

# Integrating ecosystem services and disservices: insights from plant invasions

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## ABSTRACT

There is growing interest in ecosystem disservices, i.e. the negative effects of ecosystems on humans. The focus on disservices has been controversial because of the lack of clarity on how to disentangle ecosystem services and disservices related to human wellbeing. A perspective that considers both services and disservices is needed to inform objective decision-making. We propose a comprehensive typology of ecosystem disservices, and present a framework for integrating ecosystem services and disservices for human wellbeing linked to ecosystem functioning. Our treatment is underpinned by three key assumptions: (1) ecosystem attributes and functions are value-free; (2) the perception of benefits or nuisances are however dependent on societal context, and preferences and actions by societal actors may trigger, enhance or alleviate benefits or nuisances derived from ecosystems; and (3) the notion of disservices must account for the role of human management in assessments of ecosystem values, i.e. the social and technological measures that identify, protect, promote or restore desirable levels of services, and concurrently minimise, mitigate or adapt to disservices. We illustrate our ideas with examples from plant invasions as a complex social-ecological phenomenon.

## INTRODUCTION

The concept of ecosystem services (ES) has emerged from the recognition that complex interactions in ecosystems can result in flows of energy, matter and information, which contribute to human wellbeing. Examples include fostering basic needs through food, fibre and energy provision as well as regulation services (e.g. carbon sequestration, pollination, pest control) and contributions to cultural aspects of wellbeing (Agarwala et al., 2014; Díaz et al., 2015; MA, 2005; Smith et al., 2013). The focus on ES has created an additional perspective which differs from, and is complementary to, traditional conservation policies for ensuring the sustainable use and the protection of ecosystems (Agarwala et al., 2014; Bonn et al., 2016; Brown and Westaway, 2011). Yet, one of the major recurring points of criticism of the notion of ES is that it often considers only the beneficial outputs of ecosystems and ignores unpleasant, unwanted or economically harmful effects (Lyytimäki and Sipilä, 2009; Lyytimäki, 2014; Schröter et al., 2014). These negative sides of ecosystems have been termed ecosystem disservices (EDS). Following Shackleton et al. (2016: p. 590), EDS are “the ecosystem generated functions, processes and attributes that result in perceived or actual negative impacts on human wellbeing”.

EDS can be produced, for example, by biological invasions (Shackleton et al., 2016), and by other ecosystem attributes that are perceived as unwanted (Escobedo et al., 2011; Lyytimäki et al., 2008). They are produced by ecosystem functions, such as wildfires or floods, which pose danger to people and – although they may constitute natural processes – can be mitigated or exacerbated through management (Lyytimäki, 2014). The same ecosystem function may be perceived as ES by some people and EDS by other people (cf. Saunders and Luck, 2016), depending on, among other things, acquired knowledge, people's behaviours, and overall political, economic and social settings (Rasmussen et al., 2016; Shackleton et al., 2016; Stoll et al., 2015). Configuration of anthropogenic pressures as well as provision and perceptions of ES and EDS may vary spatially, temporally and between individuals or societal groups (Chan et al., 2012; Shackleton et al., 2016).

The notion of EDS has its main roots in urban ecosystem research (Dobbs et al., 2014; Escobedo et al., 2011; Lyytimäki, 2014; Lyytimäki and Sipilä, 2009), particularly in work associated with complex human- environment systems that characterise large cities (von Döhren and Haase, 2015). EDS have been used to evaluate the value of green space for urban residents (Lyytimäki and Sipilä, 2009; Lyytimäki et al., 2008) given that urban green spaces can provide many ES but also a range of EDS, from allergenic substances and volatile compounds emitted by vegetation (Dobbs et al., 2014), to blocking of sunlight by trees (Roy et al., 2012), and the presence of wild animals in people's backyards (Lyytimäki, 2014). The notion of EDS has also been extended to agricultural systems (e.g. Ma et al., 2015; Schäckermann et al., 2015) to account for problematic aspects of human managed ecosystems (Ma

et al., 2015), to denote increases in production costs e.g. for pest control (Schäckermann et al., 2015; Swinton et al., 2007; Zhang et al., 2007), or other ecological costs arising from animal activities (Kronenberg, 2014; Whelan et al., 2015).

The usefulness of EDS has more recently been discussed for other contexts, namely fisheries and forests (see Shackleton et al., 2016). Yet, EDS have seldom been considered in the context of broader social-ecological challenges (Saunders and Luck, 2016; Shackleton et al., 2016), such as plant invasions. Plant invaders provide both benefits (Tassin and Kull, 2015) and nuisances (Simberloff et al., 2013) for human wellbeing, depending on people's preferences and the spatio- temporal context (Kueffer and Kull, 2017). In some contexts, invasive plants contribute to people's livelihoods, by supporting daily basic needs and economic incomes (Kull et al., 2011), or by enhancing regulating functions, including coastal sediment dynamics and soil protection. In other contexts, however, plant invasions can lead to undesirable outcomes for human wellbeing. Examples include health problems associated with allergenic compounds or skin irritations, wildfires in non-fire prone areas, or competition with another service-providing species (Fenesi et al., 2015; Gaertner et al., 2014). The beneficial or detrimental impacts of plant invasions can be exacerbated by the magnitude, rate and scale of the invasion process (e.g. Eviner et al., 2012). The same species can promote ES at some spatio-temporal extent, e.g. trees confined to private gardens, or contribute to EDS provision at later stages, e.g. trees become widespread in the wild (the “transient disservices”; Saunders and Luck, 2016). This inevitably depends on (the lack of) human management (Brundu and Richardson, 2016).

Previous attempts to categorise EDS have relied on comparisons with pre-established classifications of ES. For instance, Ma et al. (2014) introduced the term ‘provisioning and regulating EDS’ to account for soil loss in agricultural systems. Price (2014) used ‘supporting and regulating EDS’ in the context of forestry. Other authors, mostly in reference to urban ecosystems (von Döhren and Haase, 2015), proposed mixed typologies, based on both the origin and consequences of EDS. Escobedo et al. (2011) classified EDS as financial (economic costs triggered by EDS), social (impacts on human health and fear) or environmental (affecting intrinsic ecosystem attributes). Lyytimäki and Sipilä (2009) categorised EDS based on their origin (as social, social-ecological or ecological), and based on the impacted societal actors (individuals, communities, or humankind). More recently, Lyytimäki (2014) categorised EDS with respect to weather-related events and ecosystem functions causing harm, as well as human fears and risks, activities, or aesthetic issues. Despite their usefulness in specific cases, the above-mentioned typologies do not yet provide the means for distinguishing between the occurrence of a perceived negative service, i.e. an EDS, and the reduction of an ES. For instance, a lack of an explicit differentiation of reduced ES and genuine EDS led to ambiguity in the literature (Shackleton et al., 2016), e.g. by denoting habitat loss (Zhang et al., 2007) and pesticide output in agricultural systems (Swinton et al., 2007) as EDS. To tackle the conceptual problem that reduced ES are not necessarily EDS, Shackleton et al. (2016) classified EDS based on their effects on the economy, physical and mental health, or aesthetic and cultural issues of human wellbeing.

Although EDS have been accounted in the scientific literature (Shapiro and Baldi, 2014), a comprehensive conceptual

framework that incorporates both EDS and ES is lacking (compare Saunders and Luck, 2016; von Döhren and Haase, 2015). In our view, such a framework should address three conceptual issues: (1) nuisances from ecosystem to wellbeing can either be expressed as reduced ES (e.g. decrease of water provision, or reduction of soil erosion protection), or as genuine EDS (e.g., wildfires and pests; see Saunders and Luck, 2016; Shackleton et al., 2016 for reviews); (2) benefits and nuisances should account for human activities, since feedbacks between ecological changes and societal responses may trigger, enhance or reduce either ES or EDS; and, (3) an EDS framework should facilitate deliberation about both positive and detrimental aspects of ecosystems for human wellbeing acknowledging that there is not only one state in nature that can or should be maintained or restored through management. Some experts might consider that this likely opens a Pandora's Box (Shackleton et al., 2016). For example, conservationists who place an emphasis on native, wild nature may feel threatened by a concept and associated conceptual model that might be used to justify interventions in landscapes that they value for their lack of anthropogenic imprint (following Kronenberg, 2014; Villa et al., 2014). Yet clearly, explicit negotiations of management priorities might increasingly become unavoidable in coupled social-ecological landscapes. In such negotiations EDS recognition might contribute to better informed ecosystem management approaches and possibly optimised investments to increase both biodiversity and human wellbeing (Saunders and Luck, 2016; Shackleton et al., 2016; Stoll et al., 2015).

This paper proposes a general conceptual framework of EDS. The framework encompasses a detailed typology of different

EDS, and it proposes a way to explicitly account for the role of social-ecological management in the valuation of ES and EDS. To this end, we highlight the importance of acknowledging the interconnected human-ecological nature of ecosystems. We propose to refine a precautionary approach to ecosystem management through a hierarchy: first identify potential ES and EDS, then protect ES and avoid or minimise EDS, restore and rehabilitate ES, and lastly mitigate and adapt to EDS. We illustrate our framework with plant invasions as a test case. Finally, we synthesise the wider usefulness of our typology and framework for the future study and management of benefits and nuisances arising from ecosystems.

