

Optimising ecosystem services to deliver multiple benefits

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Abstract

The inherently systemic concept of ecosystem services recognises multiple, qualitatively differing societal benefits, yet most services remain overlooked by contemporary markets and policy drivers contributing to ecosystem degradation. Societal transition from reductive, reactive decision-making about ecosystem management and policy to one founded on a systemic basis is limited by the lag effect of legacy world views and fragmented formal and informal policies. Transformation to systemically based societal decision-making norms may be accelerated by recognising that desired services should not dominate decision-making, instead constituting ‘anchor services’ around which outcomes for linked ecosystem services can be optimised with involvement of their beneficiaries. Deliberative processes can generate innovations in ecosystem use and management, including identification of ‘systemic solutions’ that deliberately optimise outcomes across a spectrum of linked ecosystem services. This service-optimising approach is more equitable through addressing outcomes for diverse service beneficiaries, more economically efficient by recognising and balancing linked benefits and disbenefits, and more resilient by refocusing on service-producing ecosystem processes. New policies and tools may be required, but application of the ecosystem services framework to evaluate outcomes in existing tools enables rapid, incremental progress. Systemic thinking about ecosystem dependencies and impacts is relevant to all policy areas and sectors of society.

Keywords

Ecosystem services; optimisation; systemic solutions; anchor services; equity; economic efficiency; resilience; systems

The rise of ecosystem services

Our human species does not differ from others in terms of our entire interdependence with the planetary ecosystems with which we co-evolved. The natural world has always met human needs by providing resources supporting basic biophysical requirements, such as food, clean air and water, materials for shelter, defence and natural medicines, and the dissipation and purification of wastes. It has also provided resources supporting our economic activities and less material quality of life. Just as locally specific geodiversity and biodiversity combine to produce distinct types of ecosystems, the local characteristics, finite capacities and inherent checks and balances of ecosystems have also shaped local distinctiveness and imposed limitations for people. The innovations through which humans have harnessed or augmented available stocks and flows of matter and energy in the

environment have underpinned agricultural and technological advances, defining civilisations and progressive social and economic revolutions throughout our cultural evolution (Everard, 2016).

As indivisible components of planetary ecosystems, humanity – from our basic biology to the metabolism of our settlements and technologies – is unbreakably interconnected with natural cycles, processes and species. Many of the ways we benefit from nature have been appreciated and supplemented throughout prehistory and history. These include, as examples, natural processes producing food and water as well as the consequences of their depletion, the significance of sacred and other culturally important places, and viable fisheries for recreational and commercial use. Other of nature's services have only relatively recently become better appreciated, such as the environmental processes stabilising the global climate (IPCC, 2014) and those operating across catchment landscapes that afford us the benefits of natural flood management (Parliamentary Office of Science and Technology, 2011) and the avoidance of pollution at source of the water that we abstract and treat downstream for human uses (Staddon, 2010). Yet many of nature's services have to date barely registered as important, including for example natural processes regulating pest and disease prevalence, the significance of coastal and riparian vegetation for natural hazard protection, or the value of species of potential medicinal and other functional importance.

Today, these benefits flowing to humanity from nature are classified and better known as 'ecosystem services'. Ecosystem services are defined by the Millennium Ecosystem Assessment (2005a) as "...*the benefits people obtain from ecosystems*". The term 'ecosystem services' first entered scientific discourse in the 1960s (King, 1966; Helliwell, 1969) though expansion of the concept rapidly followed, including in drawing attention to hazards inherent in the consequences of population growth for limited natural resources (Ehrlich and Ehrlich, 1970) and the threats inherent in species loss and extinction (Ehrlich and Ehrlich, 1981). Further development and terminological standardisation of the meanings of ecosystem services were to follow (Ehrlich and Mooney, 1983; Daily, 1997), the concept expanding beyond the axis between ecosystem productivity and human resource demands to include natural capital beyond biodiversity (Mooney and Ehrlich, 1997) and progressively embracing socio-economic and nature conservation objectives (Fisher *et al.*, 2009). Since the 1990s, the number of scientific papers addressing ecosystem services has increased exponentially (Vihervaara *et al.*, 2010), reflecting growing scientific and policy interest.

Whilst earlier conceptualisations tended to separate out physically extractable 'goods' from other 'services' (Sather and Smith, 1984; Dugan, 1990; Everard *et al.*, 1995), practice has subsequently evolved to use the term 'ecosystem services' to cover both material and the non-material benefits flowing from nature (Daily, 1997). Ecosystem service concepts, definitions, classification schemes and their applications are still evolving today, though all as a fundamental principle recognise the multiplicity of ways in which ecosystems support human wellbeing (Everard, 2017).

Systemic context

Whilst inherent in the systemic context from which ecosystem service concepts arose, the integrally interconnected nature of ecosystem services is less well reflected in their implementation into policy and practice. This is despite the word ‘system’ explicitly constituting a part of the word ‘ecosystem’. We understand systems in terms of knowing that a car engine won’t work, an ant colony does not function, a protein will lack structural and catalytic properties, an atom will be unstable and a football team can’t interact effectively if all constituent parts are not present and arranged appropriately. Ecosystems are essentially similar, comprising multi-functional arrangements of geodiversity and biodiversity interacting through myriad processes to maintain system integrity, functioning and resilience, and generating a flow of services from which humans derive a spectrum of qualitatively differing benefits.

The Millennium Ecosystem Assessment (2005a) classification of ecosystem services explicitly recognises the qualitatively different types of benefits as: *Provisioning services*; *Regulating services*; *Cultural services*; and *Supporting services* (see Table 1).

