative impacts resulting from EDS, but it is clear from the above that (i) ecosystem services cannot be examined in isolation from EDS as they are part of a continuum, and (ii) the relative magnitudes of specific EDS are variable in time and space. Thus, understanding the biophysical, social, economic and political contexts in which EDS can be successfully minimised (or controlled) is vital for seeking ways to optimise human wellbeing through ecosystem management. To date, this has not been addressed and represents a noticeable lack in understanding of the links between ecosystems and human wellbeing (Ninan and Inoue 2013). Consequently, there is need to advance recognition and appreciation of the importance of EDS. We offer that the starting place is to debate a working definition or description of what they are, along with a practical and robust typology of what are and what are not EDS, which is the objective of this paper. We start by offering a working definition of EDS. As further explanation of the definition we also consider what EDS are not by drawing on examples in the literature. In the second section, we briefly present some characteristics of EDS before offering a typology into six classes as an approach to reduce the variation and allow more specific debates and management responses relative to specific types of EDS. In the last section, we contemplate broad strategies for EDS management.

Defining Ecosystem Disservices

Although there is little by way of a widely accepted definition of EDS, several authors have put forward their understandings of the term or attributes which they believe best describe them. We summarise several in Table 1 to illustrate the range.

Although most of these convey the central concept of the term, the specifics are frequently undeveloped. Some have commented that EDS are simply the absence or diminishment of a valued ES or biodiversity (Chapin and others 2000). We suggest that this is unsatisfactory because (i) the cause/origin of an EDS may be different from that of the ES, and thus the focus only on capturing the negative impact on ES misses the nature of the EDS causing that impact (for example, soil erosion as an EDS is caused by water or wind moving soil particles, whereas erosion control is a function of the type, abundance and position of vegetation that may slow or stop the movement) and (ii) the reduction in ES might not be caused by ecosystem attributes. Escobedo and others (2011) and some others view disservices as largely the costs associated with obtaining or managing specific ES and that they are also an end product. But many costs associated with securing or managing an ES do not originate from the ecosystem. For example, erecting a fence around a national park is a monetary cost, which we argue should not be viewed as an EDS because it is not generated by the ecosystem, but rather by human need or desire to manage or secure an ES. This is an economic approach (also taken by Zhang and others (2007) and Dobbs and others (2011) to some extent) that does not account for the social or ecological components. In discussing the relevance of EDS to agriculture, Zhang and others (2007) define them as ‘‘services that decrease productivity or increase productivity costs’’. From our perspective, this too is insufficient because (i) its application to only agricultural systems is too narrow a definition to be useful across the full range of land uses and ecosystems, and (ii) it does not relate those to impacts on human wellbeing, which is the widely accepted departure point of ecosystem services, and therefore, from an integrated perspective, also disservices. In assessing the definitions or descriptions offered to date, we propose that any definition should be explicit regarding (i) that the cause/delivery of the EDS is from an ecosystem attribute or process rather than a human action that has detrimental impact for an ecosystem or ES and (ii) that it results in detrimental consequences for one or more dimensions of human wellbeing rather than on the provision of an ES.

A convenient approach would be to define it as the converse of ecosystem services, such that they would be the conditions and processes through which natural and modified ecosystems and the species that make them up, undermine or harm human life and wellbeing at various scales. As succinctly stated by Lyytimäki and Sipilä (2009), they can be regarded as ‘‘functions of ecosystems that are perceived as negative for human wellbeing’’. They elaborated by explaining that EDS can be a result of natural phenomena, as side effects of human actions or modifications to ecosystems or entirely human made. We add to this by recognising that it is not just a function, but could also be a single attribute or species, whilst we differ in that we do not regard anything that is human made as an EDS. Thus, we propose a working definition of EDS as:

> Ecosystem disservices are the ecosystem generated functions, processes and attributes that result in perceived or actual negative impacts on human wellbeing

Manifestation can be via three ways. The first is through the impact of an ecosystem process or attribute on human wellbeing directly, such as a pollen allergens or a snake bite. The second may be the diminished flow of an ES caused by an EDS, such as crop pests. The third is the loss or impairment of a supporting or regulating service caused by an EDS, such as primary production loss following a wildfire. The key is in differentiating EDS from ES that may be provided by the same process or component. For example, urban trees may sequester carbon, which is seen as a regulating ES and provide fruit (a provisioning ES), but they can also provide allergens (an EDS). In this example, the tree is not the EDS or the ES, but rather it is the provider of both EDS and ES (which may also be perceived or experienced differently by different people). Thus, the final differentiation is on how it impacts human wellbeing.

