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Operationalizing resilience for conservation objectives: the 4S's

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Although resilience thinking is increasingly popular and attractive among restoration practitioners, it carries an abstract quality that hinders effective application. Because resilience and its components are defined differently in social and ecological contexts, individual managers or stakeholders may disagree on the definition of a system's state, occurrence of a state change, preferred state characteristics, and appropriate methods to achieve success. Nevertheless, incentives and mandates often force managers to demonstrate how their work enhances resilience. Unclear or conflicting definitions can lead to ineffective or even detrimental decision-making in the name of resilience; essentially, any convenient action can be touted as resilience-enhancing in this case. We contend that any successful resilience management project must clearly identify up-front the *stressors* of concern, *state* traits, *scales* of appropriate management, and *success* indicators (the 4S's) relevant to the management targets. We propose a deliberate process for determining these components in advance of resilience management for conservation. Our recommendations were inspired and informed by two case studies wherein different definitions of stressors, state, scales, and success would result in very different management choices, with potentially serious consequences for biodiversity targets.

Key words: Hawaii, scale, southwestern fire regime, state, stressors, success

Conceptual Implications

- Resilience management attempts to align abstract concepts with real-world challenges, and different perspectives may yield very different decisions.
- A priori identification of the ecological and social characteristics of a particular system is essential to ensure that stakeholders are in agreement about focal system state, scale, stressors, and success.
- A proactive approach to defining resilience in a particular system should occur prior to management implementation so that success can be understood and recognized.

Introduction

Resilient systems will regain their basic characteristics and resilient system functions will persist after disturbances (Folke et al. 2004). In light of accelerating environmental change, resilience is therefore an attractive concept. Resilience frameworks are used to guide and plan restoration (Allen et al. 2002; Suding et al. 2004), and resilience management is intended to reduce the long-term need for restoration investment (Allen et al. 2002; Holl & Aide 2011). Management that promotes resilience has been mandated across U.S. resource management agencies (e.g. Schultz et al. 2012). Scientists united in 1999 to form the Resilience Alliance, an international body promoting resilience in order to help social–ecological systems adapt to change. Efforts such as the United Nations Office for Disaster Risk Reduction's 100 Resilient Cities Projects are intended to help municipalities respond to and withstand emerging physical, social, and economic challenges. As these efforts grow, an increasing number of system characteristics predictive of resilience have been identified. High biodiversity, taxonomic diversity, functional diversity, and adaptive capacity have been linked to high resilience (Kéfi et al. 2016; Timpane-Padgham et al. 2017). Resilience is linked to human prosperity and sustainable development, which are dependent upon lasting, functioning, and diverse ecosystems (Folke et al. 2016).

However, resilience can be understood in diverse ways. Resilience research and thinking have inadequately incorporated human social dimensions, failing to adequately describe social–ecological desired states (Adger 2000). This failure is particularly important since the stressors that are of greatest concern in conservation (e.g. climate change, habitat loss, biological invasions) stem from anthropogenic impacts, and management responses are subject to human values, preferences, traditions, cultures, and constraints. Adger (2000) noted that "the concept of resilience has not effectively been brought

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across the disciplinary divide to examine the meaning of resilience of a community or a society as a whole." MacKinnon and Derickson (2013) highlight how resilience "privileges the restoration of existing systemic relations rather than their transformation." That is, strict resilience thinking may idealize recent conditions without acknowledging that not all people may find those conditions desirable. Resilience in its strict form (as interpreted by the Resilience Alliance) is evaluated with relation to a specific disturbance or stress (Speranza et al. 2014), but in common usage the term is often equated with "healthy" (e.g. Halpern et al. 2012; Speranza et al. 2014). As a result of these inconsistencies of meaning, as well as the complexities of systems, translating conceptual resilience to effective, on-the-ground decision-making is difficult (Quinlan et al. 2016).

In an attempt to bring more real-world applicability to resilience, studies have identified key challenges that hinder effective resilience management. For example, Timpane-Padgham et al. (2017) conducted a systematic review of ecological attributes linked to climate change resilience and concluded that diversity and connectivity are keys to such resilience and that selecting appropriate spatial *scale* of management is a central challenge impacting management success. Scale was also identified as problematic in a case study review by Müller et al. (2016) and in a critical review of resilience assessment tools (Sharifi 2016), which further found that real-world applicability is hampered by failure of tools to engage stakeholders and address uncertainty.

