



Using the ‘regime shift’ concept in addressing social–ecological change

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Abstract

‘Regime shift’ has emerged as a key concept in the environmental sciences. The concept has roots in complexity science and its ecological applications, and is increasingly applied to intertwined social and ecological phenomena. Yet what exactly is a regime shift? We explore this question at three nested levels. First, we propose a broad, contingent, multi-perspective epistemological basis for the concept, seeking to build bridges between its complexity theory origins and critiques from science studies, political ecology, and environmental history. Second, we define the concept in a way that is consistent with this epistemology, building on previous work on speed, scale, stickiness, and interrelationships, but also emphasising human perceptions and rhetorical uses of the notion. Third, we propose a novel typology of the ways in which the regime shift concept is used in analysing social–environmental phenomena in geography and beyond. These uses are categorised along two axes. On the one side, we distinguish between description of past or present changes and normative prescriptions for the future. On the other side, we distinguish between whether the focus is on material shifts (social and ecological) or conceptual shifts (discourses and ideas). We illustrate the typology with reference to social–environmental changes in landscapes around the world that are dominated by plantations or the widespread naturalisation of Australian *Acacia* species. We conclude that the regime shift concept is a boundary object with value as both an analytical and communicative tool in addressing social–environmental challenges.

Keywords *biological invasions; regime shifts; epistemology; systems theory; social–ecological changes; tipping point*

Introduction

Sudden changes in the environment, human activities, and their interactions are increasingly

in the spotlight (Chapin *et al.*, 2010; Leadley *et al.*, 2014; Russill, 2015). Observers point to the unpredictable dynamics of ocean fisheries, the conversion of peat lands to palm plantations,

transformation of grasslands by alien trees, or major climate change with fundamental effects on humans and their livelihoods. The term 'regime shift' has emerged as an unavoidable tool in conceptualising and analysing such profound changes, along with related concepts like 'tipping points', 'irreversible thresholds', or 'critical transitions' (Andersen *et al.*, 2009, p.50).

The term 'regime' is used here, as we develop later, to denote behaviours, conditions, and interconnected processes that are perceived to be characteristic, stable, and self-sustaining in reference to a particular phenomenon of interest. This understanding of 'regime', characteristic of generic definitions, is distinct from more specific usages—especially as a mode of political rule or governance (cf. Merriam-Webster, 2017; OED, 2017). In the social–environmental realm, a regime might incorporate people's behavioural patterns, social relationships, economic exchanges, cultural values, and natural processes and patterns relating to a particular phenomenon of interest. The term 'shift' is then used to refer to major, rapid, fundamental, and persistent transformations of such a regime.

The regime shift concept has been used to address different phenomena, ranging from natural resource management (Biggs, Carpenter & Brock, 2009; de Zeeuw, 2014) or the transformations of energy-provision systems (Kemp, 1994; Strunz, 2014; Westley *et al.*, 2011) to broad-scale interactions of human societies with the environment (Aoki, 2015; Kinzig *et al.*, 2006; Wrathall, 2012). The concept has been used to investigate causality, multi-scalar internal feedbacks and interactions, or linkages between regime shifts in different sub-systems (Cumming *et al.*, 2014; Kinzig *et al.*, 2006; Leadley *et al.*, 2014; Sims & Finnoff, 2016). There is often a normative aspect: for instance, in some research the analysis of past and ongoing changes may implicitly be described as moving from a more desirable state to a less desirable one (Kinzig *et al.*, 2006), whereas other research might explicitly seek to facilitate or steer desired future transitions in support of sustainability outcomes (Geels & Schot, 2007; van den Bergh, Truffer & Kallis, 2011; Westley *et al.*, 2011).

Despite its rapid uptake in diverse contexts, the use of the regime shift concept faces several challenges. In particular, the need to bring multiple disciplines together to address major social–environmental challenges, often across social and natural science divides, raises problems of transferability, communication, and epistemology. Interdisciplinary integration, as exemplified by

the Future Earth project launched at the Rio +20 conference, is difficult. This difficulty was exactly our experience as a team with disciplinary connections to human geography, biogeography, forestry, invasion ecology, and landscape planning that came together to study the spread and management of Australian acacias in human-shaped landscapes around the world. 'Regime shift' was proposed as an analytical concept for the project yet provoked different reactions from different participants. These different reactions arose because the regime shift concept as used in the study of social–ecological systems has quite specific roots in dynamical systems theory and has been developed in complexity theory (Hui & Richardson, 2017). This epistemological background has, as we review later, given rise to a variety of critiques from alternative perspectives.

In geography, the integration of ideas from systems approaches has a troubled history. An early wave of enthusiasm for analytical approaches inspired by first-generation systems theories took place in the 1960s and 1970s, promoting system theory's holism and thus avoiding the pitfalls of reductionism, and supporting its potentially unifying application across the field's human–physical divide (Ackerman, 1963; Chorley, 1978; Haggett & Chorley, 1967; Harvey, 1969; Huggett, 1980; Johnston, 1991). This initial adoption was met by stinging critiques from others holding different epistemological points of view who were worried about system theory's aggregate nature, its difficulty incorporating non-rational aspects such as actors' perceptions, its application of a mechanical or ecological analogy to social dynamics and, most trenchantly, for its ideology of control (Gregory, 1980; Kennedy, 1979; Liliensfeld, 1978).

The current rise of the 'regime shift' concept accompanies a more recent wave of enthusiasm for later-generation systems ideas in the study of society–environment phenomenon, exemplified by the social–ecological system and resilience approaches (Berkes, Colding & Folke, 2003; Gunderson & Holling, 2002), which have become widespread in a variety of fields, including geography. These ideas have again led to some epistemological friction, notably with scholars from political ecology critiquing the lack of attention to power and values in these approaches (Beymer-Farris, Bassett & Bryceson, 2012; Cote & Nightingale, 2012; Kull & Rangan, 2016).