Table 1: The four categories of ecosystem services defined in the Millennium Ecosystem Assessment classification

- *Provisioning services* include “Products obtained from ecosystems”, such as food, fuel and fibre, fresh water, medicinal substances and energy;
- *Regulating services* address “Benefits obtained from the regulation of ecosystem processes” including those moderating climate, air quality, erosion, disease transmission and pollination;
- *Cultural services* include predominantly non-material benefits enriching human lives, ranging from aesthetic and spiritual meanings, inspiration for folklore and art, and recreation and tourism; and
- *Supporting services* include processes within ecosystems essential for their ongoing functioning, resilience and capacities to produce other more directly exploited ecosystem services, addressing such factors as soil formation, habitat for wildlife and the cycling of nutrients.

The Millennium Ecosystem Assessment (MA) classification scheme is used here as it is inclusive of non-marketed and other services that are not directly exploited. These less directly used services are often considered as ‘primary services’, ‘intermediate services’ or ‘production functions’ in other subsequent ecosystem service reclassifications – particularly The Economics of Ecosystems and Biodiversity (TEEB, 2010), the Common International Classification of Ecosystem Services (CICES: Haines-Young and Potschin, 2013), and the UK National Ecosystem Assessment (UK NEA, 2011) valuation model – that inform valuation of more directly exploited provisioning, regulatory and cultural services. The rationale for their exclusion is that supporting services, as initially defined in the Millennium Assessment, have been redefined by TEEB (2010) and Braat and de Groot (2012)

as ecosystem functions rather than services, such that valuation of supporting services can result in double-counting their contributions to other ecosystem services that are more directly beneficial to and exploited by people. Notwithstanding the emphasis of valuation upon more directly exploited services as a means to avoid 'double-counting', it is vital that the underpinning roles of supporting services (or functions) is fully appreciated in policy development if we are to avert the continuing tendency to undermine the functioning, resilience and capacities of ecosystems to continue to generate other more directly exploited services. Many of these non-marketed services (or functions) have been historically omitted from corporate and policy-level decision-making, and as often degraded in ensuing decisions and actions founded on realisation of single or a narrow subset of ecosystem service benefits, often of immediate utilitarian value rather than long-term resilience. Therefore, whilst acknowledging that it is far from perfect, the MA classification of ecosystem services serves as an inclusive and consensual basis for systemic assessment of the multiple, simultaneous benefits provided by ecosystems and the functions that maintain them.

Experience informs us that ecosystems do not produce services individually, but rather in intimately interconnected clusters. Compare, for example, a short and steep river catchment rising on a 'hard' geology with a long, meandering lowland river systems spanning flat and fertile soils. We know that the characteristics of each river system will differ in multiple connected ways – flow rates, concentrations of nutrients and other geochemicals in the water, geomorphological structures and functions along the river, associated vegetation, fish and invertebrate populations and the opportunities they afford humanity for food provision, waste assimilation, sporting and navigation potential, and so forth. We also know that this whole 'package' of functions, characteristics and benefits might be perturbed in a closely interconnected way by interventions such as dam construction, annexing of floodplain for development, significant inputs of pollutants as well as natural forces such as regime shifts in the climate. The same principle applies to other habitats ranging from coastal margins to marine waters, woodlands and rangelands, coral reefs and urban ecosystems. The delivery of ecosystem services as systemically connected sets was recognised by Schomers and Matzdorf (2013) as comprising 'environmental services' and by Balvanera (2016) as 'bundles', or packages of closely connected ecosystem services. Thinking in terms of clusters of systemically connected services, as for example the three primary constituents of the food-water-energy nexus with ramifications for wider dimensions of human security and wellbeing (Biggs *et al.*, 2015), offers a more integrated means for considering the interconnected outcomes of ecosystem interventions. This represents a more integrated basis for sustainable planning than the historic tendency to manage for single or a few services in isolation, overlooking wider systemic ramifications that often include unforeseen negative externalities.

Humanity's non-systemic past and legacy

For much of history, at least since the founding of fixed civilisations and certainly since the European Agricultural and Industrial Revolutions, humanity has rather lost touch with the systemic essence of the ecosystems we exploit, the services that they produce, and our interdependence with them. Rather, we have tended to seek

maximisation of single or narrow subsets of favoured ecosystem services. Practical examples include extraction of fish from marine systems, timber from forests and farmed produce from land, all often driven by narrowly framed rewards enshrined in markets. Yet, without systemic consideration, modern intensive fishery, forest exploitation and farming systems continue to erode soils and degrade sea bed communities, mobilise stored carbon, deplete natural biodiversity and geodiversity, perturb nutrient cycles and delicate ecological balances, and downgrade aesthetic value and overall ecosystem functioning, integrity and resilience. Similar considerations apply to mining practices that efficiently and remuneratively extract minerals and aggregates, yet incur generally unaccounted costs in terms of perturbation of aquifers and surface water flows, habitat for wildlife both directly and indirectly through disruption of migration routes, dust and noise generation potentially affecting the tranquillity and health of local communities, etc.

Our wider use of landscapes globally for modern intensive agricultural practices, driven significantly by immediate rewards for maximisation of food and commodity production (a subset of marketable provisioning services), are recognised as amongst the greatest threats to wetlands (Millennium Ecosystem Assessment, 2005b) as well as a wide range of other terrestrial ecosystems and their services (Millennium Ecosystem Assessment, 2005a). The situation at sea is no less favourable with the pace of stock depletion through industrialisation of capture methods in common marine fisheries contributing to 7% of 600 marine fisheries monitored in 2005 being in depleted state with a further 17% over-exploited, 52% fully exploited with only 1% recovering from depletion (FAO, 2005). This situation is compounded by conversion of intertidal habitat, particularly 'nursery' areas important for recruitment of new stock, for port, resort, agricultural, urban and industrial development (de Groot *et al.*, 2012).

