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Advancing sustainability through mainstreaming a social–ecological systems perspective

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The concept of social–ecological systems is useful for understanding the interlinked dynamics of environmental and societal change. The concept has helped facilitate: (1) increased recognition of the dependence of humanity on ecosystems; (2) improved collaboration across disciplines, and between science and society; (3) increased methodological pluralism leading to improved systems understanding; and (4) major policy frameworks considering social–ecological interactions. Despite these advances, the potential of a social–ecological systems perspective to improve sustainability outcomes has not been fully realized. Key priorities are to: (1) better understand and govern social–ecological interactions between regions; (2) pay greater attention to long-term drivers; (3) better understand the interactions among power relations, justice, and ecosystem stewardship; and (4) develop a stronger science–society interface.

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Introduction

Humanity depends on nature for life support, but human activities are changing ecosystems around the world in profound and uncertain ways [1]. Overcoming prominent conservation and development challenges of the 21st century requires an understanding of the complex and evolving links between ecosystems and human societies [2]. For example, the conservation of tropical forests cannot be achieved without also considering expanding agricultural markets and increased demand for agricultural commodities [3,4]. Food security, in turn, depends not only on securing environmentally sustainable agricultural production, but also requires institutions that ensure a more equitable distribution of agricultural products [5,6]. Similarly, the sustainability of the world's fisheries cannot be addressed separately from the livelihoods of coastal communities [7], or from the management of other potential protein sources such as agriculture, aquaculture, or bushmeat [8]. More than ever, integrated approaches are needed to foster sustainable development — that is, an equitable advancement of human well-being that does not compromise ecosystem integrity [2].

The concept of social–ecological systems [9,10] — also termed coupled human–environment systems [11,12] or coupled human and natural systems [13] — provides a

powerful analytical frame for understanding the interlinked dynamics of environmental and societal change (Figure 1). Social–ecological systems are complex adaptive systems characterized by feedbacks across multiple interlinked scales that amplify or dampen change. These feedbacks underlie the capacity of the biosphere to sustain human progress and development. However, they also sometimes result in non-linear behavior where minor changes in a controlling (or slow) driver cause abrupt, system-wide reorganization [14,15•,16]. Such dynamics can generate surprises and substantial uncertainty about system behavior. As interactions between people and ecosystems increase in scale, scope, and intensity, understanding the dynamics of social–ecological systems is becoming increasingly important.

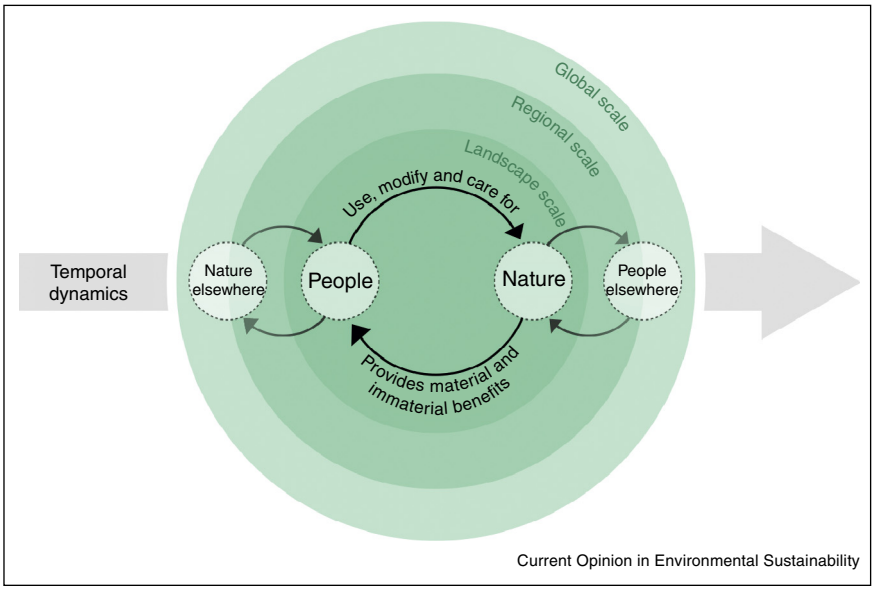
Notably, the concept of social–ecological systems is not rigid. For example, Scholz [11] identified sixteen different frameworks for analysing human–environment relationships. Despite its flexibility, the concept has also been criticized, especially because it may foster a false dualistic understanding of humanity as an entity outside the natural environment [17].

