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Insight

A framework for ecosystem resilience in policy and practice: DECCA

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ABSTRACT. Ecosystem resilience is increasingly considered within political responses to environmental problems, and is a key element of recent environmental legislation in Wales. The actual mechanisms of ecosystem resilience are complex, making it difficult, from a management perspective, to meaningfully describe or report on them for ecosystems at a national scale. For this reason, the legislation and associated policies in Wales have taken a pragmatic approach, using environmental attributes that have previously been causally linked with ecosystem resilience as a framework for description and reporting. These attributes are diversity, extent, condition, connectivity, and adaptability, and are referred to as "DECCA". The framework has proved useful and influential, and provides a novel example of how established and relatively simple scientific principles can inform and put into practice legislation about complex environmental systems; the Welsh case serves as the first example of a national government implementing resilience policy. However, the attributes remain proxies for actual resilience, and there are knowledge gaps for converting theory to practice. These include fundamental understanding of the underlying mechanisms of resilience and related concepts such as environmental tipping points, and methodological issues such as how resilience can be quantified and confidently reported on. There is a need to develop a research framework for addressing these issues, linked to policy cycles to ensure new evidence and understanding are appropriately interpreted and adopted.

Key Words: *ecosystem resilience; policy implementation; Wales*

INTRODUCTION

A series of new Welsh legislation passed in 2015 and 2016 has mandated ecosystem resilience. The Well-being of Future Generations (Wales) Act (2015) outlines seven well-being goals, one of which is a resilient Wales: "A nation which maintains and enhances a biodiverse natural environment with healthy functioning ecosystems that support social, economic, and ecological resilience and the capacity to adapt to change." The Environment (Wales) Act (2016) gave Wales's environment agency, Natural Resources Wales (NRW), a statutory purpose to pursue the sustainable management of natural resources, with the objective to maintain and enhance the resilience of ecosystems and the benefits they provide and, as a result, to contribute to the achievement of the goals in the Well-being of Future Generations (Wales) Act. In Section 6, Biodiversity and Resilience of Ecosystems, public authorities in Wales have an enhanced biodiversity duty to "maintain and enhance biodiversity so far as consistent with the proper exercise of their functions and in so doing promote the resilience of ecosystems."

The Environment (Wales) Act sets out an adaptive delivery framework for embedding the ecosystem approach through sustainable management of natural resources (SMNR) across government. The State of Natural Resources Report (SoNaRR) sets out the national evidence base for SMNR. In turn, the Welsh Minister's Natural Resources Policy (2017) sets out the national priorities for SMNR, drawing from the national evidence base in SoNaRR that highlights the importance of delivering resilient ecological networks. NRW delivers Area Statements that contribute to implementing the Natural Resources Policy in a local context, and take a collaborative, place-based approach. The first SoNaRR, published in 2016, outlines the five attributes of resilience, which indicate the direction of change. SoNaRR finds that no ecosystem in Wales is currently achieving an adequate level of quality for resilience in all attributes. This shortcoming is having an impact on the ability of our ecosystems to provide benefits for our well-being.

The Environment (Wales) Act draws its approach to SMNR and its focus on ecosystem resilience from the Ecosystem Approach of the Convention on Biological Diversity (CBD; Secretariat of the Convention on Biological Diversity 2004), specifically the fifth of its 12 implementation principles: "Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach." The rationale of this principle states, "Ecosystem functioning and resilience depends on a dynamic relationship within species, among species, and between species and their abiotic environment, as well as the physical and chemical interactions within the environment. The conservation and, where appropriate, restoration of these interactions and processes is of greater significance for the long-term maintenance of biological diversity than simply protection of species." Principle 6 is also relevant: "Ecosystems must be managed within the limits of their functioning." In considering the likelihood or ease of attaining the management objectives, attention should be given to the environmental conditions that limit natural productivity, ecosystem structure, functioning, and diversity. The limits to ecosystem functioning may be affected to different degrees by temporary, unpredictable, or artificially maintained conditions and, accordingly, management should be appropriately cautious. The Environment (Wales) Act seeks to build ecosystem resilience and functioning away from any natural limits or tipping points resulting from development and other anthropogenic pressures.