## **METHODS**

### **The EDS typology**

To build the EDS typology, a literature search was performed in ISI Web of Science, between May and July 2015 (updated in February 2016). The search string was TOPIC = ("ecosystem\* disservice\*" OR "environment\* disservice\*" OR "landscape disservice\*" OR "ecologic\* disservice\*" OR "ecosystem\* dis-service\*" OR "environment\* dis-service\*" OR "landscape dis-service\*" OR "ecologic\* dis-service\*"). The time span of our search was 1900–2015. Following recommendations for increasing the reliability of literature reviews (Higgins and Green, 2011), our search was further extended to the first 50 records retrieved by a search on Google Scholar in February 2016. The records retrieved by ISI (number of records, n=40) and additional records retrieved from Google Scholar (n=50) were scrutinised and non-relevant records were discarded e.g. those which only mentioned the words “ecosystem disservice” but did not address their actual assessment or categorisation,

or those which simply mentioned EDS, but focus on ES. We then reviewed the categories presented by each record from the final set of selected publications, and organised the examples and categories to produce a common EDS typology. Since our goal was not to conduct an exhaustive literature search on the EDS concept, the records indicated in this manuscript are purely illustrative of each EDS category.

We outline our proposed EDS categories in Section 3. They are grounded on the same premises that underlie ES, i.e. they influence different dimensions of human wellbeing (Agarwala et al., 2014; MA, 2005). Since the definition of human wellbeing is still being debated (Jax and Heink, 2015), here we consider human wellbeing as the desirable conditions for an individual or societal group (Jax and Heink, 2015), which depends on: objective attributes related to people's material and social contexts, subjective thoughts, feelings and satisfactions towards life, and psychological responses associated with social connectedness, security, and life satisfaction (Agarwala et al., 2014; Smith et al., 2013). Following Smith et al. (2013) we thus consider the following wellbeing dimensions: health, including life expectancy and mortality, and physical and mental health conditions; social cohesion, considering physical and emotional links that connect humans in society: education, resulting knowledge and skills; safety and security, as physical, personal and national freedom from harm and financial destabilisation; living standards, as the access to goods, services and resources; leisure time, as pleasurable activities away from work and responsibilities; spiritual and cultural fulfilment, as opportunities to fulfil spiritual and cultural needs; and connection to nature, as personal connectedness to ecosystems and biotas. These dimensions contribute to general life satisfaction and

happiness (Smith et al., 2013).

### **The ES and EDS framework and ES categories**

The integration of EDS into a general ES framework presented in Section 4 was grounded on the main ideas underlying the ‘ecosystem service cascade model’ (Haines-Young and Potschin, 2010). The ecosystem service cascade describes how the biophysical structure of ecosystems sustains the ecological functions and processes needed to provide ES. These ES then contribute to the benefits for human wellbeing with a respective value (see Haines-Young and Potschin, 2010; Spangenberg et al., 2014a for details).

Several initiatives have focused on the assessment or categorisation of ES. Prominent examples are the Millennium Ecosystem Assessment (MA, 2005), The Economics of Ecosystems and Biodiversity (TEEB, 2010), Mapping and Assessment of Ecosystems and their Services (MAES, 2013), the Common International Classification of Ecosystem Services (CICES; Haines-Young and Potschin, 2013), and the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES; Díaz et al., 2015). The ES categories adopted in our framework were based on CICES; these are considered applicable to different spatial and thematic scales, and are thus context-independent which allows for multi-study comparisons (Haines-Young and Potschin, 2013). CICES provides a five-level, hierarchical typology, the first level of which separates ES into provisioning, regulating and maintenance, and cultural services (Haines-Young and Potschin, 2013). A comparison of CICES, MA and TEEB classifications is presented in Table S1.

### **The EDS typology and the ES-EDS**

### **framework illustrated with plant invasions**

A similar procedure to that used in Section 2.1 was considered to illustrate the EDS typology in line with an ES framework for (alien) plant invasions in Section 5. In this case, the search string was: TOPIC=(“plant invader\*” OR “exotic plant\*” OR “alien plant\*” OR “allochthonous plant” OR “plant invasion\*” OR “tree invader\*” OR “exotic tree\*” OR “alien tree\*” OR “tree invasion\*”) AND (“ecosystem disservice\*” OR “environment\* disservice\*” OR “landscape disservice\*” OR “ecologic\* disservice\*” OR “ecosystem dis-service\*” OR “environment\* dis-service\*” OR “landscape dis-service\*” OR “ecologic\* dis-service\*” OR “ecosystem service\*” OR “environment\* service\*” OR “landscape service\*” OR “ecologic\* service\*”). The records retrieved in ISI (n=184) were checked for relevance (e.g. excluding topics such as invaders from outer space). Each record was reviewed and we selected representative records to extract illustrative examples of the effects of plant invasions on human wellbeing.

### **A TYPOLOGY FOR EDS**

Here we propose a detailed typology for EDS, considering a wide number of human wellbeing dimensions which can be negatively impacted by ecosystems in a direct way (Table 1). Our typology is based on an expanded definition of EDS that considers the direct “perceived or actual negative impacts on human wellbeing” (after Shackleton et al., 2016).

The typology includes five categories. The first category comprises health EDS and includes the direct consequences resulting from unwanted effects of biota on human health, including the outputs from their existence, e.g. air pollution caused by plant

metabolism, viruses and pollen transmission. The second category comprises impacts on physical material for human life (material EDS), disrupting social cohesion, and living standards of human wellbeing. It includes those circumstances in which the physical expansion or introduction of living organisms results in outcomes that contribute directly to degradation of human materials and structures, such as buildings and houses, including traffic and communication infrastructure such as roads, e.g. through vegetation growth or animal excrements. The third category (security and safety EDS) considers impacts on the physical, personal and national security and safety of people. It includes all circumstances in which human freedom from harm becomes affected, either through, e.g. fear of animal attacks in wild or remote areas, fear of densely vegetated areas such as parks or forests due to a perceived higher risk of becoming a victim of a crime, or physical harm, e.g. caused by natural processes such as falling tree branches or fire, those that may be enhanced or mitigated through human activities. Cultural and aesthetic EDS (the fourth category) refer to biota or ecological outcomes that mostly impact on mental enjoyment of and connection with nature: human perception, aesthetics, spiritual, symbolic, cultural and religious values, such as species or landscapes considered as unpleasant. Leisure and recreation EDS, the fifth category, relate to ecosystem outputs that inhibit (the willingness for) physical connection with nature, through leisure and recreation activities, for instance by, e.g. vegetation occurrence obstructing water courses for water sports and other recreational activities in the wild.

The assumption that EDS have direct consequences for human wellbeing allows us to distinguish EDS from situations in which an ecosystem nuisance is instead

derived from the reduction of an ES (i.e. reduced ecosystem services). For instance, unwanted ecosystems functions can impact on well-recognised provisioning ES from agricultural (e.g. pests and weeds affecting crop growth; or fungus degrading processed food; Lyytimäki et al., 2008; Schäckermann et al., 2015), forest (e.g. timber quality damaged by fungus and other animal activities, or wood damaged by deer rub; Ango et al., 2014; Lyytimäki et al., 2008) or grazing systems (e.g. cattle diseases or poisoning by the consumption of toxic plants; Shackleton et al., 2016). Thus, the impact on people's living standards or the decrease of financial income that emerges from such impacts is determined by reduced ES, and not necessarily by genuine EDS (see Section 4 for details).

Additionally, our typology also overcomes the attribution of an a-priori normative judgement to ecosystem properties, e.g. since the same property can be considered in multiple EDS categories. Instead, the framework allows to account for how ecosystem functions, resulting

from such properties, impact on wellbeing. For instance, the occurrence of snakes (as an ecosystem property) can bite (Health EDS), degrade infrastructures through excrements (Material EDS), give a sense of fear (Security and safety EDS), be considered as ugly (Cultural and aesthetic EDS), and occupy wild areas used for outdoor leisure (Leisure and recreation EDS). At the same time the occurrence of snakes can contribute to ES such as pest regulation, source of poison useful for medicinal purposes, and promote physical and intellectual experiences. This example shows the need for an integrative framing of both ES and EDS.

## **INTEGRATING EDS AND ES INTO A GENERAL FRAMEWORK**

## **The ES and EDS framework**

We propose a general framework that includes three main components of a social-ecological system to consider both ES and EDS: the ecological realm, the social realm, and the social-ecological interface (Fig. 1). Drawing into this model the flows underlying the ES cascade model (Haines-Young and Potschin, 2010; Spangenberg et al., 2014a), we argue that the provision of ES and EDS at the social-ecological interface depends on the attributes and functions generated in the ecological realm, while it contributes to benefits, i.e. increasing human wellbeing, or nuisances, i.e. reduction of human wellbeing in the social realm (Haines-Young and Potschin, 2013; Spangenberg et al., 2014a, 2014b).

The perception of benefits and nuisances in the social realm depends on the attribution of human values to the outputs of the ecological realm. However, in extending previous frameworks, we assume that the outputs from the ecological realm are also determined by social-ecological management actions that are interrelated with the valuation resulting from the social realm. To account for the dynamic role of humans in the interdependence of ecological and social processes we introduce the social-ecological interface where the attribution of ES and EDS happens in specific social-ecological, temporal and spatial contexts.