EDS may originate from any ecosystem, irrespective of the level of human influence or activity within them. Given that it is widely recognised that human-modified natural systems also deliver some ecosystem services we include modified systems (for example, agricultural, urban, cultural landscapes). Due to the focus on the 'impacts to human wellbeing' human-induced alterations to ecosystems would not be considered as an EDS, but if their effects result in changes to the ecosystem processes or functions which in turn cause a decline in human wellbeing they would then be considered as EDS.

Negative impacts of EDS may be actual losses which are undoubtedly detrimental to human health or wellbeing, or from perceived losses which are largely dependent on social viewpoints (Dunn 2010; Lyytimäki 2015). We agree that although the latter effects are more context specific and harder to define, both are equally valid and cause very real impacts on or changes in human behaviour and wellbeing, and consequently, at times, landuse and management decisions. In the same manner, some ES are also hard to measure and are perceived differently by different people, such as aesthetic benefits (Chan and others 2012).

What Ecosystem Disservices are not

Within the limited literature on EDS numerous examples of EDS are provided, many of which are independent of the MA (2005) classification of ES or explicit links to ecosystems and their outputs, either positive or negative. For example, Lyytimäki and Sipilä (2009) mention a person dropping litter in an urban park as an EDS. According to our definition, and the MA (2005) classification, this would not be an example of an EDS because the dropping of litter is not an outcome of an ecosystem process. Thus, in strengthening the debate around the importance of EDS for human wellbeing it is necessary to avoid it becoming a catch-all for any behaviours, sentiments, events or phenomena that may have some negative impact on human wellbeing at various scales. To this end, we briefly describe four types of events or behaviours that we argue are not EDS when subject to close scrutiny. Exclusion of phenomena is an important part of any classification system and allows for better understanding and focus on agreed categories.

Reduced or Constrained Supply of an Ecosystem Service is not an EDS

Ecosystems provide a variety of services and benefits to humans. These have been classified as provisioning, regulating, cultural and supporting by the MA (2005). In some instances, the direct links to the welfare of a specific group of people is obvious (for example, rural villagers needing firewood for cooking) and in other instances the link is less obvious to the beneficiaries (for example, pollination services of crops consumed by urban residents). The supply of these ES is inherently spatially and temporally variable, at times resulting in a constrained supply, as may certain human actions also constrain supply. However, it is not the absence or constrained supply of an ecosystem service that is the EDS (as suggested by Power 2010 (Figure 1)), but rather the cause of the constrained supply if it is from an ecosystem function, process or attribute. For example, a disease resulting in reduced pollination; in which case the disease is the EDS and the reduced pollination is a lowered supply of an ES, which results in lower ES benefits, that is, food. The EDS *results* in a constrained supply, rather than the EDS *being* the constrained supply. The constrained supply of a specific ES may also be a direct consequence of human action, that is, harvesting of firewood or medicinal bark, abstraction of water, but such human actions are not EDS but are simply negative impacts on, or degradation of, ES supply.

Events or Phenomena that Have no Ecosystem Origin are not EDS

As noted earlier there is a well-developed literature and understanding on natural hazards and disasters. The more devastating ones are those that arise suddenly and impact large spatial scales, such as earthquakes, tsunamis or volcanic eruptions. The question becomes, are these EDS? In sharing the word 'ecosystem', it is clear that the concept of EDS is embedded in the concept of ecosystems. An