The Well-Being of Future Generations (Wales) Act and the Environment (Wales) Act both require that public bodies work to maintain or enhance ecosystem resilience, but a major

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impediment to this objective is the difficulty of practically measuring resilience for management purposes. Although there is a good understanding of components that contribute to resilience, efforts to measure resilience are undermined by the large gap in our understanding of the importance of a given component at a specific place and, within each component, of the composition needed to ensure characteristics and dynamics of resilience as well as the shape of the relationships between each variable, e.g., individuals, species, institutions. Complex, underlying ecological processes are still a black box of understanding. There is the additional need to understand how resilience can relate to society, particularly with respect to undesirable characteristics that can also be resilient. This gap prevents the scientific community from developing a tool to measure resilience. The ability to quantify resilience would support timely research efforts to identify when an ecological system is approaching the limits of its functioning, before shifts in functioning are triggered.

DEGRADED WELSH ECOSYSTEMS

The Welsh landscape has evolved over time, with woodland clearing occurring many millennia ago. The loss of woodlands led to the creation of new habitat, to which the ecosystem gradually adapted. Wales has a long legacy of coal mining that dates to the 15th century, when mines were mostly for small-scale industry. During the 16th and 17th centuries, an export industry developed, and production accelerated. By the 1700s, Welsh mines were fueling the industrial revolution, peaking at 620 mines in the early 1900s, but leaving a legacy of contaminated soils and polluted mine water.

The advent of green-revolution technologies in the 1950s led to another rapid shift in the rate of change of land use. Over 90% of land in Wales is used for agriculture and forestry (Welsh Government 2015). Wales has 80% of its land area characterized as uplands (and rural), which has historically been used for livestock grazing. Green-revolution ideologies and productivist-centered subsidies resulted in the intensification of land use, contributing to further habitat loss and degradation, fragmentation, and isolation; excessive nutrient input and other forms of pollution; and over-exploitation and unsustainable use of natural resources such as soil and water. All of these events have contributed to further biodiversity loss and ecosystem changes.

The Biodiversity Intactness Index (BII; Scholes and Biggs 2005) provides estimates for biodiversity loss as a result of human pressures by focusing on the status of originally present species in a reference condition. Decreases in BII, i.e., the loss or population decline of originally present species, may capture falling ecosystem resilience. Of 240 countries assessed using the BII, Wales ranks in the lowest 12% globally (Sanchez-Ortiz et al. 2019) reflecting its highly modified state and likely lower levels of ecosystem resilience compared to many other countries.

Very little of Wales remains unmodified by human influence, with near-natural areas mostly confined to higher altitudes and certain coastal areas subject to low-intensity agricultural or recreational use. The Welsh lowlands are more intensively used, mainly for agriculture, commercial forestry, and urban purposes. Here, many remaining areas of biodiversity value are primarily seminatural and are represented as a significant number of small, fragmented parcels, located within modified systems. Seminatural habitats retain many of their characteristic species. Modified land-cover types include the built environment as well as places where ecological processes and species composition have been hugely altered, for example, improved grassland, arable land, and conifer plantations.

The representation of seminatural habitat varies significantly across Wales. The Welsh lowlands are highly modified: 17.3% is seminatural habitat; whereas 84% of the upland area is seminatural habitat. Seminatural habitats in Wales cover a total of 626,100 ha, or 30% of the Welsh land surface (Blackstock et al. 2010). Wales has 55 habitats of principle importance that include blanket bog, ponds, and seagrass beds, and were selected for prioritized action from the UK Biodiversity Action Plan (BAP) using criteria based on the level of threat they face, their relative importance as habitat in Wales, and whether remedial action will be able to improve their status. The most extensive of these in Wales (each with a resource of greater than 30,000 ha) include upland heathland, blanket bog, upland oak woodland, purple moor grass and rush pasture, lowland dry acid grassland, and coastal and floodplain grazing marsh (Natural Resources Wales 2016). A key challenge for SMNR in Wales is to retain the distinctiveness of rural communities and historic landscapes, which are important to both place and the cultural value of landscape. The extremely degraded quality of some landscapes means that significant changes in resource-use patterns will be required to restore healthy ecosystem functions that deliver benefits for nature and society.