The present paper aims to build bridges across the above-mentioned epistemological and disciplinary gulfs. Researchers from diverse academic backgrounds are using the regime shift notion as

a tool for deconstructing the elements of complex environmental phenomena to understand the range of possible human responses. We ask what the 'regime shift' term means once it has been borrowed from describing phenomena such as lacustrine ecology or fire regimes and applied to complex social-ecological phenomena involving politics, economics, culture, and more. This shift in use of the concept means that it gains an important *metaphorical* power (Merriam-Webster, 2017). That is, analogies are made between biophysical and socioecological phenomena, as well as between their respective modes of analysis. We ask just how far such analogies can go before they become problematic and promote regime shift as a means to spark, through its use as a boundary object, interdisciplinary and transdisciplinary dialogue.

More specifically, we ask what conceptions of 'regime shift' might be both internally consistent and generalizable to broader studies of human-environment dynamics in geography and beyond. We take a critical, yet constructive, approach to refine the concept and promote dialogue towards better interdisciplinary understanding. To facilitate interdisciplinary integration, it is necessary to better understand how such concepts with roots in the systems and complexity sciences can become more accessible to a broader range of scientists with different epistemological and methodological perspectives. We aim to show how both concept and metaphor can be useful as boundary objects to communicate about and analyse society-environment phenomena, by reviewing their epistemological and ontological underpinnings and by establishing a typology of different uses.

The paper is addressed to nature-society scholars in general, inside and outside of geography, who can see in the discussion of regime shifts an instructive case of interdisciplinarity. It is also addressed more specifically to scholars of 'social-ecological systems' of the resilience school, to encourage better interdisciplinary collaboration and dialogue. The regime shift concept can be a useful tool not just for research analysis, but also as the basis for communication with stakeholders and decision-makers. By refining the concept, our aim is thus to contribute to 'translational' research on society-environment phenomena (Schlesinger, 2010).

This review essay explores three dimensions of the discussion mapped above. First, we place the regime shift concept in its epistemological contexts. In doing so, we propose a new approach that builds upon the strengths of systems and complexity theories but also on critiques of the application

of this epistemology to the social world. This alternative approach considers a regime shift as a boundary object that can enable contingent, multi-perspectival, and testable hypotheses, debatable assertions, and communicable ideas. Second, we investigate the ontology of social regime shifts: what is this thing that we claim exists? We review the ways in which the term has been defined in the study of social-ecological systems and propose a refined definition relevant to our alternative approach. Third, building on these epistemological and ontological foundations, we propose a novel typology based on a critical engagement with the ways in which the concept as we define it has been used in the analysis of social-environmental phenomena. We illustrate the typology with a case study of the spread and governance of Australian acacia trees around the world.

Epistemology: systems and metaphors

The predominant conceptualisation of social-ecological regime shifts builds on a relatively specific epistemology arising out of systems thinking. In this section, we introduce a different understanding, adapted to the social realm, of a regime shift, conceiving of it as a contingent, multi-perspective metaphor. This new understanding seeks to address some of the challenges encountered when applying systems-based ideas to the social realm.

The regime shift concept, as currently used in the study of social-ecological systems, emerged just over a decade ago, at first in discussions of lacustrine ecology, marine ecosystem properties, and climate change, and then in discussions of diverse social-ecological challenges (Berkes *et al.*, 2003; Cote & Nightingale, 2012; Parker & Hackett, 2012; Russill, 2015; Scheffer *et al.*, 2001). The term 'regime' was explicitly chosen instead of 'stable state' or 'equilibrium' to better characterise regions of stability in systems that are inherently dynamic, stochastic, and chaotic, exhibiting non-linear dynamics. A 'regime shift', then, was defined as a sudden, profound change in one or more processes that sustain the dynamic patterns and conditions that characterise and maintain a particular regime (Biggs *et al.*, 2012; Scheffer & Carpenter, 2003).

It should be noted that the term 'regime shift' has also emerged in the intertwined literatures on sustainability transitions, socio-technical transitions, and transitions management. Notably, authors using the 'multi-level perspective' use regime to refer to constellations of rules, practices,

and institutions that maintain stability in society–technology configurations and look at how cross-scalar influences can provoke important shifts (Geels, 2002; Kemp, 1994). This work shares some similar assumptions with studies of social–ecological systems, but there are also some important differences (Smith & Stirling, 2010). A ‘regime shift’ concept (although not always with that name) has also been used in the political sciences, largely in the historical institutionalism school, which specifically addressed path dependencies and critical junctures in how humans organise themselves (Pempel, 1998; Skocpol, 1979). Finally, regime shift (or, more accurately, ‘regime change’) is common in public discourse, notably referring to the forcible removal of a government, often an authoritarian one (OED, 2017).

The concept of regime shift upon which we focus, which arises out of the study of social–ecological systems, is drawn from non-linear systems theory, as made explicit by several authors (for example, Biggs *et al.*, 2012; Gaertner *et al.*, 2014). Systems thinkers see the world as made of systems, each being ‘an integrated whole distinguished by an observer whose essential properties arise from the relationships between its parts’ (Ison, 2010, p.22). Systems thinking has evolved over the past half-century across diverse disciplines and following different albeit related intellectual lineages including cybernetics, network science, and complex adaptive systems. Systems approaches range from the ontological—those that seek to analyse and model phenomena by characterising them as systems, to the epistemological—that is, approaches focused more on systems in terms of learning, control, and communications (Becker & Breckling, 2011; Checkland, 2000; Ison, 2010). Systems perspectives vary also in their reliance on closed versus ‘radically’ open concepts of systems, on equilibrium versus non-linear behaviour of complex systems over time, on realist versus constructivist understandings of systems, and on deductive to inductive approaches (Holling & Meffe, 1996). Despite the variety of conceptualisations, common concepts across all forms of system thinking include reference to boundaries, emergent properties, hierarchy, thresholds, feedback loops, inputs, and outputs (Briske *et al.*, 2010; Csete & Doyle, 2002; Ison, 2010; Liu *et al.*, 2007; Newell *et al.*, 2005; Voigt, 2011).