The Ecosystem Approach

Implementation of the systemic intent of ecosystem services has to take place within the complexity of 'real world' socio-environmental systems. To assist this process, the Convention on Biological Diversity (CBD) (undated a) promoted the Ecosystem Approach, defined by twelve principles (summarised in Table 2), as a systemic basis for implementation of the ecosystem services framework within operational geographic and socio-economic contexts.

Table 2: Summarised versions of the twelve principles defining the Ecosystem Approach (Convention on Biological Diversity, undated a)

- Principle 1: The objectives of management of land, water and living resources are a matter of societal choices.
- Principle 2: Management should be decentralized to the lowest appropriate level.
- Principle 3: Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems.

- Principle 4: Recognizing potential gains from management, there is usually a need to understand and manage the ecosystem in an economic context.
- Principle 5: Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach.
- Principle 6: Ecosystems must be managed within the limits of their functioning.
- Principle 7: The ecosystem approach should be undertaken at the appropriate spatial and temporal scales.
- Principle 8: Recognizing the varying temporal scales and lag-effects that characterize ecosystem processes, objectives for ecosystem management should be set for the long term.
- Principle 9: Management must recognize that change is inevitable.
- Principle 10: The ecosystem approach should seek the appropriate balance between, and integration of, conservation and use of biological diversity.
- Principle 11: The ecosystem approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices.
- Principle 12: The ecosystem approach should involve all relevant sectors of society and scientific disciplines.

First use of the term 'Ecosystem Approach' in a policy context occurred at the Earth Summit in Rio de Janeiro in 1992 (Laffoley *et al.*, 2004), when it was adopted as a foundational concept of the CBD (Convention on Biological Diversity, undated a). The Ecosystem Approach was subsequently affirmed at the CBD's Seventh Conference of Parties in 2004 as "...a *strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way*" (Convention on Biological Diversity, undated b). The Ecosystem Approach has since gained wider recognition including, for example, adoption by the Ramsar Convention (on wetland of international importance) in 2002 (Ramsar Convention, 2002).

The Ecosystem Approach is now widely adopted as an integral component of environmental policy, endorsed for example by the 2002 World Summit on Sustainable Development in Johannesburg (United Nations, 2002). The Ecosystem Approach is implicit in the European Water Framework Directive (Commission of the European Communities, 2000). It is also the recommended approach to halting the loss of biodiversity agreed in Gothenburg by the European Union Heads of

Government and with regard to both natural and constructed wetlands by the Ramsar Convention (Beaumont *et al.*, 2007).

A slow transition

Although the language of ecosystem services and the Ecosystem Approach today is increasingly incorporated into science and policy pronouncements, systemic application and practical realisation of systemic outcomes remains frustratingly sparse. Tangible if slow progress is evident, for example in popularisation of the concept of the food-water-energy nexus (as noted previously), the more ecosystem-based and multi-benefit approaches of Natural Flood Management (Parliamentary Office of Science and Technology, 2011), sustainable drainage systems (Woods-Ballard *et al.*, 2007) and nature conservation focusing on better connected habitats more porous to species of conservation concern and providing a wealth of ecosystem services (Lawton, 2010). However, the lag effect of legacy world views, vested interests and entrenched assumptions held by people and encoded in models, results in fragmented, issue-by-issue responses to negative outcomes from narrowly framed exploitation of land, mined, manufactured, waste and other resources. The overwhelming societal tendency remains one of reacting to acute problems as they manifest, rather than systemically informed management choices that reflect system processes and resilience. A legacy of this is our currently fragmented policy environment, constituting a poorly integrated patchwork of 'societal levers': markets, statutory legislation, common/civil law, market-based instruments and protocols (Everard, 2011). This disjointed set of incentives and constraints often only peripherally influences the choices of resource owners relative to more powerful forces such as market rewards posited on short-term maximisation of narrow outputs, overlooking wider impacts. The piecemeal nature of this formal and informal policy environment is neither sufficient nor sufficiently integrated to achieve coherence between the choices of local resource owners and wider societal aspirations and consensus about securing flows of ecosystem services of optimal benefit to society (Everard *et al.*, 2014).

Effective implementation of the ecosystem services framework and the Ecosystem Approach must necessarily be systemic. Despite many studies, policies and reports today now using aspects of the language of ecosystem services, their systemic realisation is often lacking or at best suboptimal. Many perpetuate a narrow focus on single or a few perceived priority 'services', such as water, food supply or protection of favoured species. But perpetuation of a narrow focus overlooks the all-important systemic context of ecosystem services, resulting in non-focal services such as carbon cycling, soil quality or spiritually important landscapes still tending to be overlooked. Through this fractured approach, supporting ecosystem services in particular, and consequently the capacity of ecosystems to continue to provide the wider range of more directly exploited services, often become inadvertently degraded. Rather than reflecting the systemic context of ecosystem services, narrowly focused implementation merely uses new terminology to perpetuate the prevalent forms of largely market-driven maximisation of one or a few services with the externalisation of ecosystem functioning and sustained provision of many associated services.

Ecosystem services imply far more than new words for old, narrowly framed policies and practices: consideration of ramifications across the whole socio-ecological system and innovation of novel resource use and management approaches to achieve a connected set of beneficial outcomes is integral to their proper understanding and implementation.

Systemic solutions

The historic paradigm of focusing on and managing ecosystems to maximise single or narrow subsets of benefits has tended to be of dubious net value to society once all externalities are taken into account. Practical examples are afforded by the overall outcomes of intensive food production systems that deplete soil carbon and perturb hydrology and water quality, hard defences erected to protect assets at risk of flooding that displace floodwater elsewhere whilst also disconnecting habitat and ecosystem functions, or wastewater treatment systems planned without regard to often intense energy and material inputs or climate-active gas and other waste outputs. A shift to systemic options appraisal necessarily takes account of implications for all linked ecosystem services and their associated values to society within decision-making processes. Though attainment of this goal – indeed this stated policy intent – remains at best aspirational given the fragmented nature of the legacy formal and informal policy environment, there is at least sufficient knowledge about how to approach this type of transformation to a systemic basis.