RESILIENCE RESEARCH

In the seminal work of Holling (1973), he refers to resilience as the capacity of a system to absorb and utilize or even benefit from perturbations and changes that attain it, and so to persist without a qualitative change in the system's structure. However, severe perturbations can potentially trigger a number of reactions across spatial or temporal scales that can bring the system over a threshold, causing it to shift to a new state; small shifts, which are not visible, can move system functioning toward a precipice, where additional perturbation creates a systemic change in ecosystem functioning (Scheffer et al. 2001). Within the resilience perspective, both vulnerability and resilience are seen to be the product of complex interactions between internal and external stressors. Adaptive capacity within the system functions through an adaptive cycle. Systems with high adaptive capacity are seen as more resilient. Rockström et al.'s (2009) and Steffen et al.'s (2015) work on developing the planetary-boundaries approach aims to define a safe operating space for human societies to develop and thrive, based on an evolving understanding of the functioning and resilience of the Earth system (Steffen et al. 2015). This approach conceptualizes the Earth system as a series of nine critical processes with boundaries proposed, within which is considered a safe operating space. The boundaries represent thresholds, beyond which abrupt or risky change becomes more likely. Steffen et al. (2015) estimate that four Earth system processes are already operating in zones of uncertainty, indicating the urgency of action to reverse these trends. However, the generality of these assumptions at a global level needs to be balanced with sensitive, context-dependent research approaches to quantifying resilience in order to achieve a middle ground (Holling and Gunderson 2002, Schlüter et al. 2015).

For at least 20 years, ecologists have been writing about the need to measure resilience for practical application to management and conservation. Carpenter et al. (2001:765) wrote: "In our research on ecosystem management in diverse regions of the world, the importance of clear and measurable definitions of resilience has become paramount. Practitioners have repeatedly asked how resilience, and trends in resilience, can be measured for particular socio-ecological systems (SES)." A special 2005 feature published in the journal Ecosystems (Carpenter et al. 2005) focused on quantifying resilience. The articles largely focused on identifying surrogates of resilience, which led to the development of resilience frameworks that are vague and difficult to quantify. Many of the mechanics were still unclear, but the following two decades saw a plethora of research conducted across terrestrial, aquatic, and marine ecosystems, not only to support the theory of the relationship between biodiversity and resilience, but also to expose the mechanics of how biodiversity supports ecosystem resilience. Meta-analyses synthesizing the results of numerous experiments have tested the breadth of applicability, generality, and magnitude of the role and effects of diversity (Balvanera et al. 2006, Cardinale et al. 2006, 2011, 2012, Worm et al. 2006, Stachowicz et al. 2007, Gross et al. 2013). A further special feature published a decade later (Angeler and Allen 2016) achieved improvements over earlier efforts to quantify resilience, yet further research is still needed to be able to quantify resilience for management and conservation practices. The understanding of the underlying mechanisms of resilience is steadily improving, for example, as more long-term data sets become available, to analyze system dynamics such as the resilience of Western North American forests (Hessburg et al. 2019) and ongoing research in panarchy theory identifying increasing variance and "flickering" as indicators of impending regime shifts (Carpenter and Brock 2006, Scheffer et al. 2009). Although there is an abundance of research on resilience and panarchy in complex systems that acknowledges scale and the importance of cross-scale linkages, the research seldom extends beyond description (Allen et al. 2014). Added to this is the need to understand how resilience can relate to society, particularly with respect to undesirable characteristics. As a result, the practitioner and conservation community are still challenged to understand how much resilience exists within ecosystems under management, where the thresholds lie, and how close the ecosystem may be to a threshold.