### **The ecological realm**

The ecological realm (Fig. 1A) reflects the set of ecosystem attributes and functions that constitute or generate ES and EDS (Spangenberg et al., 2014a). It also considers the influence of abiotic components of the ecosystem such as weather events regulated by vegetation (Lyytimäki, 2014; Sagie et al., 2013) insofar as they are situated within the boundaries of

an ecosystem (Shackleton et al., 2016). The ecosystem considered can be either a natural or anthropogenically influenced one, such as agricultural or forested land.

Ecosystem attributes and functions are neither positive nor negative: the same function or attribute can generate, maximise or reduce ES and EDS (cf. Saunders and Luck, 2016). For instance, the processes underlying a tree's carbon cycle can contribute to climate regulation through carbon sequestration (e.g. Baró et al., 2014), or produce volatile organic compounds, contributing to air pollution and human health problems (i.e. health EDS; e.g. Roy et al., 2012). This depends on the multi-spatial and temporal scales, and social contexts.

While the ecological realm can be anthropogenic in a material sense, it is 'value-free' in the sense that it describes the biophysical flows of energy, matter and information. These flows can change across spatial and temporal scales, and relate to the intensity and frequency of underlying ecosystem functions. It is, however, that by identifying those ecosystem attributes and functions that either enhance or reduce human wellbeing in given spatial and temporal contexts is conferred, depending on human-value attribution (Chan et al., 2012; Cumming et al., 2014; Reyers et al., 2013; Saunders and Luck, 2016). In our case, this human-value attribution can be understood as a measure of importance given to, or interest in, a particular phenomenon, be it ecological, economic or social.

### **The social realm**

The social realm (Fig. 1B) relates to elements of human values, preferences, and principles (Chan et al., 2012), as well as human and institutional perception and behaviour produced in the complex, context-

dependent dimensions of economics, politics, and culture. The latter define a demand for ES and an exposure to EDS, and the desirable or undesirable appropriation of the benefits or nuisances from ecosystems (Spangenberg et al., 2014b).

For example, landscape features can be perceived as cultural ES (as defined in CICES; Haines-Young and Potschin, 2013) by some people – i.e. “the landscape is beautiful” – and as a cultural and aesthetic EDS (as proposed in Table 1) by other people – i.e. “the landscape is ugly”. Such valuation thus depends on, among other things, the cognitive structure that people form through their experiences, individual cultures, preferences, principles, virtues, and norms, and the circumstances of the social, political and economic environment people are in (Brown and Westaway, 2011; Shackleton et al., 2016). Also, temporal advances in scientific, cultural, or generational knowledge might affect individual views of benefits or nuisances derived from the same ecosystem functions or attributes. For instance, environmental education can change the perception of particular species, e.g. bat species that were previously negatively perceived due to folklore (e.g. related to Dracula and feeding on human blood) become welcome after demystifying their negative impact and explaining their function in the ecosystem (e.g. pollinating tree fruits or predating mosquitoes; Kingston, 2015).

This operationalisation of the human valuation of ecosystem outcomes can be achieved through different approaches, ranging from monetary calculations of benefits or damages (TEEB, 2013), to the assessment of the willingness to do various things for a certain desire (Whelan et al., 2015), or the estimation of human happiness and satisfaction indices (Smith et al., 2013).

## **The social-ecological interface**

The integration of the ecological and social realms at the social- ecological interface (Fig. 1C) allows distinguishing ecosystem attributes and functions without having a-priori values, thereby opening the concept to a broader assessment of benefits and nuisances; a lack of which is one of the most recurring points of contention in ES research (cf. Schröter et al., 2014).

We assume that ES and EDS are not entirely antagonistic, yet their beneficial or detrimental effects can be opposite to each other, i.e. benefits can express ES or reduced EDS and nuisances can express EDS or reduced ES. For instance, human health can either benefit from several ES, such as food, pharmaceuticals, and genetic materials; or from the mitigation of health EDS, namely the decrease of plant species with allergenic potential (reduced EDS). Contrastingly, human health can be impacted by the decrease in quality and quantity of such ES (reduced ES), as well as by the action of health EDS, namely food poisoning, ecosystem contamination, or diseases (Table 1). Also, human safety and security can be positively influenced by the capacity of ES to regulate and mitigate events such as floods and by the decrease in the occurrence of certain security and safety EDS, such as the removal of trees prone to falling. The opposite is also possible: human safety and security can be minimised either by the loss of regulation and maintenance ES, or by the enhancement of security and safety EDS (Table 2).

We emphasise that a clear separation of the social realm from the ecological realm is difficult since humans are part of both the ecological and social realm, with actions influencing the social- ecological interface. Social-ecological management, particularly feed- backs between ecological shifts and

societal responses to social- ecological changes, may trigger, enhance or reduce either ES or EDS. For instance, placing societal assets (such as houses) or ecological features (such as alien species) in systems prone to disturbance such as floodplains affected by floods or storms, or in fire-prone vegetation, may enhance potential nuisances; and the promotion of monocultures or the suppression of natural processes may trigger EDS and reduce ES. Also, and especially under global change, ES and EDS depend on the human capacity to adapt to or learn from ecosystem changes, i.e. the social-ecological memory from Nykvist and von Heland (2014). This can, for instance, favour the provision of certain ES, e.g. since people learned how to cope with changes; or the disappearance of ES and emergence of EDS, e.g. since people did not adapt to the novel ecosystem (see Section 4.4).

### **The management hierarchy for ES and EDS**

We argue that the notion of EDS should account for the role of management in the consideration of human values attributed to ecosystems. In the past, the precautionary approach has often guided ES management, i.e. the assumption that anthropogenic disturbances of (natural) ecosystems should be avoided or reverted if possible. Such a framework might be too narrow when considering EDS and the possibility of other ecosystems nuisances.

We expand a precautionary approach by suggesting a management hierarchy to guide social and technological actions. This hierarchy has been reported as being efficient in terms of policy development and management implementation for achieving ecosystem health and ecological sustainability (McKenney and Kiesecker, 2010; Tallis et al., 2015). We suggest to

expand such framework so that it includes: first identify and evaluate potential ES and EDS, which are relevant for a given social-ecological system, then protect and maximise ES, avoid and minimise EDS while restore ES, and finally compensate and adapt to EDS (Tallis et al., 2015; Fig. 2).

Specifically, as a first step, the management hierarchy includes the identification and recognition of ecosystem outcomes, as well as the main trade-offs and dynamics between and within the distinct ES and EDS. This evaluation may be conducted through several approaches, such as ecological and economic methods (TEEB, 2013), or by assessments of human satisfaction, preference, or happiness (Smith et al., 2013). As a second step, the hierarchy includes the protection of ecosystems or the maximisation of benefits from natural resources, including the development of nature-based solutions (Kabisch et al., 2016). Avoidance and minimisation strategies include actions for preventing and reducing impacts, whether they are derived from EDS themselves or affect ES, e.g. by abstaining from detrimental management actions or pursuing technical solutions that allow for societal demands to be met while retaining ES supply. This can, for instance, be accomplished through technological development that minimises human dependency or overexploitation of ES, i.e. the non-ecosystem services proposed by Cumming et al. (2014). Offsets of human management can be included under the restoration and compensatory mitigation of nuisances (Tallis et al., 2015) e.g. by adopting social and technological mechanisms to actively restore the ecosystem in order to maximise desirable levels of ES provision, or to minimise the risk of exposure to a specific EDS (Biggs et al., 2012; Cumming et al., 2014; Reyers et al., 2013; Sagie et al., 2013). Adaptation

considers strategies to cope with changes in the provision of ES (Biggs et al., 2012) and EDS, through actions that reduce such impacts without changing the likelihood that they will occur in the ecological realm, e.g. changes in people's behaviours and perceptions towards the nuisances associated to EDS in the social realm.

Considering humans as simultaneous occupants of both the social and ecological realm means that context-dependent actions for the implementation of this hierarchy in our framework can be accomplished both through interventions that target the social realm (e.g. public awareness, governance dialogue, and the creation of social norms, mechanisms and opportunities) and the ecological realm (e.g. remediation of impacted areas by means of appropriate technology, depending on the multi-scale, -temporal, and -actor context; Tallis et al., 2015). For instance, while we can anticipate (identify) the possible occurrence of natural disasters, most often they can hardly be avoided. Yet, the protection and restoration of regulating ES and the minimisation and adaptation to the nuisances from natural disasters can be accomplished through appropriate risk management, e.g. reduction of vulnerabilities and enhancement of resilience at specific social, political, and economic dimensions (Biggs et al., 2012). Table 2 exemplifies social-ecological management actions that can influence the amount of benefits and nuisances from ES and EDS to human wellbeing. These social-ecological actions are nevertheless dependent on value-based considerations: negotiations, discussions, debates, politics, and other values (and interests) involved in human choice towards evaluating and deciding which management activities are to be undertaken, e.g. to make priorities, or deal with conflicting views (Brown and Westaway, 2011; de Wit et al., 2001; McKenney and Kiesecker, 2010; Woodford

et al., 2016).