The concept of ‘systemic solutions’ describes the use or emulation of natural processes to achieve multiple, simultaneous ecosystem service outcomes. Defined as “...*low-input technologies using natural processes to optimise benefits across the spectrum of ecosystem services and their beneficiaries*” (Everard and McInnes, 2013), systemic solutions contribute to sustainable development by anticipating and averting unintended negative impacts and optimising benefits across a range of ecosystem services and their beneficiaries. They thereby increase net societal equity and economic value and the resilience of the supporting ecosystem. Practical and established examples of systemic solutions include a converging range of urban ecosystem-based technologies, such as SuDS (sustainable drainage systems) and other ‘green infrastructure’, integrated constructed wetlands (ICWs) and other multifunctional wetlands, washlands, urban trees and Natural Flood Management. These systemic solutions yield multiple benefits contrasted, for example, with many single-service solutions that may be efficient in serving their intended goals yet overlook other implications and opportunities for wider ecosystem services.

The concept of systemic solutions has wide applicability, supporting a diversity of human needs and adding value to technological solutions. As one example, nature-based catchment management solutions can be systemically planned and hybridised with ‘hard’ engineered water management techniques to increase their efficiency, longevity and net societal value of the water system, for example through reducing treatment costs of better quality raw water or reducing sediment loads thereby extending dam life and reducing sedimentation in pipework and on roads. Landscape management also has a significant role to play in averting flooding of rail, road, power and other engineered systems. Another example is in urban settings, where recognition and incorporation of environmental services, such as via their

integration as 'green infrastructure', can reduce risks from flooding and air quality whilst enhancing aesthetic, amenity and other wider dimensions of quality of life for people clustered in increasingly dense urban centres.

Regardless of systemic intent, there will generally be a central driving disciplinary need or policy imperative in most operational contexts. Historically, as we have seen in intensification of farming methods, exploitation of capture fisheries or maximisation of real estate development in urban areas, the driving factor may have dominated decision-making, with potential externalities either overlooked or dismissed. However, taking a 'systemic solutions' approach, enhancement of the primary ecosystem service delivering this need can be reframed not as dominating decision-making, but as an 'anchor service' around which achievement of wider societal benefits and policy aims can be optimised (Everard, 2014). Drawing again on the concept of 'environmental services' (Schomers and Matzdorf, 2013) or 'bundles' (Balvanera, 2016) – that ecosystems do not deliver beneficial outputs in isolation but as linked packages of closely connected ecosystem services – greater cumulative societal benefits can be achieved if multi-service and beneficiary outcomes are planned from the outset of decision-making processes, with the further benefit of greater value-for-money arising from polling currently fragmented budgets into multi-beneficial solutions.

Implications for a sustainable future

It is timely, not to mention consistent with stated international, national and other policy aspirations and commitments, that systemically connected approaches progressively supplant our patchwork of inherited, narrowly-framed technical, legal and fiscal 'fixes'. This is necessary to address the 'wickedness' of today's challenges. 'Wicked problems' describe the multifaceted nature of many societal challenges that are difficult or impossible to solve because of incomplete, contradictory and changing requirements that are often difficult to recognise (Rittel and Webber, 1973), including many that occur within the complexity of human-ecosystem interactions behind a changing climate (Opdam and Wascher, 2004). However, there are also more practical considerations for the equity, economic efficiency and longer-term resilience of society's decisions and actions.

Equity considerations

The essentially anthropocentric nature of ecosystem services, framed as "...*the benefits people obtain from ecosystems*" (Millennium Ecosystem Assessment, 2005a), recognises the heterogeneity not of merely different forms of ecosystem services but also the diverse value systems of an equally heterogeneous spectrum of service beneficiaries. There is no hierarchy of rights in the ecosystem service classification. Nevertheless, market economics do today tend to dominate a great deal of contemporary decision-making, automatically biasing ecosystem use and management to favour the already economically and politically empowered. The principle of equity suggests equal rights of access to natural and other resources, illustrating how the ecosystem services framework can be helpful in articulating how the distribution of benefits and associated disbenefits needs to become more

equitably addressed in progressive policy, resource use, management and other interventions in natural resources.

Ecosystem services then are a valuable tool for measuring and planning for greater equity across social, national and other divisions, and a basis for engagement and participation of affected people. This applies within current generations (intragenerational equity), but also between present and future generations (intergenerational equity). Intergenerational equity formed a central, if still serially underrepresented, consideration and commitment under the 1987 Brundtland Report, *Our Common Future* (World Commission of Environment and Development, 1987). The resilience of ecosystems and flows of services from them constitute the foundational capital underpinning human opportunity for the future, highlighting the importance of regenerating ecosystems damaged under past and present exploitation and stewardship. Rebuilding this currently degraded and still-declining natural capital is not merely a laudable aspiration but, in reality, the only equitable and realistic framing of how sustainable development should now be interpreted (Everard, 2016 and 2017).

Economic considerations

There are also compelling economic reasons for optimising ecosystem service outcomes from resource use. Economic efficiency in this context refers not merely to narrow monetisation of ecosystem services, nor the legacy of the neoclassical economic paradigm of maximisation of short-term profit from resource use as a flawed surrogate for net societal wellbeing. Instead, it relates to optimisation of value to all in society across the range of ecosystem services, including both services that may be monetised and marketed and those that may not (Kenter *et al.*, 2015) and which are still significantly undervalued in decision-making (Braat and de Groot, 2012).