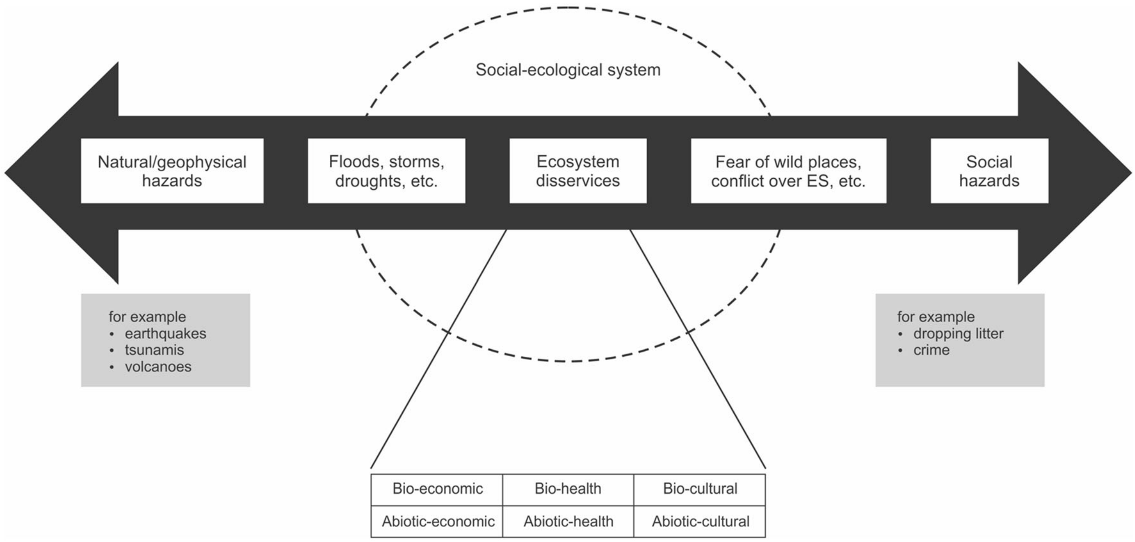

Figure 1. Ecosystem disservices within the continuum from natural to social hazards. The social-ecological system boundary is not solid to reflect that the boundaries between ecosystem disservices and other harmful phenomena (termed hazards) are usually fuzzy

ecosystem is taken to be an identifiable suite of interacting biological organisms and the physical environment which supports them. We read the presence of biological organisms (biodiversity), processes and interactions as differentiating elements. Therefore, by that reasoning, a phenomenon such as an earthquake, which has no biological attributes, origins (although it can have biological consequences) or links to biological processes would not be deemed as an EDS, but rather as a natural hazard, or perhaps a geo-physical disservice. However, we acknowledge that some natural hazards, for example, droughts and floods, can also, at times be triggered or exacerbated by changes in biological processes, though they can happen with or without the influence of biological processes, which results in some fuzzy boundaries. Consequently, we envisage it as a continuum rather than discrete classes. To that end, we have placed natural/geo-physical hazards on the left of the continuum in Figure 1, which is differentiated from social hazards at the opposite extreme. Nevertheless, we recognise that hazard events or phenomena that have a link to biological process qualify to be EDS. Ecosystem disservices, the topic of this paper, fall in the middle of the continuum and originate in or from an ecosystem and are manifest in social-ecological systems (Lyytimäki and Sipilä 2009), as are ES. They are therefore likely to require different policies and responses to both natural and social hazards.

Social Responses To or Within Natural or Transformed Ecosystems are not an EDS

As mentioned above, the dropping of litter has been used as an example of an EDS by Lyytimäki and Sipilä (2009). The same might therefore be said about graffiti or aesthetically unpleasing architecture or car design. These are all examples of human behaviours and values that are typically divorced from ecosystem functions and processes. Whilst we accept that humans are an integral component of ecosystems, humans themselves and their actions do not constitute ecosystems (but can impact on ecosystems and be impacted on by ecosystem processes). As described, we argue that there has to be some fundamental non-human biological or natural elements to constitute an ecosystem, and hence also an EDS.

Land Management Actions that Impact Biodiversity or Transform Ecosystems are not an EDS

Humans transform and manage landscapes in many ways that alter ecosystem structure, function, processes and composition. Some of the management actions may have unintended negative impacts. Power (2010), for example, mentions the application of pesticides that results inadvertently in the loss of biodiversity as an EDS. From our definition, such an action would not be an EDS for two reasons. Firstly, it does not have an ecosystem origin. The pests against which the pesticides were applied would constitute an EDS; but the negative consequences of human management actions to control a specific EDS, or even manage an ES, are not themselves an EDS. Secondly, the described impact is not on human wellbeing, but on biodiversity.

Characteristics of Ecosystem Disservices

EDS are complex phenomena, and therefore, highlighting and understanding their characteristics and their associated challenges are important (Fisher and others 2009), especially those underlying their inherent complexity. They share many characteristics in common with complex phenomena, including ES and general social-ecological systems (Fisher and others 2009). But these warrant elaboration and illustration from an EDS perspective as it helps the reader (and the manager) better conceptualise and understand EDS in terms of the definition offered. We start off with six general characteristics and end with four that are more specific to EDS than ES. However, it is necessary to appreciate that many ES and EDS are intimately linked and can be viewed as the opposite sides of the same coin; for example, floods as an EDS and flood attenuation or control as an ES. The damage caused by floods as an EDS and the impacts on human wellbeing will depend to a large degree on the presence of vegetation to buffer infrastructure and lives, that is, the ES.