The regime shift concept, as noted by Biggs *et al.* (2012, p.611), traces its origins to mathematics, specifically dynamical systems theory and René Thom’s catastrophe theory. It arrived in the

field of social–ecological systems via Holling’s (1973) pioneering work on ecological resilience. In the social realm, the same concept, although labelled ‘tipping point’, was harnessed by economist and complex systems theorist Schelling (1971) in his work on residential segregation. Despite these more formal, quantitative origins, some of the uses of the regime shift concept have—as Stone-Jovicich (2015) shows for social–ecological resilience ideas more broadly—‘moved a long way from their ecological origin’ and ‘broadened both their theoretical lens and methodological toolkit’. Nevertheless, they are still rooted in the analysis of non-linear behaviour of complex systems over time.

While we build on the social–ecological regime shift concept as developed in the above-mentioned forms of systems thinking, several constraints that typify its underpinning epistemology lead us to introduce a modified understanding. A substantive literature presents critiques of the use of systems approaches in the social sciences in general (Giddens, 1979; Lilienfeld, 1978), and more specifically in geography (Gregory, 1980; Kennedy, 1979; Kull & Rangan, 2016; Watts, 2011), in ecology (for example, Taylor, 2005; Taylor, 2011), and in resilience thinking (for example, Biermann *et al.*, 2015; Brown, 2014; Kirchhoff *et al.*, 2010; Porter & Davoudi, 2012). In Table 1, we review some of the challenges or perceived incompatibilities with systems approaches identified in the social sciences. Our goal in Table 1 is not to be comprehensive in reviewing these critiques, but rather to remind readers of controversial aspects underlying the use of the regime shifts concept for social systems that we thus must address in our proposed approach.

Because of critiques such as those reviewed in Table 1, systems-based approaches are only one subset of approaches used in studies of the social world—for instance, in ecological anthropology (particularly in the 1970s), in world systems theory (Stone-Jovicich, 2015), or in economics. For some epistemologies, it is difficult, or even inappropriate, to reduce and synthesise the diversity and richness of human experience to boxes and arrows, balls and cups, or quantitative variables. While certain systems approaches address historicity, multiple perspectives, power relations, control ideologies, and so on, they do so in particular ways. In other words, the common history of systems thinking approaches, the predominant relationships and interactions with particular disciplines or epistemological traditions within disciplines, and the metaphors used—often from

Table 1 A summary of challenges and social science and humanities critiques encountered when applying different forms of systems approaches to social contexts.

Fundamental differences from natural systems	Social scientists contest mechanistic applications of systems approaches that see the world in ways that can appear reified, un-reflexive, and which reduce the world to inputs and outputs (Kirchhoff <i>et al.</i> , 2010, Palsson <i>et al.</i> , 2013). Furthermore, they argue that there are fundamental differences between social systems and biophysical systems, particularly with respect to the system structure, behaviour, and the multiplicity of interpretations (Adger, 2000, Bentley <i>et al.</i> , 2014, Brown, 2014, Cote & Nightingale, 2012, Turner, 2014).
Difficulties in incorporating modulating influences and contingency	In a more formal sense, strict systems approaches based on mathematical relationships allow only for direct causal effects between separated elements. These do not allow for a modulating influence of contexts on interactions, and they require the definition of discrete elements. In particular, they do not allow for historical contingency, in the sense that the same cause–effect relationship may work differently in time, space, and between individuals, depending on the social context (DeLanda, 2006, Frawley, 2014, Taylor, 2011, Turner, 2014). Some forms of complexity theory explicitly incorporate what they call ‘contextuality’ (Chu, Strand & Fjelland, 2003), and some social–ecological systems authors seek cross-fertilisation from other social science approaches (Stone-Jovicich, 2015). But contingency and the irreducible uniqueness of each case are not in the epistemological core of systems thinking, which in contrast is the case for certain intellectual traditions in the humanities.
Poor compatibility with multiple perspectives, feelings, and interpretations	Social systems are <i>multi-perspective</i> , with certain aspects like perceptions, beliefs, memories, and culture that shift across time, domains, levels, persons, and generations. There are multiple perspectives of what constitutes a particular system and makes it function. Despite recognition of this in some forms of system analysis (for example, when Ison (2010, p.22) defines systems as ‘an integrated whole distinguished by an observer ...’), and the recognition of the ‘constructive role of variation’ in work on adaptive management (Holling & Meffe, 1996), this multi-perspectivity remains constrained within the bounds set by a systems perspective. Aboriginal worldviews, for instance, simply do not fit into a systems epistemology (Howitt, 2001; Trudgen, 2000). Relativity of perspectives, and incorporation of the humanistic domain of feelings, interpretations, and worldviews, remains only poorly compatible with most applications of systems ideas (Palsson <i>et al.</i> , 2013).
Discomfort with emphasis on generalisation and simplification	Systems approaches tend to emphasise <i>generalisation</i> , at least at an intermediate level (Ostrom, 2007; Pahl-Wostl, 2009), rather than <i>context dependence</i> , <i>differentiation</i> , <i>individual agency</i> , and <i>geographical context</i> (Coenen <i>et al.</i> , 2012). This generalisation can require strong simplification and reduction to a few variables and interactions. Such abstraction and simplification means that the experiences of individual organisms—differentiation, pain, struggle, injustice—are largely ignored (Turner, 2014).
Difficulties in addressing questions of power	Systems approaches have been critiqued for poorly addressing notions of <i>power</i> and <i>equity</i> : who has power, why, how it operates, who wins, who loses, whose interests are affected, and what ideas accompany these changes (Brown, 2014; Michon, 2011; Smith & Stirling, 2010). For instance, systems-based resilience thinking has been accused of being technocratic and ‘apolitical’ (Beymer-Farris <i>et al.</i> , 2012; Birkenholtz, 2012; Cote & Nightingale, 2012; Turner, 2014; Watts, 2011). Although the question of ‘resilience for whom’ has been addressed within a social–ecological systems approach (Lebel <i>et al.</i> , 2006) and innovative recent work has created strong overlaps between social–ecological systems science and other social science traditions on power (for example, Ahlborg & Nightingale, 2012; Stone-Jovicich, 2015), system science approaches nevertheless privilege certain perspectives on agency—those that are