Representation in some form of this breadth of values in decision-making is a complex and still much-contested topic, and one beyond the scope of this brief review. Suffice to say that some form of monetary or other representation of ecosystem services currently excluded from market and political considerations may be helpful as a means to supplant the current situation of them being assigned a default value of zero (Science for Environment Policy, 2015). Without such valuation or other weighting in governance systems, the metaphor of 'The Tragedy of the Commons' (Hardin, 1968), expressing how common resources not owned by their users are likely to be subject to progressive over-exploitation and degradation, is likely to prevail. The metaphor is contested, significantly by work by Ostrom (1990) identifying a set of eight principles for community management of 'common-pool resources' (CPRs) derived from empirical observations in communities stewarding resources as diverse as grazing land in Switzerland and similar effective examples of 'governing the commons' from her research in Kenya, Guatemala, Nepal, Turkey and Los Angeles. Nevertheless, in the absence of either informal community protocols or government enforcement, the 'Tragedy of the Commons' still tends to hold true, for example in the cases of the collapse of inadequately governed international marine capture fisheries (The Economist, 2014), competitive exploitation of deep aquifers drying out already water-stressed landscapes as a

result of proliferation of uncontrolled tube well development (Postel, 1999) and overloading of the assimilative capacities of the global atmosphere with climate-active gases (Everard *et al.*, 2013). A further, widely replicated example globally is that of construction of a large dam that may make sense to business and government interests benefitting from large-scale piped water and hydropower, and these benefits may outweigh the costs of dam construction presenting an apparently positive benefit-to-cost ratio. Yet reservoir filling and wider catchment perturbations inevitably result in a wide array of negative implications for displaced people and their livelihoods, inundation of culturally important places, blockage of migration of terrestrial and aquatic organisms including loss of recruitment to natural fish populations, silt trapping and the consequent erosion and reduction in renewal of fertility of downstream grazing and cropping lands on floodplains, and many ecosystem services impacts besides (World Commission on Dams, 2000; Everard, 2013). Net societal value is only recognised when comprehensive consideration of implications for all ecosystem services and their beneficiaries, or victims, spanning wide spatial and temporal scales are factored into valuation.

An innovative approach to factoring more of the values of ecosystem services into landscape use was undertaken as a case study under the UK National Ecosystem Assessment (UK NEA) programme. This case study modelled the relative benefits and implementation costs incurred under contrasting 'market value' and 'social value' policies for forest planting in Great Britain (Bateman *et al.*, 2014). The 'market value'-driven forest planting scenario sought to minimise initial investment, skewing planting to uplands of low agricultural value at a relatively low annual cost (£79 million) but returning a net negative return on investment (a net cost of £65 million) when consequences for overlooked services were considered. By contrast, the 'best value'-driven scenario sought optimal return on investment to society through co-production of a range of ecosystem services, skewing planting closer towards towns in lowlands with a relatively higher annual implementation cost (£231 million) but with a substantially positive return on investment (a net benefit of £546 million). Comparison of likely outcomes under the 'market-driven' and 'social value' forest-planting scenarios reveals that factoring wider ecosystem service benefits into decision-making can change optimal strategies and ensuing public value. This conclusion is mirrored in a range of additional case studies of other habitat types and resource management options in the same UK NEA report.

Resilient decisions and actions

Underpinning the intended and wider beneficial outcomes considered above is the sustainability of underpinning ecosystems, the functioning of which underwrites continuing human wellbeing and opportunity. Optimisation of management to deliver multiple ecosystem services, including those inherent in the health and functioning of these supporting ecosystems, is therefore also a sound investment in the resilience of ecosystems and their capacities to sustain flows of services beneficial to humanity into the future.

The tendency to date has been to regard sustainable development as a journey to reduce society's 'footprint' on ecosystems, or in other words to become less damaging. However, in the light of declining global ecosystem vitality and increasing

human population and demands, it is necessary to elevate that vision and to reframe the challenge of sustainable development instead as the quest to develop symbiotic lifestyles with those much-depleted supporting ecosystems, and ultimately to regenerate their vitality and service-producing capacities as the only sound, equitable and economically efficient means to underpin continuing human wellbeing (Everard, 2016 and 2017).

Putting ecosystem services into practice

Implementation of the ecosystem services framework entails far more than rebranding legacy management approaches and policies addressing generally fragmented benefits flowing from ecosystems. Rather, it requires a systemic transformation of societal policy, decision-making, rewards and sanctions, transparently and inclusively to address the full spectrum of benefits and disbenefits resulting from resource use, management and policy decisions (Schleyer *et al.*, 2017). Transition to management and use patterns that optimise ecosystem services delivering multiple benefits cannot therefore arise from the anachronistic paradigm of seeking mitigating measures retrospectively once narrowly informed decisions have been made. Instead, environmental and social implications, both potentially positive and negative, must necessarily become integral to primary decision-making. The ecosystem services framework provides a valuable tool to understand, innovate and transparently audit the systemic ramifications of decisions.

New policies and tools will be required to embed ecosystem services across the spectrum of societal policy and practice, challenging existing norms, assumptions and vested interests. However, this transition can be approached incrementally, for example initially by progressively factoring systemic ecosystem services perspectives into existing management tools. Existing, widely used and accepted tools such as Environmental Impact Assessment (EIA), Strategic Environmental Assessment (SEA) and 'programmes for measures' to achieve the goals of the EU Water Framework Directive could all be better informed by using the ecosystem services framework better to identify multi-benefit solutions with fewer unintended externalities. One practical current example is realisation of wider societal benefits arising from Natural Flood Management methods, as compared with narrowly flood-focused 'defence' measures that tend to generate a range of disbenefits for ecosystem processes. The same could also be said of expansion of the conceptual framework used in Life Cycle Assessment and EU REACH chemical appraisal tools, currently based on narrow hazard parameters such as ozone-depleting potential, persistence and eutrophication impacts, but amenable to a shift in focus towards structured consideration of outcomes for ecosystem services across product life cycles. Clear and strong government leadership and published guidance is in reality all that is required to provide regulators and businesses with confidence and clear incentives to bring systemic appraisal into the mainstream of innovations, decisions and investments.