## **THE ES AND EDS TYPOLOGY AND FRAMEWORK ILLUSTRATED WITH PLANT INVASIONS**

### **Plant invasions from an EDS perspective**

Biological invasions are an interesting test case for our EDS typology and framework as negative outcomes on ecosystems and the need to manage ecosystems to minimise and adapt to such outcomes have long been discussed in the literature on the management of biological invasions (e.g. Brundu and Richardson, 2016; de Wit et al., 2001; Dickie et al., 2014; Funk et al., 2013). Here, we acknowledge alien plant species as those species that were introduced, accidentally or intentionally, by humans to new geographic areas. They may become invasive, i.e. spread from sites of introduction, and some become abundant and cause diverse impacts on the environment or society (Richardson et al., 2011). Many invasive plant species have major impacts on biodiversity and ecosystem functioning (Eviner et al., 2012; Fenesi et al., 2015; Simberloff et al., 2013).

Based on our proposed EDS typology, we can identify different EDS resulting from plant invasions: as providers of health EDS (e.g. through allergenic pollen transmission, Pyšek and Richardson, 2010; Schindler et al., 2015), security and safety EDS (e.g. creating fire occurrence in non-fire prone areas, Carruthers et al., 2011; Gaertner et al., 2014; Kull et al., 2011), cultural and aesthetic EDS (e.g. by forming monocultures perceived as unpleasant; Kueffer and Kull, 2017), or leisure and recreation EDS by spoiling rivers for water activities in the wild (Fig. 3a and b).

### **Plant invasions at the social-ecological interface**

Although plant invasions can act as EDS providers (Shackleton et al., 2016), they can also provide important ES (Fig. 3c and d). Many alien plant species have been intentionally introduced to new areas to provide ES to individuals or groups of people, such as provisioning or aesthetics (Carruthers et al., 2011; Dickie et al., 2014; Kull et al., 2011), or to minimise the effects of a given EDS, such as pests (see also Fig. 3c,d). Many plant invaders are key resources in social-ecological systems around the world, especially in poor communities (Dickie et al., 2014; Kull et al., 2011), or in production systems (Koskela et al., 2014; van Wilgen and Richardson, 2014). At the ecological realm, plant invaders can impact on several attributes and functions (see Table S2) that sustain the provision of wood and food, while at the same time changing the functioning or quality of other ecosystem functions and attributes e.g. by reducing water quality and amount, or disrupting coastal sediment movement (Dickie et al., 2014; Gaertner et al., 2014; Koskela et al., 2014; van Wilgen and Richardson, 2014). The simple establishment of an invasive plant can contribute to both carbon sequestration and food provision in some spatial and temporal contexts (Dickie et al., 2014) or increase fire load and promote competition with native species in other contexts (de Wit et al., 2001; Fenesi et al., 2015). Also, changes in the biomass of invasive plants can contribute to ornamental enjoyment and spiritual perception (Carruthers et al., 2011; Shackleton et al., 2007) or result in the loss of a perceived wilderness character of landscapes and conservation areas (de Wit et al., 2001; Shackleton et al., 2007; see Table S2 for further examples).

The set of changes provoked by plant invasions are space and time dependent (Eviner et al., 2012): they are dependent on

the stage of the invasion process (Simberloff et al., 2013). There is thus a complex interaction between the type and magnitude of invasion impacts depending on, among other things, the characteristics of the species, their invasive potential, the extent and time of invasion, and features of the invaded environment (Gaertner et al., 2014; Kueffer et al., 2013; Pyšek and Richardson, 2010; van Wilgen and Richardson, 2014). An example are ornamental plants that provide benefits in private gardens but cause nuisances once widespread in the wild (Dehnen-Schmutz et al., 2007).

The actual benefits (ES) or nuisances (EDS and reduced ES) emerging from the changes triggered by plant invasions in ecosystems can only be recognised in the social realm. Specifically, the variety of values, socio-political conditions, perceptions, attitudes, knowledge and ideas attributed to plant invaders by humans (Kueffer and Kull, 2017) define the level and direction of impacts from these species. One of the most emblematic examples can be recognised in the genus *Acacia*. In Madagascar, *A. dealbata* is exploited as a source of fuel wood and charcoal, and contributes substantially to living standards and social cohesion, especially in poorer villages. In contrast, in Portugal, where it was introduced for afforestation and soil erosion prevention (Kull et al., 2011), *A. dealbata* is a widespread invader which lowers biodiversity and increases fire hazard (Gaertner et al., 2014; Le Maitre et al., 2011). Another example is the mesquite (*Prosopis* spp.). The introduction of mesquite has been considered either as beneficial, due to the provision of food in Peru or wood in Kenya, or as source of security and safety EDS, leisure and recreation EDS and production EDS, such as physical injuries to humans in South Africa (Shackleton et al., 2015). Table 3 gives examples of benefits and nuisances

promoted by plant invasions to human wellbeing.

As for the social realm, the beneficial or detrimental effects that plant invaders have on wellbeing inevitably shift according to the temporal and geographical context, and overall institutional, political and technological context of the human society impacted by plant invasions. For instance, while the introduction of *Acacia mearnsii* could be considered to have benefitted the South African economy in the past (Kull et al., 2011; van Wilgen and Richardson, 2014), the use of more advanced technology in the production of chemical tannins in South Africa reduced the current demand for the species (Carruthers et al., 2011). Another example results from the attribution of financial incentives, such as carbon credits (especially under the Kyoto protocol), which justifies afforestation with alien conifers in New Zealand (Dickie et al., 2014). Also, the perception of plant invasions as providers of benefits or nuisances can shift depending of the state of knowledge: although people may enjoy the beautiful flowers of *Acacia dealbata* or *Carpobrotus edulis*, the public awareness of these as promoters of water depletion and soil erosion in their lands, may alter people's perception of this species from beneficial to problematic (Marchante et al., 2010).

### **Plant invasions and the management hierarchy**

A particular challenge of managing invasions is that their effects, valuation and management options are tightly interlinked (Humair et al., 2014; Kueffer, 2013; Woodford et al., 2016). Caution is warranted as an invasive plant may provide benefits or nuisances in the social realm, without necessarily being considered an a-priori beneficial or detrimental asset in the ecological realm. For instance, people will

value invasions differently depending on available management options and the capacity to use ES and mitigate EDS provided by them, at certain geographical and temporal contexts (Kueffer, 2013).

There are thus trade-offs between beneficial and detrimental effects of invasions, and levels of acceptance of these differ between societal actors (Humair et al., 2014; Kueffer, 2013; Kueffer and Kull, 2017; Saunders and Luck, 2016; van Wilgen and Richardson, 2014). Consequently, managing ES and EDS resulting from invasions is often only possible at the social-ecological interface. At this interface, managing invasions (and further social-ecological challenges) could first rely on: (1) identifying specific situations - which ecosystem functions are being modified, at which level, and how irreversible these changes are; (2) considering ecosystem complexity - which potential ecological dynamics and feedbacks can be altered and in which direction of change; (3) realising opportunities in ecosystem service change – how to balance benefits versus nuisances, considering the distinct measures of human valuation; and (4) accounting for multiple social-ecological dimensions - how can invasion outcomes be altered in time, at multiple spatial scales, and through management, learning and changing social perception.

The management hierarchy that we propose (Section 4.4) offers a general strategy for assessing ES and EDS in the light of invasions, in that it provides an objective foundation on which to base decisions about maximising benefits and reducing nuisances for human wellbeing. These decisions should be considered based on human values and interests involved when deciding which management actions are to be implemented, e.g. through deliberation about conflicting views and priorities in invasion management (Bach and Larson, in press; de Wit et al.,

2001; Humair et al., 2014). Management actions need to be tailored for particular geographic locations and time periods because the balance of ES and EDS will be different for different geographic and social-ecological contexts (Kueffer and Hirsch Hadorn, 2008).

We highlight four sequential strategies to manage the invasion process of alien plants from an ES-EDS perspective. The first strategy involves identification and assessment of potential changes in the ecological realm, including trade-off analyses that address the balance of benefits and nuisances provided by invasions in specific social-ecological contexts. The second strategy involves mostly prevention and early-detection actions, through either the protection of pre-existing ecosystem functions, or the enhancement of ecosystem functions and attributes leading to benefits, and the avoidance of potential nuisances derived from alien/invasive plants (as EDS). The third strategy focuses on the mitigation and rapid response to both ES minimisation and EDS maximisation. This can be exemplified by distinct actions aiming at the treatment of the invader itself and its effects e.g. through eradication, containment and habitat restoration and rehabilitation (Funk et al., 2013; Simberloff et al., 2013; van Wilgen and Richardson, 2014). The last strategy involves adaptation to the occurrence or expansion of invasive plants, either by recognising potential novel ES (benefits), or accepting ES transformations (including reduced ecosystem services) and EDS emergence (nuisances). Examples from adaptation include the use of plant invaders for livelihoods, the harvesting of species for bioenergy goals and wood (Mugido et al., 2014), or their maintenance for carbon sequestration or landscape aesthetics (Dickie et al., 2014; Gaertner et al., 2016;

Shackleton et al., 2007).