(Continues)

Problems with a perceived ideology of control

measurable and explicit—over others. Furthermore, many systems-based approaches implicitly give power to the experts who perceive and describe the system, to the detriment of others (for example, it is not sufficient to ask ‘resilience for whom’ but also ‘resilience seen by whom and how’). The tendencies of early systems theory approaches to reduce complex systems into legible and manageable components has been criticised for facilitating an *ideology of control*—a presumption that the beholder of the system has sufficient knowledge to tweak the dials to reach certain outcomes. This presumption can reproduce structures of domination and begs questions about why, and for whom, certain systems regimes are seen as desirable (Beymer-Farris *et al.*, 2012; Gregory, 1980). The ideology of control has been critiqued from *within* different systems paradigms, notably by Holling and Meffe (1996) who argue that non-equilibrium, non-linear, and multi-scalar concepts of system dynamics suggest that management should not seek to control, but instead adaptively ‘facilitate existing processes and variabilities’. Theories of complexity and adaptive systems, notably, integrate a sentiment that systems dynamics are inherently uncontrollable and complex (Chu *et al.*, 2003; Folke *et al.*, 2002).

information and complexity theory or engineering—limit the intellectual space that the systems traditions provide. This can hinder interdisciplinary and transdisciplinary collaboration with experts from contrasting epistemological backgrounds. Recent social sciences research on scientific practice in fields such as science and technology studies or transdisciplinarity has recurrently shown the pervasive but often implicit and therefore difficult-to-uncover performativity of scientific traditions and metaphors in the sciences, including systems science thinking (Castree *et al.*, 2014; Feyerabend, 2010; Miller *et al.*, 2008; Rasmussen & Arler, 2012; Taylor, 2005).

We argue here for a different perspective that is at least partly incommensurable with a systems analysis framework and therefore cannot simply be subsumed under it. A critical realist epistemology may be one way forward, as it finds a third way between positivist research and relativist, constructivist stances. It allows for tacking back and forth between empirical realities and the social processes that produce our understandings of those realities (Forsyth, 2003; Mingers, 2014; Sayer, 2000; Stone-Jovicich, 2015; Taylor, 2005; Turner & Robbins, 2008). We suggest a broader understanding, or epistemology, to underpin the regime shift idea. In it, a ‘regime shift’ is seen as a contingent, multi-perspective boundary object that enables the creation of hypotheses or ideas that can be appropriated, tested, and debated by different approaches (including, of course, systems-based analyses). The concept needs to be *contingent* in the sense that it must allow for the expression of non-deterministic, context-dependent, and historically particular conjunctures of causes and effects.

It needs to be *multi-perspectival* in legitimising different points of view, experiences, and analytical moments with respect to the events being discussed. Finally, it can serve as a *boundary object* that promotes debate, the advancement of knowledge, and sometimes surprising outcomes, its power bringing into conversation a variety of different participants and worldviews (Baggio, Brown & Hellebrandt, 2015; Brown, 2014; Cohen, 2012; Kull, Arnauld de Sartre & Castro-Larrañaga, 2015).

Boundary objects are either concrete objects or abstract notions that are accessible to different social groups with (partly) non-overlapping epistemologies and/or interests. They are, in the words of Star and Griesemer (1989, p.393), ‘plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites’. Boundary objects such as regime shifts must strike a balance between robustness and plasticity (Star & Griesemer, 1989) in that they should refer to an ontological core that is both specific and flexible. As Brand and Jax (2007) argue regarding the notion of ‘resilience’—another boundary object—clarity and specificity aid specific scientific use as an analytical concept; malleability and broadness aid in fostering communication.

A specific way in which the regime shift concept serves as a boundary object is as a heuristic *metaphor* used to communicate a certain interpretation of reality (Chew & Laubichler, 2003; Larson, 2011). Metaphors create analogies between one kind of object or idea and another (Merriam-Webster, 2017). The regime shift concept as applied to social–environmental

phenomena makes exactly such analogies, both at the ontological level between biophysical and social–ecological systems, and at the epistemological level between how such phenomena are analysed. As we reviewed previously, these analogies can become problematic, necessitating the kind of alternative framing we advocate. Instead of understanding a regime shift as a type of systems behaviour that can be described and analysed using systems models, we propose that regime shift be defined specifically enough to facilitate dialogue and research about a bounded range of phenomena, but flexible enough to allow for people with different worldviews and epistemologies to contribute to the debate. For instance, as we note below, factors including rural outmigration, forestry policies, and invasive plant behaviour have shaped non-native acacia landscapes in Portugal (Appendix S2). This situation can be productively modelled as a regime shift within system approaches (for example, Figueiredo & Pereira, 2011; Santos *et al.*, 2016), but such approaches could be productively complemented by others that build on the identified regime shift as a communicative tool to investigate historical contingencies in the process, different perceptions of what exactly is the shift of concern, and whose ideas of future pathways and adjustments can or should hold sway.

Ontology: what is a social–ecological regime shift?

After describing a type of knowledge system that might be useful for the ‘regime shift’ concept as applied to social systems, we now propose to define ‘what it is that can be known’ as a regime shift, or, loosely said, its ontology. In this section, we establish the essential elements of a generic core ‘regime shift’ definition consistent with the alternative critical realist epistemology described previously. We then demonstrate the relativity or malleability of the concept, and justify why we think that it is best seen as a perception. In this sense, we advocate regime shifts as boundary objects to communicate as well as analytical constructs to analyse differentially situated and always political (Smith & Stirling, 2010) human perceptions of specific types of dynamics in the world in which we live.