As previously mentioned, some species or processes may offer both positive and negative benefits to humans at different times. For example, large charismatic mammals (such as hippopotamus, lions or elephants) frequently have high existence or cultural values represented in the ecotourism revenues that they attract, but when individuals of that same species attack visiting tourists or people living close by, then they represent an EDS (Lele and others 2013). Similarly, throughout the savannas of the world wildfires are viewed positively by pastoralists for stimulating a flush of new growth for herbivores and reducing populations of harmful parasites and poisonous plants. But when such fires damage infrastructure, crops, livestock, harmless wild animals and even human life they may be viewed in a totally different light. Trees planted along city streets are welcomed for the biodiversity they represent as well as the multiple benefits such as shade and beauty, but when their leaves or flowers despoil the pavements or block the stormwater drains, then they are regarded as an EDS. All these examples indicate that how an EDS is identified or viewed depends upon the perspectives and experiences of the viewer, which are embedded in local cultures, values, norms and perceptions. In this way, the flow parallels that of Chan and others (2012) who differentiate services from benefits from values. Here the flow would be disservices, costs (an accounting measure of the loss, often in monetary terms, but need not be) and losses (the felt impairment or elimination of amenity or benefit).

Pertinent attributes of EDS as drivers and components of complex systems include the following six characteristics important for their understanding and management.

EDS Operate at Variable Spatial Scales

EDS occur at multiple scales. A pest outbreak may affect a single field through to several square kilometres to thousands of square kilometres, as may a flood event, or the challenges posed by invasive alien species. The management responses and resources required to eradicate or mitigate them must therefore be commensurate with the scale of the event.

EDS Operate at Variable Temporal Scales

A key aspect of EDS is that they occur widely and, for some types, even frequently, but the precise timing is irregular. The frequency of some may be measured at scales of seasons (for example, agricultural pests), others over years (for example, wildfires), others more at decades (for example, droughts and floods) and some over centuries (for example, nutrient leaching or soil erosion, aesthetics of landscape change). Mismanagement of ES may result in a change in the temporal scale at which certain EDS occur.

EDS may be Interactive via Direct and Indirect Feedbacks

Many EDS do not occur in isolation, but interact with one another which may compound the ultimate impacts on human wellbeing. For example, invasive alien plant species with high biomass have impacts on biodiversity, water, nutrients and aesthetics, but simultaneously they may increase the fuel loads for wildfires, sometimes with devastating effects. Similarly, people suffering the debilitating effects of tropical disease such as malaria are less able to combat other EDS. Such interactions make the prediction, management and mitigation of EDS a far more complex task than dealing with them on an individual basis.

Many EDS Exhibit Threshold Phenomena and Non-linearities

For many EDS their occurrence may be dependent on particular threshold conditions having been met (Escobedo and others 2011). One example might be wildfires, which do not pose a threat to human wellbeing until a combination of particular conditions are in place, namely sufficient fuel load, appropriate weather conditions and an ignition source. All three must be in place simultaneously and for the first two, must be above certain minimum levels for a wildfire to be sustained. In a similar fashion, locust outbreaks in Australia are dependent on particular climatic conditions. The production of allergens by urban trees is only problematic when there are sufficient densities of allergen producing species and appropriate weather conditions to trigger flowering. Understanding these thresholds and conditions is one of the key areas for future research into EDS and their mitigation.

EDS Impacts are not Equal Across Different Socio-economic Groups

As with ecosystem services, some people or sectors of society are more at risk to the impacts of specific EDS than others. Not unsurprisingly, people whose livelihoods are directly and immediately dependent on the productivity of the natural environment (farmers, fishers, pastoralists) are at risk to a greater range of EDS than people less directly reliant on the immediate environment (such as urban dwellers), although the latter are not immune. Additionally, the local context may make people more at risk in some locations than in others, such as those living in floodplains, on steep slopes or in marginal areas. Another clear differential is in the ability to cope with the impacts; poorer societies and households will be less able to cope than more affluent societies or households. Often the poverty or wealth dimension is overlaid with the location or context just mentioned, that is, risky environments are more likely to be home to poorer people than wealthy ones. This requires an environmental justice perspective in analysing and responding to EDS.

Perceptions of EDS are Context Specific

Perceptions of EDS are not static, but differ between individuals of differing lifestyles, cultures, ages, education and experience of the EDS (Escobedo and others 2011). Young and fit people are not as prone to environmental diseases and sicknesses as are the elderly or newborns. Educated urbanites are in favour of carnivore reintroductions into Europe, whereas rural dwellers and farmers are more likely to be against it because they are more familiar with the negative consequences (Bostedt and others 2008). A tree may be aesthetically pleasing to one party, but may provide allergies to another. Thus, the same function may be valued as a service or a disservice, depending on the individual, community or society valuing it (Lyytimäki and others 2008). Consequently, any debate and management interventions around EDS needs to consider to whom it is an EDS?

The following four characteristics are more specific to EDS than ES or complex systems generally.