The diversity, extent, condition, connectivity, and adaptability (DECCA) approach is not as comprehensive in its consideration as the Earth system; rather it has a strong focus on regional ecosystem processes. Like the planetary boundaries, however, DECCA is meant to be a practical exercise that can translate to policy action. DECCA enables the implementation of Welsh legislative commitments "to maintain and enhance biodiversity and promote the resilience of ecosystems." For processes that cross political boundaries and form part of a global commons, such as CO_2 concentration, stratospheric ozone depletion, atmospheric aerosol loading, and ocean acidification, impact is not wholly dependent on actions taken within Wales. DECCA therefore primarily focuses on biosphere integrity, land-system change, and biochemical flows, while acknowledging the role that increased carbon capture through forest cover and soil sinks will also have on the global commons. It further acknowledges how even these territorial processes, such as migration of bird species, are affected by actions taken elsewhere in the UK and abroad.

Although gaps in scientific understanding of how to measure resilience still exist, anthropogenic activity continues to threaten current functioning of biophysical systems (Steffen et al. 2015), and the time to act is now. Thus, the policy landscape continues to move forward to legislate and implement policy on ecosystem resilience, with Welsh national legislation leading the way. The concept of resilience is firmly embedded in The Well-being of Future Generations (Wales) Act and The Environment (Wales) Act. To be meaningful, however, legislation needs to present ecosystem resilience in a way that can be understood unambiguously, and applied to real-world situations to deliver practical outcomes. The expectations of legislation are therefore greater than what the science it references currently delivers. In preparation for the Welsh legislation, a working group was set up to explore ecosystem resilience as part of a much wider development program (The Living Wales Programme). The working group reviewed the literature and current best practices (Latham et al. 2013), and highlighted the issues around complexity and lack of understanding in the context of Wales described above. Yet it also showed that many studies have linked particular characteristics of the environment to ecosystem resilience, and that these characteristics can sometimes be measurable and linked to practical activities. There was, therefore, potential for developing a pragmatic approach to ecosystem resilience. Even if the underlying ecological mechanisms that deliver ecosystem resilience are not fully understood, by focusing attention on improving these characteristics and thereby altering structures and processes, we seek to transform ecosystems from their current degraded states into a more desirable state for supporting biodiversity and the delivery of ecosystem services such as flood control and clean water. We hope that the altered ecosystems will also be more resilient to shocks and stressors, and thus continue to provide critical ecosystem services. This approach has become known as "building resilience."

In order to move forward to implement this new legislation on ecosystem resilience, NRW published its response to the five attributes of ecosystem resilience in the SoNaRR 2016 report. In Chapter 4 of SoNaRR, NRW defines ecosystem resilience as, "The capacity of ecosystems to deal with disturbances, either by resisting them, recovering from them, or adapting to them, whilst retaining their ability to deliver services and benefits now and in the future" (Natural Resources Wales 2016:6). It elaborates on the five aspects of ecosystems listed in the Environment (Wales) Act that should be considered with respect to resilience, describing them as "attributes": indicators for assessing resilience. These five attributes of ecosystem resilience are diversity, extent, condition, connectivity, and adaptability, and are collectively referred to as DECCA.

NRW recognizes that the current state of science does not enable them to quantify resilience of different ecosystems. Nonetheless, indicating positive and negative impacts and directions of change based on the five attributes of resilience enables NRW to implement the forward-thinking resilience legislation, and to move forward in a fashion that, while uncertain, is considered to be good enough. Below, each of the five attributes are outlined, serving as a guide for other national governments seeking to move ecosystem management forward for improved system functioning, delivery of ecosystem services, and resilience.

ATTRIBUTES FOR CONSIDERING RESILIENCE

Within the DECCA framework, the adaptability of ecosystems is recognized as an outcome of resilience. The overall adaptability of ecosystems invites specific consideration of the adaptive cycles that many ecosystems undergo, understanding that ecosystems are not static entities and will change over time. The key question here is whether ecosystems will adapt and change in the desired direction given future environmental and socioeconomic changes, as well as demands such as climate change, and if DECCA can be a tool for triggering transformative governance across different policy contexts (Chaffin et al. 2016).

Diversity

Diversity matters at different levels and scales, from genes to species and from habitats to landscapes. It supports the complexity of ecosystem functions and the cascades of interactions that deliver services and benefits (Ceulemans et al. 2019). If diversity is lost, systems may collapse. The functions of individual components of a system are also susceptible to disturbance; diversity provides redundancy of functions and enhances the capacity of the system as a whole to adapt to future change (Byrnes et al. 2014).