Publications invoking the ‘regime shift’ concept in the study of (social–)ecological systems display a relatively tight conformity in definition. They also cite a limited number of key references, with the work of Marten Scheffer and several

authors associated with the Resilience Alliance (www.resalliance.org) attracting most attention (Appendix S1). For instance, Kinzig *et al.* (2006, p.1) describe the central idea as applied to both social and natural systems:

The seemingly stable states we see around us in nature and in society, such as woody savannas, democracies, agro-pastoral systems, and nuclear families, can suddenly shift out from underneath us and become something new, with internal controls and aggregate characteristics that are profoundly different from those of the original. The types of changes that involve alterations in internal controls and feedbacks are often called ‘regime shifts’.

In a review of articles containing the key words ‘regime shift’ (see Appendix S1 for sources), almost all definitions of regime shift included, in one way or another, four key ideas:

1. *Speed*. The change is sudden, abrupt, or rapid.
2. *Scale*. The change is dramatic, large, non-linear, or passes thresholds to profoundly different states (or has substantial impacts).
3. *Stickiness*. The change is long-lasting, persistent, difficult, or impossible to reverse, hysteretic.
4. *Systemic change*. The change is characterised as being from one regime (or ‘quasi-equilibrium’, ‘stable state’, ‘apparent homeostasis’, ‘basin of attraction’) to another, resulting in reorganised internal controls, feedbacks, and characteristics (structures, functions, rule sets ...).

A systems-based epistemology is not mandatory to characterise particular phenomena with the first three key traits listed previously. The fourth, however, uses a terminology specific to systems thinking. In the spirit of surpassing the epistemological boundaries identified in the previous section, we suggest using terminology such as ‘tightly interrelated patterns, functions and processes’, instead of explicit systems-based concepts like homeostasis. What is meant by this is that several, and often wide-ranging, aspects of a society–environment phenomenon are tightly interconnected across scales and sectors, which typically adds to the coherence of a regime and enhances the dynamics of regime shifts. In that case, a ‘regime shift’ could usefully be defined as *a major, sudden, and persistent change in the tightly interrelated patterns, functions, and processes that are perceived to characterise and/or maintain particular society–environment*

phenomena of interest. Furthermore, this understanding of regime shift emphasises *relativity, multiple perspectives, and the metaphorical or boundary object role* of the concept. In this definition, patterns, functions, and processes can be physical or social, and include perceptions, ideas, or ideologies.

The aforementioned definition begs some important questions: how big is *major*, how fast is *sudden*, how strict is *persistent*, and what *patterns, functions, and processes* are of importance? Given that regime shifts are heuristic constructs used to analyse a given phenomenon of interest, the spatial or temporal scale depends upon the phenomenon the observer is seeking to describe or understand. Thus it is by definition a relative and situated concept, a regime shift *with respect to something and at a given scale* (Carpenter *et al.*, 2001). So for instance, the conversion of a hectare of *fynbos* shrubland in South Africa through the planting of, or invasion by, Australian acacias is a dramatic landscape change *for that plot*, but could be perceived as insignificant *at broader spatial scales* unless many such changes occur within a given timeframe. Conversely, a minor policy decision in a country's Ministry of Forests may not constitute a regime shift in the workings of that Ministry, but could be seen as such if the scale of interest is a plot of land that is wholly cut, planted, or developed because of that decision. Similarly, the definition of 'sudden' depends on whether the temporal frame of reference is geological, archaeological (Aoki, 2015), or a three-year policy programme or management plan. The socio-technical transitions literature usefully provides a model for making such analyses, in identifying pathways to regime shifts in relation to higher scale (landscape) and lower scale (niche) phenomena, and in doing so focusing attention on slow moving and fast moving variables (Geels, 2002; Geels & Schot, 2007).

Similar caveats apply to irreversibility. Leadley *et al.* (2014, p.665) argue that many 'regime shifts lack the nonlinear characteristics and difficult-to-reverse nature of regime shifts mediated by tipping points'. For instance, the regime shifts identified by Gee and Burkhard (2012, p.193) for offshore wind energy farms in Germany are arguably reversible. The development of artificial reefs at the foot of each wind turbine can be undone by the removal of the platforms; and public perceptions about the seascape may reverse (for example, Eltham, Harrison & Allen, 2008). Irreversibility is particularly problematic as a concept in social systems, as it depends on human agency, a

combination of behaviours, intentions, and capacity to act, conditioned by various structures (Giddens, 1979). In principle, any social system can, to different degrees, be made to change in different directions, although this does not always occur (Nykqvist & von Heland, 2014).

The relativity of the regime shift concept is heightened by the fact that it is humans who perceive regime shifts. Any representation is a simplification of reality. The idea that regime shifts are relative, or heuristic, leads to a philosophical debate. Is a regime shift 'real' or is it a human conception? As noted earlier, we adhere to a critical realist philosophy that notes that entities or phenomena are autonomous from the conceptions we have of them (DeLanda, 2006), but that we are also constrained to use our conceptions to analyse, compare, and talk about phenomena, however real they are. Heuristics matter, and they do not deny realities. The people perceiving a regime shift do so from their perspective, which is shaped by their views of *which* patterns, functions, and processes maintaining *which* society–environment phenomenon are of interest or important. Thus, any regime shift argument will emphasise some processes and downplay others and is therefore only a partial, provisional, and ephemeral interpretation of reality. Furthermore, a representation of reality is always a rhetorical instrument and must be considered in the context of political and social discourses (Forsyth, 2003). To paraphrase Lebel *et al.*'s (2006) comments about resilience, it is important to ask *who decides* whether something qualifies as a regime shift, and *for what purpose*.