EDS Undermine Human Wellbeing

This is the subject of the paper and has already been extensively argued. This is the core of the EDS concept and definition and should be sufficient to galvanise policy- and decision-makers into action and encourage managers to seek ways to mitigate or eliminate EDS.

EDS Can Have Long-Lasting Impacts

EDS are variable in space and time and thus so are their impacts. Importantly, and the reason for our call for greater attention to EDS, is that their impacts can be long lasting. At the scale of an individual household, the death of a household member due to malaria can have major impacts on the future abilities of that household to survive, cope or make a living, and perhaps even compromise the wellbeing and opportunities of the next generation. At a landscape scale, steadily increasing densities of invasive alien species can irreversibly alter streambed morphology and subsequent runoff patterns. At larger scales, floods may destroy homesteads, economic and social services and infrastructure (roads, bridges, pipelines, telecommunications, schools, hospitals) which can take years or decades to replace.

The Frequency of Occurrence Can Be Highly Irregular

Not only do EDS operate at variable temporal scales, they may also be highly irregular. For example, drought prone regions may experience several droughts in a single decade and then only once in the following decade. Certain agricultural pests may be permanently present at low background levels without any cause for concern, or perhaps at a nuisance level, only to erupt as a major outbreak under specific conditions. This irregularity complicates the allocation of human and financial resources to combat the impacts. Early detection or warning systems may be established for those EDS with severe impacts over large spatial scales, but nonetheless, precisely when a drought, wildfire or viral outbreak will occur is currently an imprecise science for most EDS. It is here that research agencies can potentially make large contributions by increasing the level of certainty and predictability of EDS events which will allow early mobilisation to reduce the anticipated severity of impacts on human wellbeing (as has been done for some severe pests).

The Impacts Can Be Extremely Sudden

This is a combination of both the general threshold phenomenon and the variable time scales, which results in the onset of many EDS being extremely sudden, which is not a characteristic of the supply of most ES. A wildfire, a flood, a locust outbreak, the onset of a dire disease often happens on the scale of minutes, hours or a few days, which increases the probability of catching authorities and those households or populations most at risk more unawares. Consequently, improved monitoring, predictive capacity and early warning systems are important tools in the management or mitigation of EDS.

Categorising Ecosystem Disservices

EDS negatively impact human wellbeing (Lyytimäki and others 2008; Dunn 2010) and peoples' perceptions of EDS vary according to their context, lifestyle, culture, age and experience (Lyytimäki and others 2008; Lyytimäki 2015). There is also widespread variation in the types, intensities and origins of EDS. These differing perceptions, impacts and natures of EDS can result in sub-optimal management approaches because different types of EDS require different approaches. Therefore, a core step is development of a typology as the basis for improved understanding, measurement and management (Lyytimäki and others 2008; Dunn 2010). In the same way, ES have been categorised into four broad groups (provisioning, regulating, supports and cultural) which are now widely adopted, despite fuzzy or overlapping boundaries in certain contexts (Boyd and Banzhaf 2007; Wallace 2007; Fisher and others 2009), and which guide research, management and policy focus in different settings. As yet, there is no corresponding widely accepted typology for EDS. Lyytimäki and others (2008) classified them into aesthetic issues, safety issues, security and health issues, economic issues and mobility issues. Escobedo and others (2011), on the other hand, categorised them into financial costs, social nuisances and environmental pollution. The authors only based their classification on the impact types of EDS to human wellbeing and some of them briefly mentioned the causes of EDS which can be natural or anthropogenic. Potential axes of differentiation for the basis of a typology include (i) magnitude or severity of impact, (ii) spatial extent, (iii) frequency of occurrence, (iv) extent to which it can be controlled or mitigated, (v) dimension of human endeavour or wellbeing affected, (vi) components of the ecosystem from which the EDS originates, and (vii) the ES directly affected by the EDS. Given that our definition is based on two aspects, namely the ecosystem origin of EDS and their impact on human wellbeing, we maintain the same logic in proposing a classification framework.

EDS are diverse and have different origins. By origin, we want to identify the ecosystem component that generates a specific EDS directly or through its diverse functions or processes. Like ES, EDS can be provided by biological or abiotic components of ecosystems that are linked directly or indirectly to biological process within an ecosystem. In as much as ecosystems have biotic (biological/living) and abiotic (non-living) components they are defined by a network of interactions, functions and processes among organisms, between organisms and the environment. As a result, we acknowledge that some processes and interactions within the ecosystem can produce EDS within both the biological and abiotic components. For example, changes in ecological processes like evapotranspiration, nutrient cycles and energy flows can trigger atmospheric or even natural forest changes that can contribute to droughts, floods and storms making these EDS that have an abiotic component but are linked to biological processes within the ecosystem. The above distinguishes between natural hazards that do not have a biological process linked to them, for example, earthquakes and volcanoes to those that have an ecological process linked directly or indirectly to them, for example, droughts and floods. The question is on the magnitude of the ecosystem process contribution to the natural hazard to warrant its inclusion as an EDS, a question that is beyond the scope of this review.