## CONCLUSIONS

Ecosystem attributes and functions can contribute both positively and negatively to human wellbeing. We therefore clarify the role of ecosystem disservices (EDS) in the context of the ecosystem services (ES), in particular as the ES notion has become an additional argument for biodiversity conservation. We invite the adoption of a modified typology for integrating the terms of ES and EDS under a common framework that considers their relation to ecosystem functions, human wellbeing and feedbacks between human actions and ecosystem functioning at the social-ecological interface. We illustrate our suggestions with the case of plant invasions.

Our framework and application is underpinned by three important assumptions. The first is that the ensemble of attributes and functions in a given ecosystem (ecological realm) are intrinsically value-free. The benefits or nuisances derived from ES and EDS are, however, dependent on value attribution from individuals, groups of individuals and societies addressed by the social realm (Shapiro and Báldi, 2014).

These are shaped by their specific economic, cultural, and political context. Second, the strong spatial, temporal and socio-economic context-dependency of ES and EDS may not allow for a universal typology and single delineation of ES and EDS. Differences in perceptions by societal actors and human management may trigger, maximise or minimise the impacts from ES and EDS. In this sense, ES and EDS are not necessarily antagonistic but complementary concepts, while their beneficial versus detrimental effects can be opposite to each other. Third, because of the influence of human actions,

ES-EDS are coupled concepts and should not be perceived as static entities in dynamic ecosystems. In this context, a management hierarchy may be useful for achieving the overarching goal of sustainability, accounting for social and technological mechanisms to prevent, reduce or restore desirable levels of ES, and to minimise the risk of or exposure to a specific EDS. This human management perspective broadens the original focus of the ES-EDS notion. It elucidates the nature of beneficial flows from ecosystems to society and additionally accounts for the role of value attribution and ecosystem management in ES and EDS flows.

We are concerned that misinterpretations of our framework may arise. It may be argued that the proposed framework opens the door for too much negotiation about conservation and environmental management goals and priorities by explicitly considering a symmetry between ES and EDS. Our attempt to develop a comprehensive framework that is applicable across a wide range of ecosystems and socio-ecological contexts might also be criticised as being too reductionistic. Instead we believe that our framework facilitates more targeted discussions and deliberations about dynamics related to nature and humans and how to manage ecosystems, thereby providing the means to steer debates beyond simplistic good versus bad dichotomies that currently bedevil many environmental management efforts (e.g. Gaertner et al., 2016; Woodford et al., 2016). In our view, it thus paves the way for improved ecosystem management that is tailored to particular social-ecological contexts. We do not suggest that less attention should be paid to the beneficial roles of ecosystems and biodiversity for human wellbeing. Rather, we hope that our approach widens the conceptual understanding of the valuing of ecosystem functioning, thereby expanding

the repertoire of actions to protect and sustainably manage ecosystems and the services they provide. Finding ways to accurately balance ES and EDS with feasible valuations of costs and added values to humans is a major challenge. We call for more attention from scientists to broader social-ecological challenges. By advancing the thinking on EDS and by acknowledging the pivotal role of humans in the ES arena we hope that academics and practitioners will explicitly adopt a more dynamic notion of ES-EDS coupling in changing ecosystems to account for human action and management at the social-ecological interface.

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Table 1 The proposed typology of ecosystem disservices (EDS) with examples from the literature.

Ecosystem disservices (EDS)	Key references
<b><i>Health EDS – affecting human health</i></b>	
<ul style="list-style-type: none"> <li>- Pollen release that provokes allergic reactions or intoxications;</li> <li>- Animal bites (with or without poison) on humans;</li> <li>- Zoonotic diseases transmitted to humans;</li> <li>- Direct attacks by wild animals causing human injury or death;</li> <li>- Plants that cause irritation when consumed by humans;</li> <li>- Bacteria and virus that resist to human antibiotics;</li> <li>- Methane emissions by plants breathed by humans;</li> <li>- Toxins by algal blooms consumed by humans.</li> </ul>	<p>Baró et al., 2014; Bennett et al., 2010; Dobbs et al., 2014; Escobedo et al., 2011; Gómez-Baggethun and Barton, 2013; Limburg et al., 2010; Lyytimäki, 2014; Lyytimäki and Sipilä, 2009; Lyytimäki et al., 2008; Ma et al., 2015; Roy et al., 2012; Shackleton et al., 2016; Zhang et al., 2007.</p>
<b><i>Material EDS – damaging built infrastructures</i></b>	
<ul style="list-style-type: none"> <li>- Excrement from animals damaging buildings;</li> <li>- Roots of plants damaging streets or pavements;</li> <li>- Leaf litter considered a nuisance, e.g. stains resulting from leaf tannins;</li> <li>- Natural disasters (e.g., hurricanes) damaging infrastructures*.</li> </ul>	<p>Agbenyega et al., 2009; Dobbs et al., 2014; Escobedo et al., 2011; Gómez-Baggethun and Barton, 2013; Limburg et al., 2010; Lyytimäki and Sipilä, 2009; Lyytimäki et al., 2008; Roy et al., 2012; Sagie et al., 2013; Shackleton et al., 2016.</p>
<b><i>Security and safety EDS – disrupting physical, personal, national and financial stabilisation</i></b>	
<ul style="list-style-type: none"> <li>- Fear and risk of getting lost in the wild due to lack of light, e.g. in dense forests;</li> <li>- Fear and risk of attacks by wild animals (e.g. snakes, bears);</li> <li>- Tree branches falling in roads and causing accidents or traffic delays;</li> <li>- Dense vegetation provoking bad visibility in traffic and communication blockage;</li> <li>- Fire-prone vegetation (e.g. dense biomass stands) in otherwise non-fire prone landscapes;</li> <li>- Storms and other weather phenomena impacting human life (e.g. through loss of life)*;</li> <li>- Wild animals within private facilities (lizards or poisonous spiders inside houses, or crocodile in backyards).</li> </ul>	<p>Agbenyega et al., 2009; Bennett et al., 2010; Escobedo et al., 2011; Escobedo et al., 2011; Gómez-Baggethun and Barton, 2013; Limburg et al., 2010; Lyytimäki, 2014; Lyytimäki and Sipilä, 2009; Lyytimäki et al., 2008; Ma et al., 2015; Roy et al., 2012; Shackleton et al., 2016; Zhang et al., 2007.</p>

<b><i>Cultural and aesthetic EDS – impacts on mental/ cultural interactions with nature</i></b>	
<ul style="list-style-type: none"> <li>- Species perceived as disgusting and irritating by people;</li> <li>- Species and landscapes considered unpleasant by people;</li> <li>- Unpopular species due to religion, tradition or cultural legacies (e.g. snakes or goats associated with evil);</li> <li>- Emergence of landscape new views by vegetation perceived as unpleasant;</li> </ul>	<p>Ango et al., 2014; Escobedo et al., 2011; Gómez-Baggethun and Barton, 2013; Lyytimäki, 2014; Lyytimäki and Sipilä, 2009; Lyytimäki et al., 2008; Roy et al., 2012; Shackleton et al., 2016.</p>
<b><i>Leisure and recreation EDS – causing inhibition of physical interactions with nature</i></b>	
<ul style="list-style-type: none"> <li>- Sounds and smells produced by animals disrupting physical connection with nature;</li> <li>- Presence of weeds, pests or mosquitoes considered unpleasant for recreation;</li> <li>- Blocking of sunlight by vegetation, creating too much shading for leisure activities;</li> <li>- Habitats associated with the unknown, remoteness or wilderness considered unpleasant for outdoor activities;</li> <li>- Preference for indoor activities due to unsuited surrounding landscapes.</li> </ul>	<p>Escobedo et al., 2011; Gómez-Baggethun and Barton, 2013; Lyytimäki, 2014; Lyytimäki and Sipilä, 2009; Lyytimäki et al., 2008; Roy et al., 2012; Sagie et al., 2013; Shackleton et al., 2016.</p>

\*The incorporation of natural disasters and weather-related events is still debated. We followed Shackleton et al. (2016), considering those events as those that comprise a clear role of the biotic component of an ecosystem with limited scales and boundaries.