The relativity of the concept does not deny realities nor hinder its utility as a heuristic and rhetorical model to guide research, hypothesis formulation, and debate. It is an evocative boundary object to communicate perceptions that a particular society–environment phenomenon is rapid, major, and consequential enough to warrant the label 'regime shift'. For instance, we might label the rapid establishment of a plantation of 1.1 million hectares of acacia trees in Vietnam, coincident with major policy changes beginning with the Đổi Mới reforms (see Appendix S2 for details) as a regime shift, for this had important consequences of relevance to household livelihoods, social justice, national economics, biodiversity conservation, and invasion biology. In this case, our purpose in generating awareness or concern over the shift makes the use of the label apt, useful, and a powerful communication tool that can inspire further investigation and debate. It is a

heuristic shorthand for a more detailed, contextual, contingent set of processes. As a shorthand boundary object, and as a metaphor, however, it is important to note that its usage is context specific and could lead to confusion, for instance, about the speed of change or its spatial heterogeneity, and could lead to spurious interpretation and inappropriate policy responses (Leadley *et al.*, 2014, p.676).

Typology: different uses of regime shifts

We have established that regime shifts are a human construct, relative in character, and that they can be defined in such a way as to make the concept a useful diagnostic tool and boundary object for analysis, rhetoric, and debate about profound changes perceived to be occurring in environment and society. Here, we build on these postulates and on observations about the use of the concept in the literature on acacia invasions to propose a new typology (Figure 1) of the ways in which the regime shift concept could be employed in addressing social–environmental phenomena. The typology rests on two axes, as described later. We considered other axes, such as whether the drivers are ecological, economic, or socio-political, or whether the regime shift is intentional or non-intentional (Moore *et al.*, 2014)—but we found that the two selected axes most efficiently conceptualise the uses of the concept. By distinguishing between different purposes and temporal moments, as well as between material and conceptual shifts, we reinforce

the need for an inclusive, flexible, and contingent epistemology as outlined previously.

The *y*-axis of the typology distinguishes between different purposes and moments for which analysts mobilise the concept of regime shifts (Figure 1). It captures our recognition that the description of a regime shift is always part of a discourse with a purpose. Are we *explaining* a regime shift in the past or present, *predicting* a future shift, or *intending to catalyse* a future shift? Each is different. Many scholars use the regime shift idea as an analytical tool for analysing historical trends, explaining the current situation, or predicting future events. Yet the term is also used in an explicitly normative sense. For instance, in the literature on sustainability transitions, the focus is on how to facilitate a change in societal structure, economy, and attitudes to navigate a transition along a desired pathway to sustainability (Chapin *et al.*, 2010; Moore *et al.*, 2014; Westley *et al.*, 2011).

The *x*-axis distinguishes between the main types of dependent variables, that is, the central units of analysis, or the focal components of the phenomenon seen to be undergoing regime shifts (Figure 1). While it is tempting to separate social–ecological systems into the social and the ecological subsystems, the more pertinent division in the literature surveyed and in our case study research (Supporting Information Appendix S2) is between material and conceptual shifts. By material shifts, we refer to shifts in material flows and processes that can typically be observed empirically, and which can include both ecological (Biggs *et al.*, 2012) and social variables (Westley

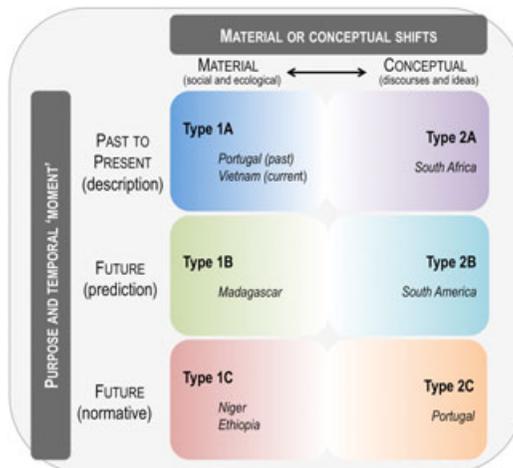


Figure 1 A novel typology of social–ecological regime shifts, applied with respect to different case studies of non-native acacia landscapes (see Supporting Information Appendix S2 for case study details)

et al., 2011). For acacia-dominated landscapes, these may include elements such as land cover, land use, seed dispersal, timber trade, wood-fuel harvesting practices, and project activities for agroforestry or weed control. By conceptual shifts, we refer to shifts in the less tangible realm of ideas, discourses, and ideologies. For example, Gee and Burkhard (2012) describe tipping points in regional identities, and Andrachuk and Armitage (2015) propose a method that focuses on fishers' perceptions of thresholds for social–ecological transformations. Of course, material and conceptual shifts are often intertwined (Sluyter, 2001), particularly with respect to changes in rules, institutions, and policies; here, however, we construct them as separate ideal types to facilitate the clarity of the typology; in the figure we visually illustrate the continuum between these ideal types. The resulting typology (Figure 1) highlights six categories of how researchers mobilise the regime shift concept.

We illustrate the typology by applying the six categories to case studies of places around the world with landscapes containing Australian acacia species, a prime example of a contemporary society–environment challenge (Richardson *et al.*, 2011) (see Supporting Information Appendix S2 for case study details). Commonly known as wattles, Australian acacias have been transferred over the oceans by traders, scientists, settlers, foresters, and gardeners for over 200 years, and then planted for ornament, for profit, and for environmental management. As fast growing, nitrogen fixing, and copious seed-producing trees, they expanded rapidly in many places. The resulting 'acacia landscapes' exhibit a number of regional particularities, differing in terms of social perceptions and expectations, ecosystem services provided, and problems caused (Kull & Rangan, 2008, Kull *et al.*, 2011, Richardson *et al.*, 2011, Vicente *et al.*, 2013).