Notwithstanding these concerns, in this paper, we review four ways in which advances in sustainability science and practice have been inspired by growing recognition of the interlinked nature of social–ecological systems. Despite the significance of these advances, we argue they still fall short of what is needed. Because of this, we also identify four priority areas in which further efforts are required to improve our understanding of social–ecological systems, and foster progress towards sustainable development.

Advance 1: recognition is growing that humanity depends on nature

The dependence of people on the biosphere is increasingly accepted in research, policy, and business. Although uncertainty remains about how to best achieve a balance between near-term and long-term improvements in human well-being and ecosystem integrity, it is now widely agreed that human well-being and ecosystem integrity are fundamentally linked [18]. People are increasingly viewed as dependent on nature and as stewards with ethical obligations — both towards other living creatures and towards future generations of people (who will depend on Earth's life support systems to continue functioning) [19]. In recognition of this, governments have commenced new initiatives such as The Economics of Ecosystems and Biodiversity project (www.teebweb.org/), the Intergovernmental Platform on Biodiversity and Ecosystem Services (www.ipbes.net/), as well as national ecosystem assessments (e.g. UK, uknea.unep-wcmc.org/; Sweden, www.regeringen.se/sb/d/17143/a/207731/). Recognition of the myriad ways in which humanity depends on nature is also growing in the private sector, as exemplified by initiatives such as the Natural Capital Declaration signed by over 40 global financial institutions (www.naturalcapitaldeclaration.org/), and sustainability leadership by individual companies (e.g. the European Outdoor Conservation Association; www.outdoorconservation.eu/).

Figure 1



Social–ecological systems are interdependent and linked systems of people and nature, which are nested across scales. This reflects that people are part of ecosystems and shape them, from local to global scales, and are at the same time fundamentally dependent on the capacity of these systems to provide services for human wellbeing and societal development. Social–ecological interactions play out against a backdrop of global change and other temporal dynamics.

Advance 2: the need for solutions to sustainability problems has increased communication and collaboration across disciplines, and between science and society

Although the multi-facetted nature of sustainability problems has been recognized for decades, the actual practice of interdisciplinarity (different disciplines working together) and of research involving stakeholders has long lagged behind theory. However, this is now starting to change. There is a growing number of studies, journals, and 'inter-disciplines' that transcend the social and natural sciences, such as the ecological economics or urban ecology. In addition, policies and institutions are increasingly supporting holistic research approaches, with funding bodies increasingly rewarding not only disciplinary excellence, but also interdisciplinarity, stakeholder engagement and practical impact. For example, the UK government, in its 2014 national review of research excellence, attributed one fifth of overall research performance to measures of impact (www.ref.ac.uk). Similarly, the US National Science Foundation has specifically recognized the need for interdisciplinarity to solve environmental problems [20]; and co-design of research with stakeholders is at the very core of Future Earth, a major new global research initiative (www.futureearth.info/). Transdisciplinary research frameworks are evolving to further support the integration of societal problems into scientific processes, and the adoption of scientifically derived solutions into practice [21•]. New platforms such as the Swiss td-net (www.transdisciplinarity.ch) explicitly support transdisciplinary research. Similarly, the International Long Term Ecological Research network (ILTER; www.ilternet.edu) has evolved to incorporate social–ecological research and perspectives from outside academia [22,23]. Moreover, curricula and academic institutions are being reformed in recognition of the need to understand and solve problems beyond those that can be addressed within traditional disciplines, as shown (for example) by extensive reforms in academic programs at the National University of Mexico, and the emergence of sustainability-oriented institutions such as Arizona State University (USA), the Stockholm Resilience Centre (Sweden), and Leuphana University Lueneburg (Germany); as well as transdisciplinary PhD programs (e.g. the Tsama programme at Stellenbosch University, South Africa), and transdisciplinary elements in many other curricula (e.g. Centre for Key Qualifications at University of Freiburg, Germany; HTW Chur, Switzerland).