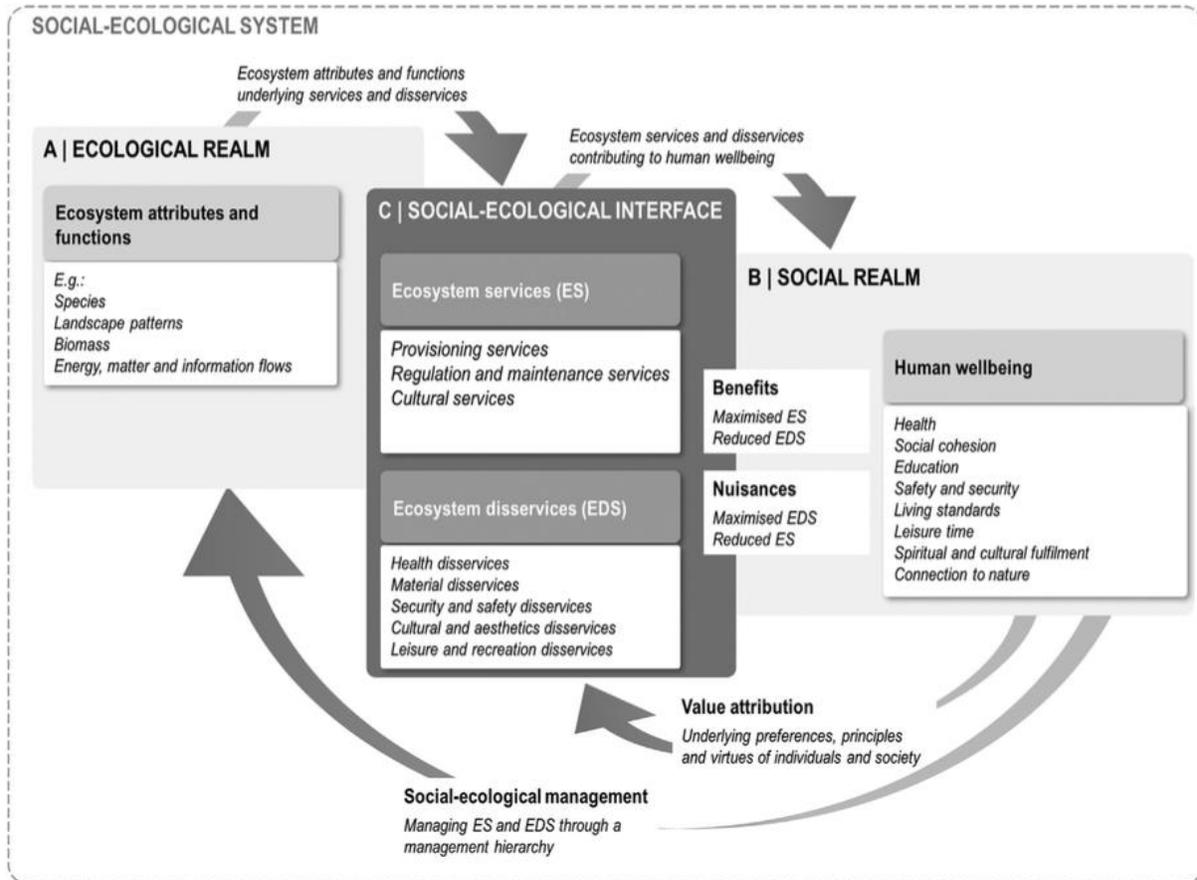


Fig. 1. The framework proposed for addressing both ecosystem services (ES) and disservices (EDS), considering: (A) the ecological realm; (B) the social realm; and (C) the social- ecological interface. The framework assumes that the attribution of ES-EDS depends also on value attribution and social-ecological management.

Table 2 Examples of how different human wellbeing dimensions (based on the categories from Smith et al. (2013)) are affected by benefits, nuisances from reduced ES (from ecosystem services - ES, based on CICES), ecosystem disservices (EDS, based on Table 1), and social-ecological management.

Benefits to human wellbeing	Nuisances for human wellbeing		Social-ecological management
	From ecosystem services (ES)	From reduced ecosystem services	
<b>Health</b>			
Provisioning ES - quality of food and water, provision of pharmaceuticals, genetic materials;	Reduced mediation of waste, toxics and other nuisances (e.g. bio-chemical remediation by algae);	Health EDS - directly affecting human health, from pollution, poisoning and hygiene, to contamination, diseases and their spread (vectors such as mosquitos), and genetic resistance to pharmaceuticals.	Mechanisms and organisations that regulate individual and societal health.  Adequate resource management and technology that promote better conditions and quality of ecosystems.
Regulating and maintenance ES - quality of water and food, regulation of climate, air quality, floods; control of pests and diseases.	Inadequate maintenance of physical, chemical, biological conditions (incl. atmospheric composition and climate regulation, and chemical condition of waters).		
<b>Social cohesion</b>			
Cultural ES - physical and intellectual interactions with ecosystems, promoting a sense of place and shared experiences between communities and generations.	Disrupted mediation of mass, water, and gaseous flows, incl. natural events that could not be mediated by biota and provoke material damages (namely storms and floods) in communication infrastructures that bring people together.	Material EDS - biota damaging communication networks (namely rivers or roads) and lead to economic inequality (economic damages to poorer communities).  Leisure and recreation EDS - unwanted ecosystem attributes that promote the	Social norms that drive perception and promote social cohesion and equitability.  Mechanisms that regulate the access to and enjoyment of ecosystems, creating opportunities for social interactions.

		lack of people connectedness.	
<b>Education</b>			
Cultural ES - that allow intellectual development, cultural diversity, knowledge systems, educational values and cognitive richness through nature.	Disruption of maintenance of physical, chemical, biological conditions, namely unsuitable development of habitat nursery and animal reproduction.	Cultural and aesthetic EDS - repulsive feelings against species or ecosystem components and diminish the desire to learn with nature.	Education, finance and communication services. Creation of opportunities to access natural areas for teaching, researching, and transferring knowledge into arts and culture.
<b>Safety and security</b>			
Provisioning ES - food and water security, energetic standards for safety.  Regulation and maintenance ES - integrity and quality of ecosystems, and the mitigation of unwanted ('natural') phenomena.	Disrupted mediation of flows (e.g., flood and storm protection, or mass stabilisation and control of erosion rates).	Security and safety EDS - EDS related to people's perception towards fear; physical exposure to ecosystems that threaten human safety or facilities or enhance costs associated to natural damages.  Material EDS - degradation of infrastructures that leads to economic inequality (economic damages to poorer communities).	Social mechanisms that provide protection, financial and social assistance in the case of damage.  Integrated resource management and technology that regulate damages derived from wildlife or ecosystem processes.
<b>Living standards</b>			
Provisioning, regulating and maintenance, and cultural ES that provide a real or perceived increase in quality for daily living,	Disrupted mediation of mass, water, and gaseous flows, incl. natural events that could not be mediated by biota and	All types of EDS - considered intrusive in daily life, from health EDS, to cultural and aesthetic EDS conflicting with people's	Social mechanisms that promote wealth equality, improve living conditions, and that allow the maintenance and creation of

including food, ornamental, economic outcomes, and ecosystem well-functioning.	provoke material damages (namely storms and floods) in communication infrastructures.	beliefs, or material EDS promoting social costs.	green space e.g., cost regulation for human health and infrastructures.
<b><i>Leisure time</i></b>			
Regulating and maintenance ES - pleasant environment increasing the willingness for people to enjoy nature.  Cultural ES - opportunities for physical outdoor activities.	Inadequate maintenance of physical, chemical, biological conditions (e.g. lack or disruption of pest and disease control);  Reduced mediation of waste, toxics and other nuisances (e.g. bio-chemical remediation by algae).	Leisure and recreation EDS - disrupted physical participation of people with nature, including the opportunities for recreation and relaxation.	Incentives for social interactions, networking and cohesion in nature (e.g., publicity).  Social opportunities to access and interact with nature, incl. activities that enhance the perceived quality of recreational and aesthetic areas (e.g., footpaths, gardens).
<b><i>Spiritual and cultural fulfilment</i></b>			
Cultural ES - physical, intellectual and spiritual interactions with nature, including aesthetic values, inspiration and cognitive development, and spiritual enrichment.	Disruption of development of habitat nursery and animal reproduction.	Cultural and aesthetic EDS - negative perception of nature on people's fulfillment, including cultural traditions, anxiety situations, fears, as well as unpleasant and repulsive due to beliefs (or past experiences).	Social opportunities for regulating inequality and improving cultural, educational and spiritual inclusion in heritage.  Social mechanisms that protect and promote sacred and cultural aspects of ecosystems.
<b><i>Connection to nature</i></b>			
Regulating and maintenance ES - sense of fulfilment towards nature outputs.	Inadequate maintenance of physical, chemical, biological conditions (e.g. lack or disruption of pest and disease control);	Cultural and aesthetic EDS - responsible for negative perceptions about nature experiences	Policies and land use planning; community and faith-based initiatives.

<p>Cultural ES - intellectual and physical interactions with nature.</p>	<p>Reduced mediation of waste, toxics and other nuisances (e.g. bio-chemical remediation by algae).</p>	<p>Leisure and recreation EDS - disrupting physical willingness to connect with nature.</p>	<p>Social regulation of the condition of ecosystems, promoting access to nature and biodiversity, recreation and aesthetics.</p>
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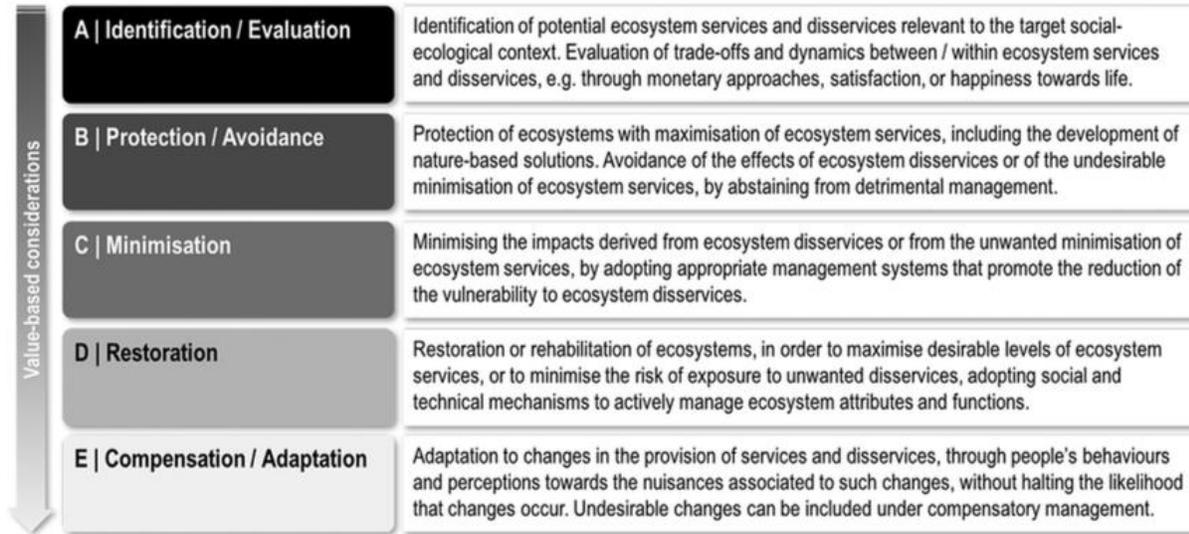


Fig. 2. The management hierarchy proposed to identify strategic environmental management activities aimed at maximising ecosystem services and reducing ecosystem disservices.