These landscapes can be considered as a set of 'model systems' useful for testing ideas about social–ecological regime shifts (Bennett, 2014; Kueffer, Pysek & Richardson, 2013). Indeed, a shared interest in these landscapes is what brought the author team together and what explains this choice of case study. Acacia landscapes are textbook social–ecological phenomena, with humans active in creating plantations and facilitating invasions, in perceiving associated environmental issues, and in deciding when, how, and where to intervene. As with invasions of non-native trees in general (Dickie *et al.*, 2014; van Wilgen & Richardson,

2014), invasions of acacias, in many situations, pose a 'wicked problem' in that the complexity of issues affecting the presence, abundance and perceived costs, and benefits of the trees make it difficult to define the management problem and decide on interventions to the satisfaction of all stakeholders (Woodford *et al.*, 2016). By refining the regime shift concept as applied to the social–ecological dynamics in question, we hope to promote deeper understandings and dialogues that facilitate adaptive and resilient management of acacia landscapes. In the following, we describe the typology in terms of the acacia case studies.

Type 1A refers to the use of regime shifts by researchers and others as a way to characterise past or on-going shifts in the material components of a social–ecological system. For instance, the dramatic changes in the landscape, rural economy, and demography of Portugal from roughly the 1930s to the 1980s are arguably fundamental and irreversible (Radich & Baptista, 2005). Likewise, it can be productive to speak of the economic, policy, and forestry transitions of Vietnam from the 1990s to the present as a regime shift or fundamental transition (Meyfroidt & Lambin, 2008; Thulstrup, Casse & Nielsen, 2013). Doing so emphasises the dramatic scale and speed of the changes. But calling the situation in Vietnam a regime shift opens an important debate, relevant to policy, about its irreversibility and persistence. From an ecological perspective, experience with acacias and their massive persistent seed banks (Richardson & Kluge, 2008) suggests that substantial problems of biological invasiveness with potentially negative consequences could result (Richardson, Le Roux & Wilson, 2015). Alternatively, the material conditions in Vietnam differ from those in South Africa, highland Madagascar, and Portugal (prime cases used to document the range of problems associated with acacia invasions), and perhaps, instead, acacia plantations will be replaced in a few decades by other crops and intensive land use (given the population density) that check invasive potential. Indeed, this was the case with 1920s plantations of *Acacia mearnsii* in upland Java (Berenschot, Filius & Hardjosoediro, 1988).

Type 1B refers to the utilisation of the regime shift concept by analysts to illustrate a possible, or predicted, scenario of dramatic material change, such as to the land system. For instance, while silver wattle (*Acacia dealbata*) is ubiquitous in highland Madagascar, its spread over the past

century arguably does not really qualify as a broad-scale regime shift to the land system, because the tree has been integrated into relatively ‘traditional’ rural livelihoods, where it grows in scrubby clumps subjected to heavy harvesting and pasture fire (Kull, Tassin & Rangan, 2007). A regime shift could, however, be envisaged in the future. As Kull *et al.* (2007) note, rising incomes could permit urban and rural Malagasy to use non-biomass energy sources for cooking, reducing the harvest pressure on the trees, thereby transforming both the rural economy and landscape, with the invading wattles occupying vastly more terrain at higher densities.

Type 1C refers to an analytical stance that is different from the previous ones that are centred on description and prediction of material changes. Instead, it encompasses instances where people describe wished-for changes to the material system. For instance, in several cases, development projects are actively being used to encourage what could be seen as a regime shift in the local land systems. In many African countries known for both land degradation and problems of famine, aid agencies and foresters specifically seek to encourage landscape changes involving tree planting and new livelihood practices (Weston *et al.*, 2015). In both Niger and Ethiopia, project managers have encouraged planting of Australian acacias such as *Acacia colei* and *Acacia saligna* for land rehabilitation, fuelwood, windbreaks, soil fertility, and even human nutrition (Kull *et al.*, 2011). The hope is that such practices will take hold and replicate themselves in farmer practices broadly, and in some cases through the self-reproduction of the plant itself, leading to a regime shift in the resilience of both the land and the local communities. In this case, aid agencies imagine a very different future social–ecological system, or regime, shaped by acacia species, that they use rhetorically to promote change.

Type 2A is the first of three types referring to the use of the regime shift concept to indicate *conceptual* changes; that is, important shifts in ideas, discourses, and their manifestations in institutions and policies. Type 2A refers to the analysis and description of past and current changes in this regard. The case of South Africa’s ‘Working for Water’ programme is a good example (again, see Supporting Information Appendix S2). This programme can be analysed as a major, rapid, and sticky policy transition with respect to acacias, fashioned out of a unique political and ideological moment in the country’s history coincident with the global rise of invasion biology (see, for

instance, Carruthers *et al.*, 2011; Turpie, Marais & Bignaut, 2008; Urgenson, Prozesky & Esler, 2013; van Wilgen, Khan & Marais, 2011; Woodworth, 2006). The veritable political ‘regime shift’ at the end of Apartheid facilitated the alignment of multiple ideas and interests that made it possible to conceive of—and institutionalise—weedy tree control as an activity for poverty reduction, development, and water resource management.

Type 2B describes a situation where analysts *predict* a plausible major, sudden, and persistent shift in the conceptual realm. For instance, it has been shown that concern over invasive species like acacias is absent or low in South America (Speziale *et al.*, 2012). An analyst might draw on parallels with the South African case mentioned previously, or cite an increasing body of regional scientific literature on invasions, or even survey social media on the topic, and predict that the rise of invasion biology as a globally accepted body of knowledge would cause a shift in attitudes. Given that attitudes towards non-native and invasive species are tightly linked to ideologies related to national borders or balance in nature, such a shift in attitude might only happen if one stabilising, interrelated, conglomerate of ideologies switches to another one.