The same is true of economic appraisal tools, which can be extended beyond narrow market metrics to take account of more systemic outcomes that can also account for value systems beyond narrow monetisation methods alone. Taxation can be extended to better deter environmental 'bads', with hypothecation of revenues into

subsidies to promote 'good' outcomes for ecosystem services (Munton and Collins, 1998). This has been the case for the funding base for transition to renewable energy systems within Germany's Energiewende programme (www.energytransition.de), under which taxes on carbon intense energy production and use are recycled into subsidies such as Feed-in Tariffs, rewarding renewable home and community-scale wind and solar generation that also generates patents and the growth of businesses better servicing technologies making positive contributions to the service of climate regulation.

Emerging tools such as 'payments for ecosystem services' (PES) are also demonstrating effective ways for incorporating ecosystem services into mainstream business and governance decision-making from local to global scales (Wunder, 2005; Farley and Costanza, 2010; OECD, 2010). The multi-functionality of wetlands has been extensively studied, with some penetration into practice already of optimisation of societal benefits arising from the design and management of both natural and constructed wetland systems (McInnes, 2011) including their role in sustainable drainage systems (SuDS) (Woods-Ballard *et al.*, 2007).

Optimising ecosystem services across policy areas

Optimisation of outcomes for ecosystem services and their associated beneficiaries is only likely to emerge when they are considered strategically and proactively as an interconnected set. This then highlights that embedding ecosystem services into societal norms cannot be imposed retrospectively and from outside, but needs to be integrated strategically into all spheres of societal decision-making. Everard (2016) developed a framework for application of systemic thinking to all sectors of human interest, using the set of policy divisions observed in governments globally – Treasury, Business, Energy, Urban design, Transport, Agriculture and food, Health and wellbeing, Culture, Local government, Natural environment, International development, Defence, Foreign policy, Research and education, and the connections between them – emphasising that this is not a matter for governments alone but for all sectors of society with interests in those (semi-arbitrary) policy divisions.

As practical examples, transport routes have formerly often been planned with little regard to catchment hydrology, yet flows of water through landscapes can be a cause of transport infrastructure flooding, disruption and costs or, conversely, can be exploited through more sensitive planning of transport routes or improved landscape management as a solution to infrastructure flooding. Defence interests are best served by recognition that conflicts, whether described as a matter of ideology or otherwise, are always at core about limiting resources, the scarcity of which may spark conflicts and equally the co-management of which represents a basis for conflict resolution and ensuing peaceful co-existence (Turton, 2003). Further recognition of the actual and potential benefits of ecosystem processes and services in urban development by planning departments may reduce energy demands and flood risk though integrating natural cooling and drainage into plans and authorisations, also integrating green spaces, biodiversity, and educational and amenity resources into plans retaining natural character and enhancing 'liveability' and potentially also linked real estate values. Many stewardship schemes already

demonstrate the value to business and trade arising from considering ecosystem services strategically as a means to grow supply chain security, brand differentiation and customer loyalty. Similar examples can be drawn regarding how consideration of ecosystem services already underpins interests in all policy areas, and could be further integrated into decision-making to support more sustainable outcomes.

Only by recognition that all human interests ultimately both depend on and affect the ecosystems upon which all in society are ultimately contingent can the challenge of optimising the management and services of ecosystems be addressed on a strategic basis.

Optimising ecosystem services to deliver multiple benefits

3.85 billion years of evolution have produced ecosystems efficient in the recycling of matter and energy and the provision of ecosystem services, at scales from global climate regulation to catchment-scale hydrological buffering and nutrient cycling, through to localised regeneration of soils and production of food and natural medicines. Human evolution and cultural progress has been supported by this wealth and breadth of benefits from nature.

The contemporary challenge of optimising ecosystem services for multiple and enduring benefits is, by majority, one of recognition of this diversity of services and the vital roles they play in supporting human interests now and into the future. The task of reorienting global society onto a sustainable pathway of development entails their progressive reincorporation into resource use, policy and management practices. The scale of necessary cultural change is massive, overturning many entrenched assumptions and rights. However, it is approachable by incremental steps that include recognition of novel business and other opportunities associated with addressing human needs and averting formerly unforeseen risks associated with ecosystem service provision, innovative tools such as PES or the progressive internalisation of the ecosystem services framework into established tools such as EIA and SEA, in addition to progressive refresh of policies and economic instruments to better account for systemic outcomes. The rationale for achieving this transformation is far from altruistic, predicated instead on future-proofing the decisions and actions of all sectors as society progresses towards attainment of consensually agreed environmentally sustainable, equitable and economically efficient goals.

Finer details of ecosystem service science and classification may still be contested and evolving. However, the priority for continuing human wellbeing is progressively to embed the core consensual element of the concept – recognition of the breath of and interconnections between nature's vital supportive services influenced by our diverse lifestyle demands and interventions – into resource use, management and policy decisions across all spheres of human activity. The foundational knowledge and tools are in our hands to broker this transition, underwriting multiple benefits that aggregate to underpin a safe, secure, enriched future for all.

References

Balvanera, P., Quijas, S., Martín-López, B., Barrios, E., Dee, L., Isbell, F., *et al.* (2016). The links between biodiversity and ecosystem services. In: Potschin, M., Haines-Young, R., Fish, R. and Turner, R.K. (eds). *Routledge Handbook of Ecosystem Services*. Routledge: London. pp.45-61.