In a similar fashion, EDS can impact different aspects of human wellbeing. Firstly, EDS can induce a decrease in the physical and/or mental health and safety of humans (for example, diseases). Secondly, EDS may cause socially constructed and defined aesthetic and cultural impacts

Table 2. Categories and Examples of Ecosystem Disservices According to Origin and Nature of Impacts

	Primary dimension of human wellbeing affected		
	Economy	**Physical and mental health and safety ('health')**	**Aesthetic and cultural ('Cultural')**
Ecosystem origin			
Biological	• Invasive species • Agricultural and fisheries pests and diseases • Red tide	• Human diseases from pathogens • Allergens • Dangerous or poisonous plants and animals • Trees scratching on windowpanes	• Bird droppings on stonework and outdoor sculptures • Tree roots cracking pavements • Scattering of human rubbish by foraging wild animals • Unpleasant odours from rotting organic matter
Abiotic[1]	• Droughts • Fires • Siltation • Leaching of nutrients	• Floods • Storms	• Soil erosion • Mud/landslide scar

[1] *Abiotic component that provides EDS that are a result of changes in ecological and/or biological processes of an ecosystem.*

(for example, leaf-fall on pavements and roads, animal excrement). Thirdly, EDS can affect economic activities negatively (for example, crop loss, infrastructure destruction). We classify EDS based on which aspect of an ecosystem is most associated with their origin (biological or abiotic) and the nature of their impacts on human wellbeing (impacts on economy, impacts on physical and mental health and safety, and aesthetic and cultural impacts) into six categories as follows (Table 2): bio-economic EDS, bio-health EDS and bio-cultural EDS; abiotic-economic, abiotic-health and abiotic-cultural.

Ecosystem Disservices Management

The focus on EDS management is premised on the fact that benefits from ecosystems need to be weighed up against EDS to have a full picture of the value of ecosystems to human wellbeing. According to Meehan and others (2011), informed and appropriate management of ecosystems can reduce EDS while promoting services, much to the benefit of human wellbeing. These benefits are both monetary and non-monetary social enhancements to human experience such as enhanced wellbeing from the knowledge that dangerous wildlife are contained, an urban park is clean and safe, and water is safe to drink. The economic benefits of EDS (or ES) management can be measured as the change in the value of flows of ecosystem goods and services or EDS (Kobayashi and others 2010; Taylor and Rollins 2012; Taylor and others 2013). For the former, good management would be expected to result in higher flows, whilst for EDS, good management would be towards reduced flows, incidences, losses and costs. The same would apply to non-economic benefits using whatever currencies that best express the flow of benefits and EDS.

In terms of managing ecosystems, the inclusion of EDS into the process can be via several strategies (Table 3) including (i) managing general ecosystem integrity, resilience and health or a specific ES or bundles with the intention that it will reduce the frequency or intensity of EDS to acceptable levels, (ii) directly managing a specific EDS to maintain it at low and acceptable levels before it crosses particular thresholds of concern and builds up to potentially devastating levels, (iii) working with the complexity of ecosystems and interactions to consciously assess trade-offs between EDS and ES at different spatial scales, (iv) mitigating the negative impacts after the event, or (v) some combination of these. The first three are proactive and are briefly covered below.

Managing EDS Through Promoting General Ecosystem Resilience and Health or ES Management

It is well recognised that the frequency or intensity of many disservices can be minimised if ecosystems are managed in a way that promotes general resilience and ecosystem health, and many would argue that this should be the preferred or default approach (for example, Villa and others 2014). In rangeland ecosystems, wildfire damage, wind and water ero-