Finally, Type 2C describes the use of the regime shift concept not to predict, but to *articulate a ‘wished-for’ change* in the political or ideological context with respect to acacia landscapes. Discussions with stakeholders in many of the acacia landscapes described earlier reveal normative framings of future changes that combine predictive scenarios of change with normative desires for changes in mind-sets, worldviews, and associated policy pathways. Such desires are also expressed in the concluding sections of scientific articles about biological invasions (for example, Low, 2012; Richardson *et al.*, 2015; Speziale *et al.*, 2012). Where such shifts require relatively major, broad-scale, and consequential changes, they can legitimately be thought about as normative regime shifts. For instance, at a conference on biodiversity and global change attended by the authors in Portugal in 2015, interlocutors spoke of the need for radical rethinking of forest policy that might result in a very different ideological and regulatory space for dealing with acacia landscapes.

The aforementioned exercise has shown that the use of the regime shifts notion can be analytical, predictive, and normative, and refer to either the material or conceptual sphere. Each use is

somewhat different, calling on diverse assumptions and forms of explanation. Clarity about the different uses of regime shift will facilitate better interdisciplinary communication and analysis (Eigenbrode *et al.*, 2007). For instance, it will help researchers to differentiate between actual changes in the landscape (material shifts) and changing perceptions (conceptual shifts) as a basis for analysing feedbacks between these different realms. And it will help to make explicit the value judgements implicit in a particular analysis. Adopting a more shared epistemology, and a refined definition of regime shifts, like the one we propose, means that our typology has been able to expand beyond the traditional limits of systems-based viewpoints. Notably, the fact that regime shifts are used for material shifts and also conceptual ones reinforces the need for epistemologies that can cope with different ways of knowing. The fact that we defined regime shifts as large, sudden, persistent changes in interrelated patterns and processes provides questions and points of entry for hypothesis making and debates within each of the typologies.

This typology could easily be applied to other social–ecological phenomena, as it is not restricted in its validity to acacia landscapes. Take for instance the question of bushfires, where the use of the term ‘regime’ even has a longer-standing tradition. Researchers have described both material and conceptual regime shifts in bushfires. Material shifts might include new management activities or the arrival of a flammable invasive weed. Conceptual shifts include the arrival of colonial anti-fire ideologies in places that used to use fire, or the revival of acceptance of fire as natural in ecological science after the 1970s. These are applied analytically to historical events, predictively to future trends, or normatively to desired future states (Bowman *et al.*, 2011; Kull, 2004; Pyne, 2009; Taylor *et al.*, 2016).

Conclusion

Humans—geographers included—communicate what they observe and think using terms, metaphors, and conceptual frameworks; in turn, these concepts structure their analyses (Binder *et al.*, 2013; Kueffer & Larson, 2014; Larson, 2011). The ‘regime shifts’ idea and related metaphors like ‘tipping points’ and ‘thresholds’ are increasingly applied to describe, explain, predict, or seek to influence phenomena at the interface of society and the environment. Yet it is important to tread carefully when applying a concept drawn from

systems theory and systems ecology to the social world. The application of systems metaphors to social processes and associated institutions—with all their contradictions, dynamism, flexibilities, power relations, inconsistencies, feelings, and more—can be difficult (Table 1). This difficulty explains, in part, the visceral reactions of some social scientists at the sometimes uncritical, un-reflexive adoption of systems concepts by social–ecological systems researchers (Smith & Stirling, 2010; Turner, 2014; Watts, 2011). Hence, we sought to build on the classic systems-based epistemology upon which the regime shift idea is based, and to push its boundaries to make room for more contingency, relativity, and human perception. We defined the regime shift concept in a broader way that still retains the fundamental insights of ‘speed, scale, stickiness, and coherence’ in describing changes to the patterns, functions, and processes underlying a particular social–environmental phenomenon, but we also defined it so as to acknowledge its context-specificity and its origins as a human conception. It is a *perception* of major, fast, persistent, and interconnected changes—to facilitate communication and analysis.

In applying these ideas to society–environment phenomena—in our case to landscapes dominated by non-native acacias—we made several observations. First, we corroborate the value of the ‘regime shift’ concept as a *communicative tool* for framing, negotiating, and communicating phenomena among diverse experts and actors. In the Anthropocene, with ever more dramatic shifts in society–environment relationships, a term such as this is clearly of broad importance, as the debates over the use of term ‘tipping point’ in climate science have shown (Russill, 2015). Second, we demonstrate the value of ‘regime shift’ as an *analytical tool*. The very relativity of the concept forces attention to definitional aspects such as speed, scale, stickiness, and coherence. In addition, creating regime shifts as an analytical category allows for the posing of detailed questions about causality, for example, between one ‘regime shift’ and another. Third, we propose a *framework to specify different kinds of uses of ‘regime shift’* in the context of social–environmental phenomena (Figure 1), distinguished by a material–conceptual continuum and by purpose and moment.

The beauty (and frustration) of terms such as ‘regime shift’ is that, as metaphors and boundary objects, they take on a life of their own and are used in different ways by different people. They

are powerful emblems, facilitating communication and analysis, apt for both quantitative models and qualitative narratives. If a particular model of ‘regime shifts’ is applied without attention to fit, definition, and epistemology—if it is used as a proverbial square peg in a round hole—then it may fall to the wayside, broken, like so many other buzzwords. If, on the other hand, the concept is carefully used to facilitate communication, discussion, prediction, and more detailed analysis, it has clear utility. Debates around regime shifts are taking place at the same time as debates about other constructs such as ‘novel ecosystems’, ‘wicked problems’, ‘adaptive management’, ‘ecosystem stewardship’, and other challenges relating to managing ecosystems in the ‘Anthropocene’ (Kueffer & Larson, 2014). One can see these all as attempts to create benchmarks and straw men to promote constructive dialogue.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's web-site.

Appendix 1. Definitions of 'regime shift' in context of social and/or ecological systems. Based on a selection of articles appearing with search terms 'regime shift' in Web of Science and Google Scholar. Listed in date order.

Appendix 2. Case studies of social-ecological regime shifts in acacia landscapes