Systems continually shift within a range of variability, making identification of stable *state* difficult, as highlighted in Seidl et al.'s (2016) discussion of variability of ecosystem services. Identifying social–ecological states—where the social and ecological traits of a state are clearly delineated—requires interdisciplinary research approaches and is rare (Rissman & Gillon 2016). In particular, engagement of stakeholders on the social side to describe a particular state requires values assessment to identify social aspects of a system's state and to detect state change (Seidl et al. 2016). Since both resource managers and stakeholders may only notice a state change when valued ecosystem traits or components are lost, a social–ecological approach to state identification may be inherently normative (i.e. values-based) (Batavia & Nelson 2016; Davidson et al. 2016; Kharrazi et al. 2016), although resilience is considered rather to be descriptive by many authors (e.g. Derissen et al. 2011) (e.g. a dictatorship or highly invaded ecosystem can be extremely resilient).

As mentioned above, although resilience in strict usage must be measured in real systems with reference to a particular *stressor*, it is often prescribed in management and policy as a more general desired characteristic of systems (e.g. a policy document defending the 2017 Resilient Federal Forests Act in the United States states that "Resilient forests better withstand drought, insects, disease, wildfire, and … climate change"; https://us11.campaign-archive.com/?e=&u=27a292edb3dc0c5b58adad795&id=0aaef32a56), and its measurement is hampered in empirical studies by interacting effects of multiple stressors simultaneously (Müller et al. 2016).

Without clear definition of desired values and states, resilience management *success* cannot be determined. That is, success is value-laden and these values must be acknowledged explicitly when assessing project outcomes (Batavia & Nelson 2016). Each manager must redefine resilience for each project (Kharrazi et al. 2016). This means that managers may measure resilience as convenient to their existing projects and priorities. Any outcome can then be deemed a success (Steelman & DuMond 2009).

In cases where stakeholders vary widely in values and viewpoints, it may be that retaining a certain vagueness of definition for resilience can help facilitate conversation, primarily because no viewpoint is dismissed. At the same time, decisions by a management entity to pursue specific actions require discussion and consensus regarding the specific components of resilience linked to those actions. We therefore suggest that, although disagreement may persist and be acknowledged (and honored) within a stakeholder group, a priori consensus regarding the definitions of the four key elements of resilience identified above, specifically as they link to particular restoration projects under consideration, is a critical operational step in resilience management. Prior to action, resilience management must (1) pinpoint the specific *stressors* to which resilience is sought; (2) identify the desired and current *states* of a system, as informed by management values; (3) define meaningful temporal and spatial *scales* of resilience management actions and targets; and (4) select clear social and ecological metrics of *success*. We have termed these essential elements *the 4S's*.

Managing for Resilience: The Importance of Conceptual Frameworks

The classical concept of ecological resilience was proposed by Holling (1973) to measure the ability of ecological systems to retain their basic characteristics in spite of perturbations. The terms "inertia" (Westman 1978, 1985, 1986) and later "resistance" were used to describe a system's ability to absorb perturbations without changing state, distinct from resilience as an ability to return to a previous stable state following a perturbation (Lake 2012). However, the distinction between resistance and resilience was not universally accepted (perhaps in part because social resistance is defined very differently; e.g. Knowles & Linn 2004) and resilience as used today may exclude or include resistance. (We hereafter exclude resistance from our discussion of resilience, because we are responding to challenges inherent in resilience management, focusing on recovery from perturbation.) The characteristics of a given ecological system at any particular time define its "state," yet this is open to interpretation (Scheffer & Carpenter 2003). A state may be defined ecologically by species assemblages or ecological functions, or socially by conventional practices and norms (Jerneck & Olsson 2008). In the social realm, valued system traits can differ according to culture, economic condition, ethnic identity, and so on (Olsson et al. 2015). This makes it difficult to integrate resilience into conservation management that involves stakeholders with different perspectives, where, for example, one individual may contend that a system has changed state while another individual feels that it has not. Resilience measures the tendency of a system to return to its original stable state following such a change (Gunderson 2000). Restoration, by contrast, may be considered a deliberate management effort to return the system to a previous state to which it will not return on its own (Gunderson 2000).

Importantly, however, resilience describes current conditions. If a system has changed drastically (e.g. a grassland that has become an invaded shrubland), but is now likely to return to its new state following perturbations, it is a resilient system. Its past condition, although possibly dominated by native species, displayed limited resilience since the perturbation resulted in a state change to shrubland and the system did not recover to grassland. Thus, contrary to common usage, resilience may not always imply strong ecosystem health and high biodiversity (Suding et al. 2004; Zellmer & Gunderson 2009), and restoration may be necessary to overcome the resilience of the current, less desirable state (Wonkka et al. 2016).