Table 3. Broad Strategies Towards Management of Ecosystem Disservices

Timing	Primary strategy	Possible effects on EDS frequency or intensity	Broad implications for management (*more specific action would depend on which of the six types of EDS (Table 2) was in operation*)
Proactive	Increase ES	Increase	Develop and implement proactive or reactive plan to address increased EDS or assess trade-offs between the two
		None	If background intensity or frequency of EDS is tolerable, continue with current strategy whilst monitoring. If background intensity or frequency is not tolerable, develop and implement proactive or reactive plan to reduce EDS
		Decrease	Continue with current strategy whilst monitoring
	Minimise EDS	Increase	Consider alternative management approaches
		None	Consider alternative management approaches, or perhaps increase funding for current strategy and monitor
		Decrease	Continue with current strategy
	Context specific trade-offs between ES and EDS	Increase	Ensure that degree of increase is acceptable (for all interested parties) *relative* to the supply of the desired ES; if not, test new management approaches
		None	If background intensity or frequency of EDS is tolerable, implement actions that provide the best ES flows. If the background intensity or frequency is not tolerable, re-examine acceptable trade-offs.
		Decrease	Implement actions that provide best ES flows
	Integrated management for healthy and resilient ecosystems	Increase	n/a
		None	Assess acceptability of context specific trade-offs
		Decrease	Continue with current strategy whilst monitoring
Reactive	Mitigation of EDS impacts	Increase	New strategy or increased funding required to mitigate EDS
		None	New strategy or increased funding required to mitigate EDS
		Decrease	Continue with current strategy

sion (abiotic-economic EDs; Table 2), air quality impacts from dust and smoke (abiotic health EDS; Table 2) are examples of EDS. In a study of the economics of ecologically based invasive plant management on the Great Basin Rangelands (biotic-economic EDS; Table 2), Taylor and Rollins (2012) reported that sound ecosystem management of invaded areas resulted in reduced fire suppression costs relative to uncontrolled areas. Similarly, Taylor and others (2013) used a simulation model to estimate the value of invasive plant management in terms of the expected effects in wildfire suppression costs with and without treatment in Wyoming Sagebrush Stepp and Mountain Big Sagebrush ecosystems in the United States. The expected net fire suppression costs averted in 'healthy sagebrush' were \$671 and \$222 per ha in Wyoming and Mountain Big, respectively. Management of the invasive species (an EDS) was thus better than fire protection measures and post-fire insurance payouts using an econometric analysis. It was also argued that the benefits of invasive plant management extend beyond the direct benefits to private ranchers and that policies to promote invasive plant management by private ranchers were likely to generate downstream socio-economic benefits. In a demonstration of the importance of investing in efforts to avoid disservices, Kobayashi and others (2010) showed that households were more willing to pay for rangeland invasive management programmes that target preventing undesirable ecosystem change than those targeting rehabilitation.

Another example of this is ecological engineering to deliberately manage for ES that help reduce EDS (Gurr and others 2004). For example, globally more than 40% of all world's food production is lost to insect pests, plant pathogens and weeds (all biotic-economic EDS; Table 2), despite application of large quantities of pesticides (Gurr and others 2004). Ecological engineering in Australia, a process that involves manipulating habitats to make them less vulnerable for pests (such as promoting pest suppression by natural enemies, or optimising crop health to make them less prone to diseases), was reported to have marked economic gains with respect to the quality and quantity of agricultural output and reduced losses to pests and diseases (Gurr and others 2004). Thus, pest control by healthy ecosystems has social and economic benefits for growers, the environment and consumers (good health, life security).

Managing EDS Within Acceptable Domains Before Thresholds are Crossed

An example of this is vector-borne diseases (biotic-health EDS), which, it is estimated, cause approximately 1.4 million deaths per year, mainly in Africa. However, various interventions have shown substantial positive impacts not only on the lives saved but also on the costs avoided. For example, an analysis of malaria control in the Copperbelt of Zambia through strong environmental management interventions averted an estimated 14 122 deaths, 517 284 malaria attacks, US$796 622 in direct treatment costs and US$5.7 million (in 1995 US$) in indirect costs from worker absenteeism (Utzinger and others 2002), demonstrating the social and economic payoffs of managing EDS. In a recent review of the status of malaria control in Malawi, Mathanga and others (2012) concluded that actions to reduce vector-borne diseases could result in major health gains and relieve an important constraint on development in poor regions. With knowledge and understanding of such EDS, social and behavioural responses such as public health education could be used to raise awareness about individual and communal actions that may control vectors, their breeding sites, prevent transmission and access to treatment.

Management of locust outbreaks in Australia is another example (biotic-economic EDS; Table 2). Pre-emptive management of outbreaks uses an integrated pest management approach built around a combination of (i) predictive modelling of when and where outbreaks are likely, (ii) ground surveys and monitoring, (iii) targeting locust swarms in 'outbreak' areas before they invade agricultural areas and (iv) spraying large swarms when detected (Hunter 2010). Whilst the frequency of outbreaks has not changed, this approach has successfully decreased the duration and spatial extent of locust invasions (Magor and others 2008). Current costs of control outbreaks and of prevent invasions are in the region of AU$ 50 million per year. By comparison, it was estimated that without control the costs would be in the region of AU$963 million p.a.