Advance 3: conceptual and methodological pluralism is increasing in an effort to better understand complex social–ecological systems

Many sustainability scientists are increasingly comfortable using multiple conceptual frames and methodological approaches to solve real-world problems. This change reflects a shift in research foci, away from an emphasis on studying different resources separately, towards a more holistic focus on multifunctional systems and their resilience to ongoing and new pressures (e.g. in coral reefs, agricultural landscapes, large watersheds), often considering multiple scales and stakeholders, and their interplay [24]. This integration, in turn, has encouraged many researchers to be open to accepting new approaches, and be epistemologically agile in adopting multiple methods in their own work. Some emerging approaches are helping to understand complex sustainability problems in a wide range of circumstances. For example, qualitative or quantitative network analysis is increasingly being applied to problems in realms ranging from illegal fishing [25] to watershed management [26•], to community resilience and tourism [27]. Similarly, scenario planning has helped stakeholders to prepare for an uncertain future in contexts ranging from agricultural development [28] to biodiversity conservation [29].

Advance 4: appreciation of social–ecological systems is beginning to influence major policy frameworks

Increasingly, the lessons learnt from social–ecological research are influencing not only researchers, but also policymakers. On a global level, the latest draft of the UN Open Working Group on Sustainable Development Goals recognizes the linkages between economic, social and environmental aspects of sustainable development (sustainabledevelopment.un.org/focussdgs.html). For example, the proposed Goal 2 — 'End hunger, achieve food security and improved nutrition, and promote sustainable agriculture' — combines the socioeconomic target of achieving food security with the environmental target of maintaining resilient ecosystems. Similarly, the United Kingdom commissioned a report on food system priorities, which recognized linkages between society and ecosystems, including aspects ranging from food production to consumer values and ethics [30]. Likewise, the Biofuels Directive of the European Union (2009/28/EC) recognizes that while biofuels provide an alternative source of energy, their indirect effects on land use change also must be managed. Finally, the recent reform of the European Union's Common Agricultural Policy (CAP) introduced a compulsory 'green direct payment', which provides economic incentives to farmers to implement various environmental measures. Especially in their implementation, some of these policies still fall short of what is necessary [31•], but there is clear evidence that social–ecological interactions are beginning to be recognized by policymakers.

Compared to only one or two decades ago, the advances outlined above reflect an important shift in how both the research community and society at large view links between ecological and social systems. The crucial role that social–ecological linkages play in the pursuit of sustainability is increasingly recognized. Yet, the consequences

of this recognition still need to be embraced much more broadly and deeply by society to successfully resolve mounting environmental and social challenges. In the face of increasingly large-scale, rapid and interconnected social and ecological change, we argue that a step-change is needed in how research is done, and how research and society relate to and engage with one another. To this end, we outline four interlinked priorities for researchers and decision makers.

Priority 1: social–ecological interactions between regions need to be better understood, and institutions should be developed to govern such interactions

To date, much social–ecological research has focused at the regional scale (typically spanning hundreds to thousands of square kilometers). The regional scale is useful because it can meaningfully connect tangible problems relevant to local stakeholders with researchers and policy makers [32], and it relates to a specific cultural context. While social–ecological challenges at smaller scales can be idiosyncratic, and at larger scales abstract, the regional scale thus provides a powerful intermediate scale. However, regions cannot be treated as separate units. New research is required to better understand social–ecological interactions between regions, and across large distances; as well as the institutional and governance contexts in which they operate [33•,34,35]. For example, forest regrowth in one region can result in unsustainable land use being displaced to other regions [3]. As new insights are generated, better-designed institutions that foster international cooperation should be developed that can adequately address the sustainability challenges of an increasingly interconnected world [36].