Extent

The greater the extent of a habitat or species, the more able it will be to contain the effects of disturbance. For example, a larger area of habitat can support larger populations of species, which will be less likely to go extinct than smaller ones (and will potentially also have a wider genetic diversity to provide more adaptive capacity), and be less affected by detrimental edge effects. Many species have a minimum size of habitat required to support a population, below which they may become extinct (Harte et al. 2009). Size also influences ecological processes: for example, a raised bog large enough to support its own hydrological system is likely to be more resilient than smaller bogs.

Condition

Condition is a broad term that interacts with the other attributes in many ways. We are using it here to make a link to how a system is managed, what inputs are applied, what is taken from it, and how it is influenced by the management of the surrounding land. An ecosystem in poor condition will be stressed and have reduced capacity to resist, recover, or adapt to new disturbances, or to deliver ecosystem goods effectively. Condition can be thought of in terms of broad ecosystem components relating to biodiversity, air, water, and land. Resilience assessments therefore consider the condition of protected sites, soil, air, and water quality, and the impacts of major land/sea uses and industries.

Connectivity

Connectivity is the movement within and between ecosystems of flora and fauna, nutrients, abiotic material, and energy. Connectivity allows ecosystems to function and recover from disturbance, but it is reduced through habitat loss and fragmentation, creation of barriers, and erosion of the permeability that allows movement across the landscape. In certain situations, connectivity may have negative aspects: for example, if it risks facilitating the spread of diseases, fire, or invasive non-native species (Gilarranz et al. 2017).

Adaptability

Adaptability differs from the other attributes because it is part of the definition of resilience rather than an attribute that supports it. However, its inclusion in the Environment (Wales) Act is important because it emphasizes a key feature of resilience: dynamism and the ability to adapt to change. This is especially relevant to climate change, which is inevitable, and in the wake of which we cannot expect to maintain the status quo. Instead, we need to think in terms of changing species distributions, composition of ecological communities, and ecosystem function and process. This is where the elements of diversity, extent, condition, and connectivity start to mesh and provide the basis for adaptation to happen. For example, maintaining diversity hotspots and connectivity between them can facilitate species' range shift (Thomas et al. 2012).

APPLICATION OF THE DECCA FRAMEWORK

The DECCA framework can be used to assess the effectiveness of existing and proposed practical interventions intended to maintain and build ecosystem resilience within areas subject to moderate or high levels of human-driven modification such as Wales. Protected areas are a practical intervention with the potential to halt and reverse the decline in biodiversity and build ecosystem resilience. However, although rates of ecosystem-resilience decline in Wales are likely to have been greater in the absence of its protected areas, neither their relatively significant extent (approximately 30% of terrestrial Wales) or a focus on providing the strictest levels of protection for its most diverse and representative sites have halted or reversed the decline of Welsh biodiversity. If protected areas are to play an effective role in halting and reversing biodiversity loss and building ecosystem resilience in significantly modified landscapes such as Wales, there is likely a need for approaches that extend their focus to other attributes of ecosystem resilience, including condition, effectively addressing human-derived pressures, connectivity, and increasing permeability between core sites.

The degraded extent of Welsh landscapes requires a more active approach to SMNR, in order to transform the function and delivery of ecosystem services across Welsh landscapes, and to ensure resilience of those ecosystems. Approximately 80% of Wales is farmed, and land-use change associated with intensive agricultural practices has driven much of the biodiversity decline experienced within the country over past decades. However, windows of opportunity for achieving transformative change exist in the post-Brexit context. For the past 40 years, Wales and the UK have been locked into the EU's Common Agricultural Policies. Because of Brexit, Wales is currently in the process of developing a new agri-environment scheme that looks to pay public money for the provision of public goods, to incentivize sustainable land management among farmers and other land managers. Practical interventions such as this offer significant opportunities to halt and reverse the decline in Wales's biodiversity, and to build its ecosystem resilience and benefits. Application of the DECCA framework to the design of such schemes offers important opportunities to consider how the breadth and depth of land-management options could be developed: to increase diversity at the field, farm, and landscape scale; to improve condition through nature-based solutions and lower-intensity agricultural management within protected areas, near seminatural habitats; and to increase the extent and connectivity of small and fragmented sites through maintenance of existing connective features, habitat restoration, and creation and collaborative working targeted within ecological networks co-designed with stakeholders using robust evidence and place-based approaches. Application of the DECCA framework by land managers to inform SMNR gives flexibility to generate innovation and place-based approaches while also joining up actions at a landscape scale to catalyze transformation in actions and outcomes.