Consciously Assessing Trade-Offs Between ES and EDS at Multiple Scales

The significant research and policy focus on managing ecosystems for a better or sustained supply of ES can at times have unintended consequences in that some EDS may also increase as a result. For example, restoration of wetlands for provisioning and regulating functions, or damming of rivers to secure water supplies might also increase the incidence of water-borne diseases such as malaria or bilharzia (biotic-health EDS). Another might be the establishment of protected areas or promulgation of regulations against hunting, both with the intention to conserve biodiversity, populations of specific species and ecotourism. Yet, such actions can also have unintended consequences as the wild animals protected may endanger the crops, livestock (biotic-economic EDS) or lives of neighbouring villagers (biotic-health EDS). In such situations it is necessary that the sought after positive benefits from the improved supply (or security of) of particular ES are consciously weighed up against the negative consequences from the increased EDS (Swain and others 2013), and appropriate actions taken.

Conclusion: Opening Pandora's Box

There has been much research and policy attention on securing ES for human wellbeing. But the obvious fact that ecosystems also provide EDS has not received equivalent attention. Any balanced view to assess and secure the real value and benefits of ES must therefore also account for the EDS (Lyytimäki and Sipilä 2009; Lyytimäki 2015). In particular, the role of ES in fostering poverty alleviation is receiving particular attention because the poor are more directly reliant on ES and lack resources to secure ES by other means. But the poor also carry a disproportional burden of EDS impacts (Anderson 2011). Thus, strategies to improve the wellbeing of the poor need not focus solely on securing ES, but also on reducing EDS and building communities' adaptive capacity to minimise or respond to EDS. Zhang and others (2007) argue that ES for which it is difficult to compute a value are neglected from planning processes and decisions regarding trade-offs. The same applies to EDS. Consequently, this paper serves as a call for greater research and management attention to EDS. We provide a definition of what EDS are and are not, along with a typology as one step towards improved understanding. Broad approaches for managing or minimising EDS are considered and need to be integrated in ecosystem level management frameworks.

A core tenet of ecosystem level management frameworks for securing ES for human wellbeing is maintenance of sufficient levels of biodiversity as a primary supporting service (MA 2005). However, the relationship between EDS and biodiversity is currently unclear. Dunn (2010) argues that regions of the world with high biodiversity have a high incidence of EDS, especially pests and diseases. The concept of option value quantifies the value of conserving biodiversity because of the future possibilities of identifying new uses from that biodiversity. But at the same time, we may also receive new diseases and pests from the same biodiversity (Dunn 2010). Most new diseases in humans are from domestic animals or wild vertebrates (Jones and others 2008 in Dunn 2010). At the opposite end of the spectrum, diminished biomass and biodiversity may result in increased EDS. For example, loss of riparian vegetation increases the probability and magnitude of flooding of adjacent lands, homes and infrastructure. In some cases, avoiding the impacts of an EDS may be an economically more compelling reason for conserving wild lands than to secure the ES. Habitat conversion frequently increases EDS (Dunn 2010). Thus, conservation and wise management should not be just about securing ES and preventing their loss, but also about avoiding, managing or mitigating EDS. Improving human wellbeing through conservation and management may be better or more cost-effectively achieved through the elimination, reduction or mitigation of EDS. This is already widely practiced in response to specific EDS, but it needs to be embedded within an ecosystem services framework in relation to the complexity and broader interactions (Lyytimäki 2015).

In moving our understanding of EDS forward, the following key questions need to be addressed: (i) what is the relationship between biodiversity and the incidence of EDS?, (ii) what are the trade-offs between optimisation of ES and the incidence or magnitude of multiple EDS?, (iii) what are the relative contributions and roles of ES and EDS in shaping local livelihood trajectories, and (iv) under what circumstances and frequencies do the relative contributions change?

The 'supply' of many EDS is more erratic than the supply of ES. Many are present at low background levels, which are not considered as problematic, perhaps as a minor nuisance. But when they build up or have a large impact, then they are viewed as problematic even though they were always there. For example, loss of a small proportion of crops due to pests may be tolerable, but loss of a significant proportion of the harvest due to a pest outbreak is deemed catastrophic. The same can be said of wildfires or epidemic diseases such as Ebola virus. In such situations, there is an urgent need to understand the ecology of the EDS, especially the conditions under which outbreaks or intensities build up, so that humans might be able to manage ecosystems to limit the frequency or intensity of the enabling conditions for outbreaks, and using the knowledge to be prepared and adaptable, both in ES management and expected wellbeing outcomes.

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