Bateman, I.J., Day, B.H., Agarwala, M., Bacon, P., Bad'ura, T., Binner, A., *et al.* (2014). *Economic value of ecosystem services*. UK National Ecosystem Assessment Follow-on, Work Package 3.

Beaumont, N. J., Austen, M. C., Atkins, J. P., Burdon, D., Degraer, S., Dantinho, T. P., Derous, S., Holm, P., Horton, T. and van Ierland, E. (2007). Identification, definition and quantification of goods and services provided by marine biodiversity: implications for the ecosystem approach. *Marine Pollution Bulletin*, 54, pp.253-265.

Bigg, E.M., Bruce, E., Boruff, B., Duncan, J.M.A., Horsley, J., Pauli, N., McNeill, K., Neef, A., van Ogtrop, F., Cornow, J., Haworth, B., Duce, S. and Imanari, Y. (2015). Sustainable development and the water–energy–food nexus: A perspective on livelihoods. *Environmental Science and Policy*, 54, pp.389-397.

Braat, L.C. and de Groot, R. (2012). The ecosystem services agenda: bridging the worlds of natural science and economics, conservation and development, and public and private policy. *Ecosystem Services*, 1, pp.4–15.

Commission of the European Communities. (2000). *Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community Action in the Field of Water Policy*. European Commission, Brussels.

Convention on Biological Diversity. (undated a). *Operational guidance for application of the ecosystem approach*. (<http://www.cbd.int/ecosystem/operational.shtml>, accessed 26th March 2016.)

Convention on Biological Diversity. (undated b). *Principles*. (<http://www.cbd.int/ecosystem/principles.shtml>, accessed 26th March 2016.)

Daily, G. (1997). *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press, Washington DC.

de Groot, R., Brander, B., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L.C., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L.C., ten Brink, P. and van Beukering, P. (2012). Global estimates of the value of ecosystems and their services in monetary units. *Ecosystem Services*, 1(1), pp.50-61.

Dugan, P.J. (1990). *Wetland Conservation: A Review of Current Issues and Required Action*. IUCN, Gland, Switzerland. 96pp.

Ehrlich, P.R. and Ehrlich, A.H. (1970). *Population, Resources, Environment: Issues in Human Ecology*. W.H.Freeman & Co Ltd, Basingstoke, UK.

Ehrlich, P.R. and Ehrlich, A.H. (1981). *Extinction: The Causes and Consequences of the Disappearance of Species*. Random House, New York. 305pp.

Ehrlich, P.R. and Mooney, H.A. (1983). *Extinction, Substitution, and Ecosystem Services*. *BioScience*, 33(4), pp.248-254.

Everard, M. (2011). *Common Ground: The Sharing of Land and Landscapes for Sustainability*. London: Zed Books.

Everard, M. (2013). *The Hydropolitics of Dams: Engineering or Ecosystems?* Zed Books, London.

Everard, M. (2014). Nature's marketplace. *The Environmentalist*, March 2014, pp.21-23.

Everard, M. (2016). *The Ecosystems Revolution: Co-creating a Symbiotic Future*. Palgrave Pivot series, Basingstoke, UK.

Everard, M. (2017). *Ecosystem Services: Key Principles*. Routledge, London.

Everard, M., Appleby, T., Pontin, B., Hayes, E., Staddon, C. Longhurst, J. and Barnes, J. (2013). Air as a common good. *Environmental Policy and Management*, 33, pp.354-368.

Everard, M., Denny, P. and Croucher, C. (1995). SWAMP: A knowledge-based system for the dissemination of sustainable development expertise to the developing world. *Aquatic Conservation*, 5(4), pp.261-275.

Everard, M., Dick, J., Kendall, H., Smith, R.I., Slee, R.W, Couldrick, L., Scott, M. and McDonald, C. (2014). Improving coherence of ecosystem service provision between scales. *Ecosystem Services*, DOI: 10.1016/j.ecoser.2014.04.006.

Everard, M. and McInnes, R.J. (2013). Systemic solutions for multi-benefit water and environmental management. *The Science of the Total Environment*, 461-62. pp.170-179.

FAO. (2005). *Review of the State of World Marine Fisheries Resources*. FAO Fisheries Technical Paper 457. Food and Agriculture Organisation of the United Nations, Rome. (<ftp://ftp.fao.org/docrep/fao/007/y5852e/Y5852E00.pdf>, accessed 25th March 2016.)

Farley, J. and Costanza, R. (2010). Payments for ecosystem services: from local to global. *Ecological Economics*, 69(11), pp.2060-2068.

Fisher, B., Turner, R.K. and Morling, P. (2009). Defining and classifying ecosystem services for decision making. *Ecological Economics*, 68, pp.643–653.

Haines-Young, R.H. and Potschin, M.B. (2013). *Common International Classification of Ecosystem Services (CICES): Consultation on Version 4, August-December 2012*. EEA Framework Contract No EEA/IEA/09/003.

Hardin, G. (1968). The Tragedy of the Commons. *Science*, 162, pp.1243-1248.

Helliwell, D.R. (1969). Valuation of wildlife resources. *Regional Studies*, 3, pp.41–49.

IPCC. (2014). *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, 151 pp.

Kenter, J.O., O'Brien, E., Hockley, N., Ravenscroft, N., Fazey, I., Irvine, K.N., Reed, M.S., Christie, M., Brady, E., Bryce, R., Church, A., Cooper, N., Davies, A., Evelyn, A., Everard, M., Fish, R.D., Fisher, J.A., Jobstvogt, N., Molloy, C., Orchard-Webb, J., Ranger, S., Ryan, M., Watson, V. and Williams, S. (2015). What are shared and social values of ecosystems? *Ecological Economics*, 111, pp.86–99.

King, R.T. (1966). Wildlife and man. *New York Conservationist*, 20(6), pp.8–11.