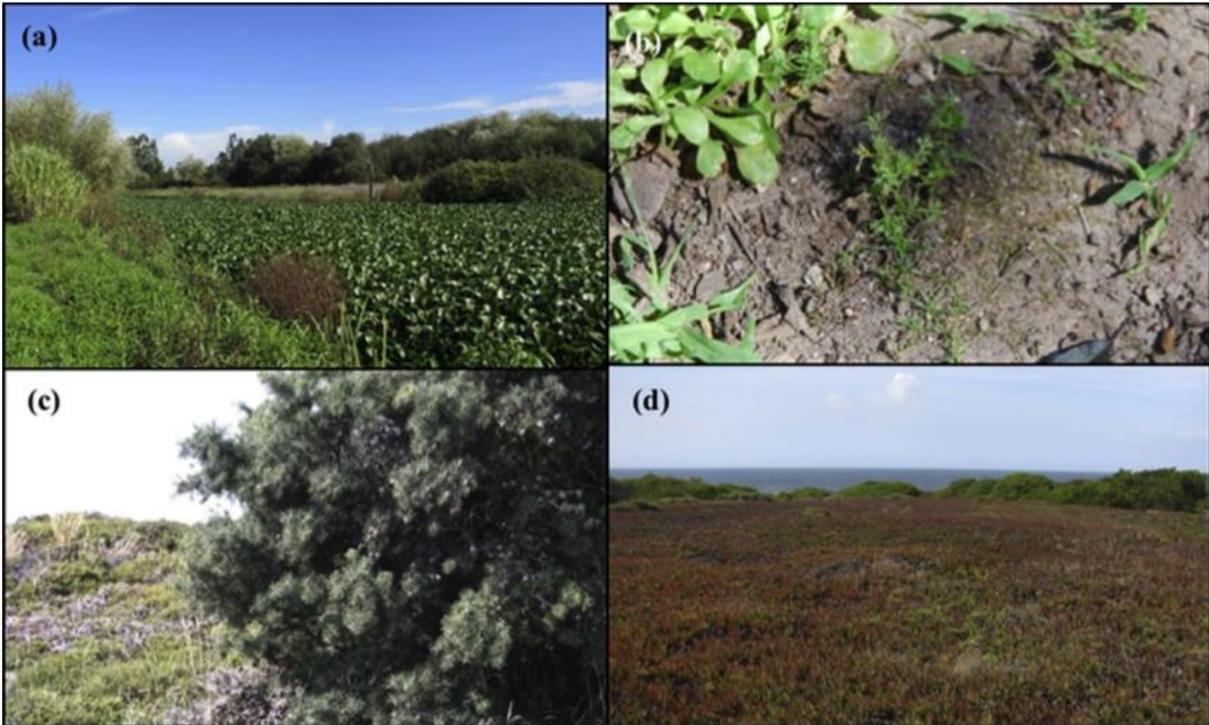


Fig. 3. Illustrative examples of nuisances (a, b), and benefits (c, d), provided by alien invasive plants in Portugal: (a) *Eichhornia crassipes*, native to South America, which invades rivers, causing blockage and disrupting water transport and sports; (b) *Soliva sessilis*, native to South America, which invades lawns, causing physical injury to people and reduces recreation opportunities; (c) *Hakea sericea*, native to Australia, and introduced for afforestation goals and to be used by locals as fences; and (d) *Carpobrotus edulis*, native to South Africa, and introduced for ornamental uses and dune fixation in coastal habitats.

Table 3 Examples of benefits, from ecosystem services (ES – based on CICES), and nuisances from ecosystem disservices (EDS – based on Table 1) and reduced ecosystem services, promoted by plant invasions on human wellbeing dimensions (categories based on Smith et al. (2013)).

Benefits from plant invasions to human wellbeing	Nuisances from plant invasions for human wellbeing	
From ecosystem services (ES)	From reduced ecosystem services	From ecosystem disservices (EDS)
<b>Health</b>		
Provisioning ES: - Blood sugar medicine from <i>Prosopis</i> species in South Africa (Shackleton et al., 2014); - Several medicinal and curative products derived from <i>Eichhornia crassipes</i> in Bangladesh (Rana and Akhter, 2010); - Styptics or astringents extracted from <i>Acacia mearnsii</i> (Kull et al., 2011; de Wit et al., 2001); - Other products from <i>Acacia</i> , <i>Cinnamomum</i> and <i>Spathodea</i> species across the globe (Dickie et al., 2014).	- Reduction of the provision of medicinal products through the elimination of other medicinal plants, by Australian <i>Acacia</i> species in South Africa, Portugal and Chile (Le Maitre et al., 2011).	Health EDS: - Physical injury due to <i>Opuntia</i> thorns in South Africa (Shackleton et al., 2007); - Myocardia or gastroenteritis associated to the consumption of flowers and seeds of <i>Ailanthus altissima</i> and <i>Robinia pseudoacacia</i> , and cardiac problems and poisoning from <i>Echium plantagineum</i> and <i>Rhododendron ponticum</i> (Pyšek and Richardson, 2010); - Pollen allergy and (or) dermatitis caused by <i>A. altissima</i> , <i>Acacia dealbata</i> , <i>Ambrosia artemisiifolia</i> , <i>Cortaderia selloana</i> , <i>Heracleum mantegazzianum</i> and <i>Schinus terebinthifolius</i> (Pyšek and Richardson, 2010); - Transmission of human parasites through invasive plants (Schindler et al., 2015).
<b>Social cohesion</b>		
Provisioning ES: - Exchange of <i>Opuntia ficus-indica</i> fruits, supporting community relationships and nurturing reciprocity in South Africa (Shackleton et al., 2007).	- Removal of <i>Acacia</i> species in South Africa leads to social conflicts, decreasing social cohesion (Dickie et al., 2014).	Cultural and aesthetic EDS: - Conflicts of interest between people (e.g. xenophobia, and conservationists versus land managers) due to <i>Acacia</i> and <i>Jacaranda</i> species in South Africa (Dickie et al., 2014; van Wilgen and Richardson, 2014);

<p>Cultural ES:</p> <ul style="list-style-type: none"> <li>- Social equity associated to people's accessibility to <i>Acacia</i> species in South Africa, providing a sense of national symbolism (Carruthers et al., 2011);</li> <li>- Poverty alleviation through employment, training and collaboration on managing <i>Acacia</i> species (Kull et al., 2011; McConnachie et al., 2013; Mugido et al., 2014; Shackleton et al., 2007).</li> </ul>		<ul style="list-style-type: none"> <li>- Conflicts over limited natural resources between communities in Ethiopia and Kenya due to <i>Prosopis</i> species (Shackleton et al., 2014);</li> <li>- Discrimination of people due to compromised selection of those benefiting from funding targeting invasive species management in South Africa (McConnachie et al., 2013).</li> </ul> <p>Material EDS:</p> <ul style="list-style-type: none"> <li>- Blocked accessibility between humans within nature reserves in South Africa caused by <i>Opuntia ficus-indica</i> (Shackleton et al., 2007);</li> <li>- Disruption of 'healthy country' including important cultural sites in Aboriginal Australia (Bach and Larson, <i>in press</i>).</li> </ul>
<b>Education</b>		
<p>Cultural ES:</p> <ul style="list-style-type: none"> <li>- Opportunities for environmental education and training focused on management of <i>Acacia</i> (Carruthers et al., 2011; Mugido et al., 2014; Shackleton et al., 2007) and <i>Opuntia</i> species (Shackleton et al., 2007).</li> </ul>	<ul style="list-style-type: none"> <li>- Disruption of personal identity due to misleading national symbolism of Australian and African <i>Acacia</i> species (Carruthers et al., 2011).</li> </ul>	--
<b>Safety and security</b>		
<p>Provisioning ES:</p> <ul style="list-style-type: none"> <li>- Financial security through cash income from <i>Opuntia</i> species in South Africa (Shackleton et al., 2007);</li> </ul>	<ul style="list-style-type: none"> <li>- Compromised food security due to impacts on livestock health by <i>Prosopis</i> species in Kenya (Shackleton et al., 2014);</li> </ul>	<p>Security and safety EDS:</p> <ul style="list-style-type: none"> <li>- Harboring of criminals in dense vegetation of <i>Acacia mearnsii</i> in South Africa (Shackleton et al., 2014);</li> <li>- Species that promote fire hazard in non-fire prone areas (Carruthers et al., 2011);</li> </ul>