To manage for resilience, it is necessary to bring reality to the abstract concept. Critical elements—stressors, state, scale, and success—must be defined. Following are two case studies in the conservation realm, illustrating the importance of these 4S's. In each case, different interpretations of "resilience" would yield different management decisions.

Case Study 1: Native Plant Pollination in a Hawaiian Dry Forest

In a 3-year study in dry forest Hawaii, we have found that few native pollinators are currently active in the system, and the majority of pollination is now carried out by non-native insects (these authors, unpublished data) (Fig. 1). Tasked with conserving native plant species and being "good stewards," land managers must consider the role of influential social elements, particularly species introductions, and resource management values. In doing so, the 4S's come to the fore.

If the ecological *state* here is defined by functions, it may be that no change in stable state has occurred. As long as pollination is occurring, the system would be considered resilient; loss of native pollinators has occurred, but the system recovered from this disturbance. If pollination declines, management may include support or introduction of pollinators (even non-natives). Because continued extinctions are unlikely to remove all pollination from the system, the system may be considered resilient. If state is defined by species assemblage, the system has entered a new stable state, with most pollinators being non-native. Managers may focus on preventing future state change. This may require tracking populations of individual species and restoring them through cultivation and rearing of native species. Depending on how managers define resilience components, they may arrive at very different management activities.

Meanwhile, the remaining S's are also at play. Because there is spatial heterogeneity in pollination, *scale* is important. Do managers restore native pollinators across the whole region, or is persistence in certain patches sufficient? Should they work on bolstering pollinator habitats at a broad scale or introducing and monitoring individual pollinator populations at fine scales? Does *success* signify that native plants are receiving pollination, that historic native plant/native pollinator relationships are restored across the landscape, that each species persists somewhere, or that native biodiversity is bolstered as much as possible in any form (a value for land managers and the public). Finally, in addition to the *stressor* of species extinctions, other stressors will dictate which management activities can be adopted. For example, invasive species have introduced novel predation and fire regimes to the region (D'Antonio & Vitousek 1992; Hanna et al. 2013), complicating future pollination management by impacting native pollinator populations as well as native, fire-susceptible plants; it may be necessary to remove some of these non-natives before attempting pollinator restoration. The four S's steer decision-making in this system by illuminating value systems.

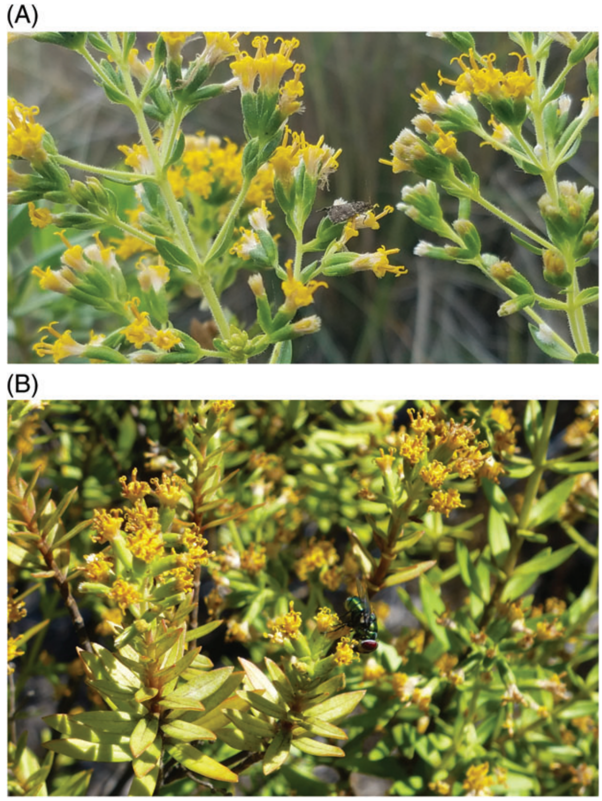

Figure 1. Flower visitors, (A) native *Mestalobes* sp. and (B) non-native *Chrysomya megacephala*, to the endemic *Dubautia linearis* in a high-elevation Hawaii dryland forest. Pollination in this system is almost exclusively being performed by non-native flower visitors, resulting in a functioning ecosystem with a novel species assemblage and raising the question of whether a new ecological *state* has emerged in this system. Depending on the definition of the *state*, it may be that the key *stressor* is native species extinctions or non-native species invasion, and it may be that *success* would emerge from fine-*scale* species-level management or from broad-*scale* habitat restoration or the existence of functional pollination networks. Careful consideration of each of the 4S's is essential to select management activities and evaluate their outcomes.