Laffoley, D., Maltby, E., Vincent, M. A., Mee, L., Dunn, E., Gilliland, P., Hamer, J. P., Mortimer, D. and Pound, D. (2004). *The Ecosystem Approach. Coherent actions for Marine and Coastal Environments. A report to the UK government*. Peterborough, English Nature, 65pp.

Lawton, J. (2010). *Making Space for Nature: A Review of England's Wildlife Sites and Ecological Network*. Department for Environment, Food and Rural Affairs, London.
(<http://webarchive.nationalarchives.gov.uk/20130402170324/http://archive.defra.gov.uk/environment/biodiversity/documents/201009space-for-nature.pdf>, accessed 24th November 2017.)

McInnes, R.J. (2011). *Managing wetlands for multifunctional benefits*. In: Le Page B. (editor). *Wetlands: Integrating Multidisciplinary Concepts*. New York: Springer. p. 205–222.

Millennium Ecosystem Assessment. (2005a). *Ecosystems and Human Well-being: Synthesis*. Washington DC: Island Press.

Millennium Ecosystem Assessment. (2005b). *Ecosystems & Human Well-being: Water and Wetlands Synthesis*. World Resources Institute: Washington DC.

Mooney, H.A. and Ehrlich, P.R. (1997). *Ecosystem Services: a Fragmentary History*. In: Daily, G. (Ed.), *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press, Washington DC. pp.11–19.

Munton, R. and Collins, K. (1998). Government Strategies for Sustainable Development. *Geography*, 83(4), pp.346-357.

OECD. (2010). *Paying for Biodiversity: Enhancing the Cost-Effectiveness of Payments for Ecosystem Services*. Organisation for Economic Cooperation and Development, Paris. 196pp.

Opdam, P. and Wascher, D. (2004). Climate change meets habitat fragmentation: linking landscape and biogeographical scale levels in research and conservation. *Biological Conservation*, 117(3), pp.285-297.

Ostrom, E. (1990). *Governing the commons: the evolution of institutions for collective action*. Cambridge University Press, Cambridge.

Parliamentary Office of Science and Technology. (2011). *Natural Flood Management*. POSTNOTE 396 (December 2011). The Parliamentary Office of Science and Technology, HM Government, London.

Ramsar Convention. (2002). *The 8th meeting of the Conference of the Contracting Parties to the Ramsar Convention*. The Ramsar Convention on Wetlands. (http://www.ramsar.org/cda/en/ramsar-documents-cops-cop8/main/ramsar/1-31-58-128_4000_0), accessed 26th March 2016.)

Postel, S. (1999). *Pillar of sand: Can the irrigation miracle last?* New York, USA: W. W. Norton & Company

Rittel, H.W. J. and Webber, M.M. (1973). Dilemmas in a General Theory of Planning. *Policy Sciences*, 4, pp.155–169.

Sather, H. J. and Smith, R. D. 1984. *An Overview of Major Wetland Functions*. FWS/OBS-84/18. U.S. Fish and Wildlife Service, Washington, D.C.

Schleyer, C., Lux, A., Mehring, M. and Görg, C. (2017). Ecosystem Services as a Boundary Concept: Arguments from Social Ecology. *Sustainability*, 9, 1107. doi:10.3390/su9071107.

Schomers, S. and Matzdorf, B. (2013). Payments for ecosystem services: a review and comparison of developing and industrialized countries. *Ecosystem Services*, 6, 16-30.

Science for Environment Policy. (2015). *Ecosystem Services and the Environment*. In-depth Report 11 produced for the European Commission, DG Environment by the Science Communication Unit, UWE, Bristol. (<http://ec.europa.eu/science-environment-policy>, accessed 24th November 2017.)

Staddon, C. (2010). *Managing Europe's Water: 21st century challenges*. Routledge, London.

TEEB. (2010). *The Economics of Ecosystem and Biodiversity (TEEB): Ecological and Economic Foundations*. Earthscan, London.

The Economist. (2014). The tragedy of the high seas: New management is needed for the planet's most important common resource. *The Economist*, 22nd February 2014. (<https://www.economist.com/news/leaders/21596942-new-management-needed-planets-most-important-common-resource-tragedy-high>, accessed 25th November 2017.)

Turton, A.R. (2003). The hydropolitical dynamics of cooperation in Southern Africa: a strategic perspective on institutional development in international river basins. In, Turton, A.R., Ashton, P. and Cloete, T.E. (eds.) *Transboundary Rivers, Sovereignty and Development: Hydropolitical Drivers in the Okavango River Basin*. Pretoria and Geneva: AWIRU and Green Cross International, pp.83-103.

UK NEA. (2011). *The UK National Ecosystem Assessment: Synthesis of the Key Findings*. Cambridge UK: UNEP-WCMC.

United Nations. (2002). *Report of the World Summit on Sustainable Development*. United Nations, New York, Johannesburg, South Africa, 26 August-4 September 2002. 167 pp.

Vihervaara, P., Rönkä, M. and Walls, M. (2010). Trends in ecosystem service research: early steps and current drivers. *Ambio*, 39, pp.314–324.

Woods-Ballard B, Kellagher R, Martin P, Jefferies C, Bray R, Shaffer P. (2007). *The SUDS Manual*. CIRIA Report C697. London: Construction Industry Research and Information Association.

World Commission on Dams. (2000). *Dams and Development: A New Framework for Better Decision-making*. Earthscan, London.

World Commission of Environment and Development. (1987). *Our Common Future*. Oxford University Press, Oxford.

Wunder, S. (2005). *Payments for environmental services: Some nuts and bolts*. Center for International Forestry Research Occasional Paper No. 42. (www.cifor.org/publications/pdf_files/OccPapers/OP-42.pdf, accessed 26th March 2016.)