<p>- Species as fence poles, namely <i>Acacia</i> and <i>Pinus</i> (Dickie et al., 2014).</p> <p>Regulation and maintenance ES:</p> <p>- Soil conservation, stabilisation and fertility, land reclamation, windbreaks against sandstorm, watershed protection, dune stabilisation, roads protection, from <i>Acacia</i> and <i>Pinus</i> species in Kenya, Madagascar, South Africa, New Zealand (Carruthers et al., 2011; de Wit et al., 2001; Kull et al., 2011; Rana and Akhter, 2010; Richardson and van Wilgen, 2004; Shackleton et al., 2007, 2014).</p>	<p>- Changes in fire and flood regimes promoted by <i>Acacia</i> species (Gaertner et al., 2014; Le Maitre et al., 2011; van Wilgen and Richardson, 2014);</p> <p>- Modification of soil quality and promotion of soil erosion (de Wit et al., 2001; Funk et al., 2013; Shackleton et al., 2014).</p>	<p>Gaertner et al., 2014; Kull et al., 2011; Richardson and van Wilgen, 2004).</p>
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**Living standards**

<p>Provisioning ES:</p> <p>- Crops, fruits, honey, fuelwood, tannins, timber and pulp for paper, namely from <i>Acacia</i> spp., <i>Eriobotrya japonica</i>, <i>Ficus carica</i>, <i>Opuntia</i> spp., <i>Morus alba</i> and <i>Psidium guajava</i> (Carruthers et al., 2011; Dickie et al., 2014; Koskela et al., 2014; Kull et al., 2011; Le Maitre et al., 2011; Shackleton et al., 2007; van Wilgen and Richardson, 2014);</p> <p>- Fodder for cattle from <i>Opuntia</i> species in South Africa (Shackleton et al., 2007).</p> <p>Regulation and maintenance ES:</p>	<p>- Depletion of water sources for both consumption and irrigation, promoted by <i>Acacia</i> and <i>Prosopis</i> species in South Africa, Portugal and Madagascar (Carruthers et al., 2011; Funk et al., 2013; Kull et al., 2011; Le Maitre et al., 2011; Shackleton et al., 2016; van Wilgen and Richardson, 2014; Vicente et al., 2013);</p> <p>- Disruption of soil-nutrient cycling, carbon</p>	<p>Health EDS:</p> <p>- Constipation caused by the ingestion of <i>Opuntia ficus-indica</i> fruits in South Africa (Shackleton et al., 2007).</p> <p>Material EDS:</p> <p>- Blocked accessibility within lands due to <i>Opuntia ficus-indica</i> expansion (Shackleton et al., 2007).</p> <p>Security and safety EDS:</p> <p>- Forests considered a security risk and used as latrine areas (Kull et al., 2011; Shackleton et al., 2007, 2014).</p> <p>Cultural and aesthetic EDS:</p> <p>- ‘Ugly’ landscapes dominated by <i>Acacia</i> species (Carruthers et al., 2011).</p>
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<ul style="list-style-type: none"> <li>- Carbon sequestration and nitrogen fixation (de Wit et al., 2001; Dickie et al., 2014; Kull et al., 2011; Qiu, 2015; van Wilgen and Richardson, 2014), namely by <i>Acacia</i> species in Portugal (Vicente et al., 2013);</li> <li>- Sand stabilisation or erosion control, especially in degraded areas by several tree species (van Wilgen and Richardson, 2014).</li> </ul> <p>Cultural ES:</p> <ul style="list-style-type: none"> <li>- <i>Acacia</i> species associated to heritage, religion, folklore, fairy tales, legends and associated rituals (Kull et al., 2011).</li> </ul>	<p>and nitrogen fixation (Gaertner et al., 2014; Qiu, 2015);</p> <ul style="list-style-type: none"> <li>- Loss of land for cattle due to dense vegetation (Kull et al., 2011; Shackleton et al., 2016; van Wilgen and Richardson, 2014);</li> <li>- Destruction of timber resources by competition with other tree species (Richardson and van Wilgen, 2004);</li> <li>- Pest transmission to tree plantations, promoted by <i>Acacia dealbata</i> in Chile, <i>A. longifolia</i> in Portugal and <i>A. saligna</i> in South Africa (Koskela et al., 2014; Le Maitre et al., 2011);</li> <li>- Other disease transmission to livestock in Kenya (Shackleton et al., 2014).</li> </ul>	<p>Leisure and recreation EDS:</p> <ul style="list-style-type: none"> <li>- Physical injury through contact with the plant spines from several invasive species (Pyšek and Richardson, 2010; Shackleton et al., 2007, 2014).</li> </ul>
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***Leisure time***

<p>Cultural ES:</p> <ul style="list-style-type: none"> <li>- Species introduced as shade trees providing opportunity for picnic grounds; e.g. pines in Cape Town (e.g. Pooley 2014), <i>Eucalyptus</i> species in South Africa, <i>Pinus</i> species in New Zealand, and</li> </ul>	<ul style="list-style-type: none"> <li>- Degradation of recreational areas and loss of touristic experiences (de Wit et al., 2001; Le Maitre et al., 2011; van Wilgen and Richardson, 2014);</li> </ul>	<p>Leisure and recreation EDS:</p> <ul style="list-style-type: none"> <li>- Discomfort caused when barefooted people contact with the thorns of <i>Prosopis</i> species (Shackleton et al., 2007).</li> </ul>
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<p><i>Rhamnus</i> and <i>Salix</i> species in Australia (Dickie et al., 2014).</p>	<p>- Blockage of water bodies by <i>Acacia mearnsii</i> in South African rivers (Shackleton et al., 2014), and tracks due to impenetrable stands (Pyšek and Richardson, 2010).</p>	
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***Spiritual and cultural fulfilment***

<p>Cultural ES:</p> <ul style="list-style-type: none"> <li>- Encouraging native biodiversity conservation, due to the appearance of exotic unpleasant <i>Acacia</i> species (Carruthers et al., 2011);</li> <li>- Spiritual and aesthetic values attributed to “plant of my ancestors”, production of traditional wines and jams from <i>Opuntia</i> species in South Africa (Shackleton et al., 2007);</li> <li>- Use of <i>Acacia mearnsii</i> for building traditional huts, sacred pool protection, firewood to support traditional ceremonies, rituals and celebrations in South Africa (Shackleton et al., 2007);</li> <li>- Visual amenity, ornamental purposes and landscape re-green provided by invasive plants (Carruthers et al., 2011; Dickie et al., 2014; Koskela et al., 2014; Kull et al., 2011; Le Maitre et al., 2011; Shackleton et al., 2007);</li> <li>- Provision of a ‘sense of place’ in urban areas associated to</li> </ul>	<ul style="list-style-type: none"> <li>- Loss of sense of place and aesthetic values due to the presence of invasive species, such as <i>Acacia</i>, <i>Opuntia</i> and <i>Prosopis</i> species in South Africa and New Zealand (de Wit et al., 2001; Le Maitre et al., 2001; Shackleton et al., 2007);</li> <li>- Threats to national pride by replacing native, emblematic species (Carruthers et al., 2011; van Wilgen and Richardson, 2014);</li> <li>- Reduced cultural value of sacred pools due to the presence of <i>Acacia mearnsii</i> in South Africa (Shackleton et al., 2007).</li> </ul>	<p>Cultural and aesthetic EDS:</p> <ul style="list-style-type: none"> <li>- Lack of beauty, art and fascination that humans experience in wild nature or historic landscapes related to the invasion by <i>Acacia</i> species (Carruthers et al., 2011).</li> </ul>
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<p><i>Jacaranda</i> species in South Africa and <i>Pinus</i> in New Zealand (Dickie et al., 2014).</p>		
<b>Connection to nature</b>		
<p>Regulation and maintenance ES:</p> <ul style="list-style-type: none"> <li>- Reduced harvesting pressure on native plants by the collection of <i>Acacia mearnsii</i> (Carruthers et al., 2011; Shackleton et al., 2007);</li> <li>- Provision of food for native wildlife, protection from predators, increased species richness by invasive vegetation (Dickie et al., 2014; Koskela et al., 2014).</li> </ul>	<ul style="list-style-type: none"> <li>- Genetic pollution, leading to the dilution and loss of unique diversity in the wild, mainly by tree invasions (Koskela et al., 2014; Le Maitre et al., 2011);</li> <li>- Global erosion of biodiversity and habitats (Carruthers et al., 2011; Dickie et al., 2014; Kull et al., 2011; Le Maitre et al., 2011; Shackleton et al., 2016; van Wilgen and Richardson, 2014; Vicente et al., 2013).</li> </ul>	<p>Cultural and aesthetic EDS:</p> <ul style="list-style-type: none"> <li>- Appearance of monospecific forests of <i>Acacia cyclops</i>, <i>A. longifolia</i>, and <i>A. saligna</i> in South Africa (Gaertner et al., 2014).</li> </ul>