Case Study 2: Fire in Southwestern U.S. Forests

Fire-adapted forests of the southwestern United States exemplify an inherently social–ecological system. Historically, fire was a management tool of Native American communities (Keeley 2002). Anthropogenic fire exclusion and suppression began around the turn of the twentieth century, leading to fuels accumulation (Pyne 1982; Fulé et al. 1997). Today, human population in the region is increasing rapidly as people move to the area for its recreational opportunities and shady forests. Heavy fuels can lead to high-severity, stand-replacing fires (e.g. Swetnam et al. 2016), threatening both human infrastructure and the dense forests preferred by regional residents. To prevent such fire-driven state change, landowners and managers may employ logging, thinning, or continued fire suppression, all of which impact ecosystem functions (Baker 1994; Forman & Alexander 1998; Lindenmayer & Noss 2006).

The Four Forests Restoration Initiative (4FRI) in Arizona is a collaboration among four national forests to restore the structure of ponderosa pine forests as they appeared before systematic fire exclusion (https://www.fs.usda.gov/4fri). Considered the largest restoration effort of its kind, 4FRI involves intensive management (Sánchez Meador et al. 2015; Odion et al. 2016). The 4 S's are fundamentally tied to decision-making. If *state* is defined by ecological function (frequent, low-severity fires), then reduction in high-severity fires may be an important indicator of *success*. On the other hand, if the desired *state* is the current, socially valued, dense forests, then thinning and burning intended to reduce fuels could result in change to a novel social–ecological state, disliked by some stakeholder groups (Butler 2013; Butler et al. 2015). *Stressors* are similarly subject to perception: whereas this and similar projects are framed as a response to the stressor of high-severity fire, these efforts facilitate timber harvest (Egan et al. 2015), a stressor with different implications. Climate change, another stressor, elevates the risk of high-severity fire across the region and raises the urgency of management in spite of the socio-ecological complexity involved. Finally, the *scale* of planned treatment in this case is enormous, but management resources may be insufficient to meet the original objectives, resulting in smaller spatial and larger temporal scales. Depending on how the 4 S's are identified and how stakeholders are engaged, treatments may proceed in discrete locations or across the full area, and sites may be prioritized based on timber or climate considerations or local resident values, leading to different restoration processes and outcomes.

Recommendations: Operationalizing Resilience for Conservation Objectives

In light of the conceptual gaps that have been identified in resilience literature, as well as our real-world experience with the two case studies, we suggest that resilience management begin with a pre-established planning process by which managers address the 4 S's explicitly as they relate to the focal management activity (Fig. 2). Before management projects are initiated, planners must first identify the specific *stressors* to which resilience management is responding (Fig. 2). Then, we recommend that planners undergo brainstorming and prioritization (e.g. Pert et al. 2013) to identify the ecological and social characteristics that define the *state* of the system they desire to protect (Fig. 2). This form of planning engages stakeholders and has been effectively trialed in other contexts (e.g. Sisk et al. 2006; Newig & Koontz 2014; Stortz 2014). There are likely various paths by which management can protect desired social–ecological states, so the successful planning process identifies the values driving those paths. Third, planners should discuss realistic *scale* (Fig. 2). Spatial scale may be limited by jurisdictional boundaries, as in the first case study above, or could be regional, as in the second case study above. Temporally, over what timescale must planners achieve success? This may be dictated by policy, political transitions, or the timescales at which stressors operate. Finally, the planners select metrics of *success* (Fig. 2). What system traits must be regained following perturbations for the system to be considered resilient? It is tempting to wait to define success until after management actions have been implemented, but this creates the risk that success is universally declared and inferior strategies perpetuated. Notably, this applied planning process does not require all stakeholders to be in broad agreement about every aspect of resilience; indeed, there may be many perspectives and interpretations of resilience within the stakeholder group. Rather, we propose that managers apply this process to the specific management focus at hand, such that consensus regarding the 4S's is reached and they are clearly defined as they relate to the management activity.

After this applied resilience planning process has been completed, managers may select resilience strategies in line with the elements they identified for the 4 S's. This may, for example, include directing restoration resources toward sites that have high value and low inherent resilience. This also may entail implementing different management activities at different sites; for example, in the 4FRI case study described above, dramatic forest thinning may be appropriate in some fire-prone areas but unacceptable in other sites where stakeholders' economic activities depend on thick forests. As with classic adaptive management, this planning process may be used again to evaluate whether ongoing management continues to address the most pressing stressors, the most valued state, and the most practical scales, and whether it is yielding success. Corrections in management following such review (a process known as double-loop learning) (Petersen et al. 2014) can help this applied resilience planning process meet conservation objectives. Community-based adaptation requires resilience in economic, ecological, and cultural realms simultaneously (Ensor et al. 2018); a state change in any will affect and may derail the others. Recognizing that social systems are intertwined with the natural environment is essential (Farley & Voinov 2016). To respect the complexity of social systems, it is important to acknowledge that multiple viewpoints exist and that agreements reached for one management decision will not necessarily transfer to the next; continued revisiting of the 4S's will be necessary over time.