Priority 2: both researchers and decision makers must pay greater attention to long-term drivers that gradually shape social–ecological systems

Although rapid changes can be very important in some settings, it is widely acknowledged that slow drivers can exert disproportionate control on the long-term trajectory of social–ecological systems [37,38•]. For example, the slow release of phosphorus from lake sediments, and even slower release from watershed soils, can be dominant drivers of lake eutrophication in agricultural regions [39]. As slow drivers push a system towards a threshold, faster-moving variables and sudden shocks can push the entire system across a threshold into a persistent, alternate regime [40]. This dynamic occurs in many ecological systems, including for example, spruce budworm infestations in northeastern USA and eastern Canada [41], and coral reefs around the world [42]. Slow drivers, however, cannot be easily studied. For this reason, research has often focused on faster variables that are more readily apparent and of immediate economic interest to society, such as agricultural production, fish catch, or timber production [43]. Slow drivers are also important for the social components of social–ecological systems [44], and include gradual shifts in cultural norms, dominant paradigms, and the distribution of power [45,46]. For example, the evolution and spread of capitalist economic systems can be considered a slow societal variable, which (according to Marxian analysis) has fundamentally shaped human–environment relationships, including overconsumption and the surpassing of environmental limits [47]. Increased attention to slow drivers, and to system-wide consequences of the interplay between slow and fast drivers, is needed to improve sustainability.

Priority 3: the interactions among power relations, equity, justice and ecosystem stewardship need to be better understood

Issues related to power and justice are important in their own right, and also can have a decisive impact on whether efforts to improve ecological outcomes succeed or fail (e.g. as in the case of REDD+ [48]). Power and justice issues therefore should be incorporated into social–ecological analyses. Key considerations to include are distributive justice and the sharing of costs, benefits and risks, but also procedural justice, access to decision-making, and contextual equity linked to the histories of injustices and cultural domination [49•]. To effectively navigate these issues, better knowledge is required about which conditions enable successful co-governance of natural resources, and about the roles played by new or external actors, to effectively redress historical injustices while also promoting ecosystem stewardship [50]. A key challenge will be to identify the mechanisms and conditions that influence outcomes for marginalized communities, including instances where differences in interests among actors cannot readily be resolved through collaboration [51]. Better understanding of how power and knowledge mobilize public discourse, and how different world views and values interact with ecosystem governance is also required, and is increasingly becoming subject to research [52,53]. Finally, it will be important to consider more deeply the role that scientists themselves play as actors, and the consequences that research may have on distributive, procedural and contextual justice [54].

Priority 4: commitment is needed by governments and society at large to support the development of a stronger science–society interface

Addressing new social–ecological problems requires the collaboration of researchers with policy makers, practitioners, and citizens — in order to develop effective policies, practices, and knowledge in a socially acceptable fashion. Although the concept of social–ecological systems has gained currency in the last few years, many researchers active in this area still face incentive structures that primarily reward disciplinary science that does

not engage with society. We expect that many researchers active in social–ecological systems research would proactively work to strengthen the science-society interface — if they are given the institutional support to do so. However, a quantum change is needed in the design of both research strategies and incentive systems if research organizations are to meet the challenges presented by an ever more interconnected and rapidly changing world. There are many ways in which science and society can be more tightly and constructively coupled, including through increased outreach, professional capacity building and cross-sectoral secondment opportunities, as well as through closer participation of practitioners in the identification of research priorities and in the research process itself [55]. Longer-term commitments of funding and political support are vital for allowing such initiatives to flourish and to ensure that institutional memory is protected against a constant cycling of people and short-term projects.

Conclusion

The concept of social–ecological systems has provided a lens of analysis that sharply puts in focus humanity's dependence on nature, our burgeoning influence upon it, as well as our ethical obligations towards it. We conclude that sustainability scientists as well as policy makers and other stakeholders are increasingly interested in the concept of social–ecological systems. Yet, there is a real danger that the growing challenges of the Anthropocene — such as climate change, global social injustices, and biodiversity loss — will outpace the progress that is being made. We hope that the advances and priorities outlined above can provide renewed motivation and stimuli for research and practice in areas where progress is most urgently needed.

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