RESEARCH NEEDS

DECCA is a tool that, despite its limitations, enables NRW to move forward in implementing legislation on ecosystem resilience. In this dynamic policy context, it is critical that the science continues to develop to support the resilience policy agenda. Advances in scientific research are needed to promote understanding of (1) how DECCA components interact to deliver ecosystem functioning in the form of ecosystem services; (2) the weighted importance of one attribute over another, as not all attributes are created equal; (3) how the weighted importance of attributes differs across different systems; (4) a better understanding of the subcomponents of each of the attributes and their weighted importance across different ecosystems; (5) improved understanding of biodiversity response and succession over time; (6) the relationship of attributes to resistance, adaptability, and recovery; and (6) how the system reacts to perturbations with respect to DECCA.

There are relevant theoretical gaps in understanding that need to be bridged to be able to evaluate resilience in SES. New approaches for detecting regime shifts require quantifying thresholds that are dynamic and can be multifold (Cumming et al. 2012, Allen et al. 2016). The concept of spatial regimes is still emerging (Allen et al. 2016). Lacking a spatial perspective impedes identifying the variables driving regime shifts (Eason et al. 2016). Current approaches to quantifying resilience are often correlative, limited to the local scale of ecosystems, and often focus on specific organismal groups, which may be unrepresentative of the ecosystem at large (Angeler and Allen 2016). Finally, there is a need to operationalize complementary aspects of resilience.

Tackling the challenge of developing a mechanism to quantify resilience requires a multi- and interdisciplinary approach, pulling expertise from a number of disciplines and combining methods. To date, there has been relatively little cross-fertilization between the different disciplines exploring resilience measurement, despite their shared theoretical foundations (Barrett and Constas 2014). Although forward-looking legislation on ecosystem resilience is lacking in other places, it is still possible to implement a DECCA approach to SMNR as part of commitments to meet CBD and zero-emission, internationally-agreed-upon targets. Indeed, considering that biodiversity is an integral component of achieving ecosystem resilience, any approach to achieving internationally-agreed-upon biodiversity targets will struggle without considering ecosystem extent, condition, connectivity, and adaptability. However, even Wales, with its forward-looking legislation, faces challenges in prioritizing ecosystem resilience and the DECCA approach to land management. Legal challenges against public bodies in violation of this legislation have yet to be tested.

CONCLUSIONS

Given the role that policy can and should play in promoting resilient ecosystems, and in particular the Welsh government's ambitious and unique Well-Being of Future Generations (Wales) Act and Environment (Wales) Act, there is a need to look at resilience beyond the local scale, and the narrow construction of objectives such as provision of clean water or species recovery. Instead, we must consider general, system-wide resilience. Anything less will fail to achieve the ambitious and proactive approach to building the resilience of ecosystems that is set out in Welsh policy and legislation. In order to implement resilience and prioritize appropriate policy and management actions, managers need to know how resilient current systems are, what are the components contributing to this resilience, and which ones require improvement. This can then contribute to understanding which actions can manage resilience. Above all, management must be mindful of thresholds representing catastrophic shifts to undesirable systems (or, in fact, the opposite, in the case of undesirable system states). Quantifying resilience can act as a building block that contributes to the development of threshold identification and the gauging of where we are with respect to those thresholds. Achieving this, however, will require a massive leap forward in current resilience thinking and practice, and bold approaches.

Responses to this article can be read online at:
https://www.ecologyandsociety.org/issues/responses.php/12865

Data Availability:

Data sharing is not applicable to this article because no data were analyzed in this study.

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