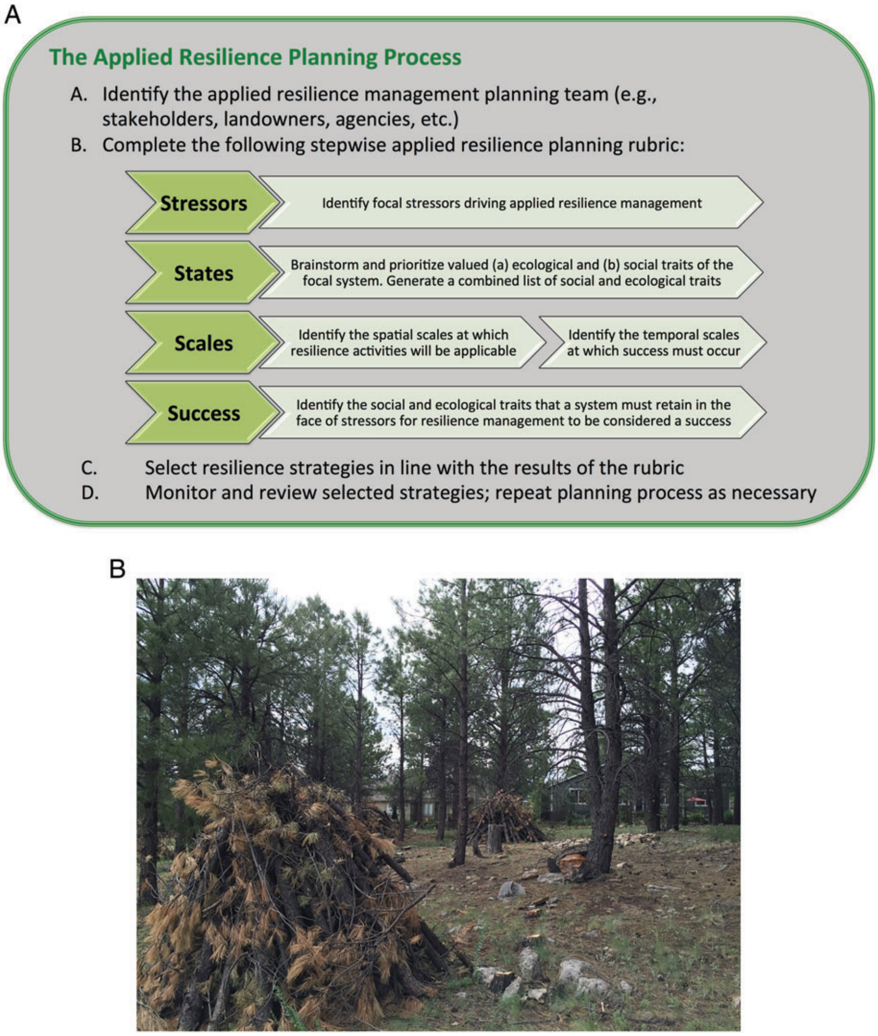

Figure 2. Applied resilience planning process. (A) A careful examination of the 4S's of applied resilience is necessary in order to select resilience planning strategies that will enhance resilience of a valued social–ecological state. Note that stage D of the process suggests monitoring and review, with a plan to repeat the process as necessary following adaptive management principles. (B) Thinning treatments such as those utilized in case study 2 provide a real-world illustration of the elements essential to applied resilience planning. The social–ecological *state* consists of dense forests at risk of high-severity fire (a major *stressor*) following decades of fire suppression, but private property owners value these cool, shady forests, leading to social–ecological tension about the *scale* at which thinning should occur and the *state* forest characteristics that would represent *success*. Under circumstances such as these, a priori identification by stakeholders of each of these elements (mutual understanding of the stressor, desired forest state, appropriate and feasible scale, and metrics of success) is essential before management activities can occur.

Resilience has been used in a largely abstract fashion (Martin 2004; Standish et al. 2014; Hosseini et al. 2016), making it easy to insert into policy without contributing meaningfully to conservation of valued systems or resources. We recommend that resilience planners adopt an applied resilience planning process by which every resilience management effort begins with deliberate delineation of the stressors, system states, scales, and metrics of success that are applicable to the project and its objectives.

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