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Developing biocultural indicators for resource management

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Abstract

Resource management and conservation interventions are increasingly embracing social–ecological systems (SES) concepts. While SES frameworks recognize the connectedness of humans and nature, many fail to acknowledge the complex role of sociocultural factors in influencing people's interactions with the environment. As such, when indicators in SES frameworks are used to measure the social dimension, easy to measure, socioeconomic indicators are the norms, while more complex social and cultural indicators are rare. To develop meaningful indicators of resilience in SES we need to understand local definitions of resilience. In this paper we describe methods used in a biocultural approach to illuminate sociocultural factors that Pacific Islanders identify as important for resilient communities. We focus specifically on two dimensions of sociocultural factors, "Connectedness to People and Place" and "Indigenous and local knowledges, skills, practices, values and worldviews," which relate to many interventions, but are not usually monitored. We offer examples of indicators that may be appropriate to measure under these dimensions. Increased use of biocultural indicators will bring additional insight on the types and combinations of indicators that work best in given contexts.

KEYWORDS

biocultural approaches, conservation, indicators, Pacific Islands, place-based communities, social–ecological resilience, social–ecological systems

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1 | EXISTING SES FRAMEWORKS REQUIRE ADDITIONAL SOCIOCULTURAL DETAIL

Interventions designed to support natural resource management, sustainable development, and conservation (hereafter simply referred to as interventions) are the result of human decision-making. However, those engaging in decision-making may have different values and worldviews from the individuals and/or communities who may be affected by the intervention. Interventions that do not acknowledge the connections between social and natural dimensions often fail (E. Sterling, Ticktin, et al., 2017; Waylen, Fischer, Mcgowan, Thirgood, & Milner-Gulland, 2010; West, 2006). Social–ecological systems (SES) approaches acknowledge the fundamental interlinkages between humans and nature and have gained substantial traction in resource management and conservation discourse in recent years (Hicks et al., 2016). SES concepts describe how social and ecological elements influence each other, by recognizing the interdependence of humans and their biophysical surroundings and their complex interactions, including reciprocal feedbacks (Binder, Bots, Hinkel, & Pahl-Wostl, 2013; Liu et al., 2007). SES approaches are particularly valuable, as they can highlight patterns that are not apparent with single disciplinary approaches, and these may offer important insights for conservation (Liu et al., 2007).

SES research often seeks to better understand social–ecological resilience, or the ability for SES to adapt or transform in order to maintain overall function in the face of change (Folke, 2006). Resilience thinking has gained interest as SES face unprecedented social, economic, environmental, and climate change. Although scholars such as Ban et al. (2013) claim that greater use of SES frameworks will improve interventions, few examples exist that demonstrate how SES frameworks were successfully used during planning.

While SES approaches have made significant progress, critics nevertheless claim that they tend to treat the social and ecological as "separate-but-connected" components, which in turn may reproduce and maintain a false dichotomy between the two (Lauer, 2016). Instead, Lauer (2016) proposes a "humans-in-nature" conception of the relationship, which acknowledges that all organisms are interdependent and that their connections lead to the codevelopment of both nature and culture. This conceptualization is compatible with the worldviews of diverse communities, including those of many Indigenous peoples (Strathern, 1980), whose place-based ecological expertise is increasingly recognized for its contributions to resource management and conservation science (Berkes, 2017).

Several frameworks have been developed to examine SES (Binder et al., 2013). By focusing on tangible interactions between humans and environment, many SES frameworks ignore other processes and relations that mediate human–nature interactions, such as power relations and cultural beliefs and values (Cote & Nightingale, 2012). A systematic review of community-based conservation case studies found that interventions incorporating the local cultural context were more likely to succeed than those that did not (Waylen et al., 2010). This suggests that the criticisms of SES frameworks do indeed point to true limitations of current interventions. Although these criticisms have been widely echoed (Fabinyi, Evans, & Foale, 2014; McKinnon et al., 2016; Stojanovic et al., 2016), the limitations of SES frameworks have yet to be fully resolved.

Given that many resource management and conservation projects are planned and implemented by natural scientists, it is not surprising that sociocultural factors have been largely left out of intervention planning. Intervention planning needs to consider the multidimensional dynamic of human relationships to nature (especially those that incorporate culture or that are not tangible) to identify locally appropriate sociocultural components important for conservation and/or resource management. Then, indicators can be developed for such components and the most appropriate approaches for measuring these indicators can be determined. This process is best done using a diverse range of knowledge sources including local knowledge and social science (Bennett et al., 2017).

In the cases where social factors have been included, relatively easily quantified characteristics that are socioeconomic rather than sociocultural are often selected at the expense of being inadequate and/or inappropriate for the local cultural context (E. J. Sterling, Filardi, et al., 2017; Stojanovic et al., 2016). For example, "material assets" is an easily measured indicator, commonly used as a proxy for wealth (McClanahan et al., 2008), yet may not be locally recognized as such (Copestake, Guillen-Royo, Chou, Hinks, & Velazco, 2009). Similarly, social capital is commonly measured as the number of community groups a household is a part of (McClanahan et al., 2008), yet may not account for more common and/or more significant other forms of social connections, such as resource sharing or informal cooperation (Nanau, 2011). Additionally, measures

of education tend to focus on the level of formal schooling (Béné et al., 2016), which excludes informal or non-Western modes of knowledge transmission that play a critical role in childhood development and learning (Lancy, 1996; McCarter & Gavin, 2011).

The Millennium Ecosystem Assessment (2005) identified Cultural Ecosystem Services (CES) that may include sociocultural components important to SES, such as "Cultural Heritage Values" and "Sense of Place." However, for reasons similar to those mentioned earlier, ecosystem service assessments have for the most part excluded intangible, meaningful CES (Chan, Satterfield, & Goldstein, 2012). Efforts have been made to mold and add to CES categories based on the experiences of local communities in order to identify the CES most relevant for inclusion (Breslow et al., 2016; Pascua, McMillen, Ticktin, Vaughan, & Winter, 2017; Raymond et al., 2009).

Lessons can also be learned from the well-being field, where considerable progress has been made in measuring indicators of well-being for assessing outcomes of interventions (McKinnon et al., 2016). While well-being outcomes have largely been assessed by economic or other material wealth indicators, there are accepted categories of well-being that include sociocultural components such as "Culture and Spirituality" and "Social Relations" (McKinnon et al., 2016). Kaplan-Hallam and Bennett (2018) highlight broad topics under each well-being category that potentially relate to interventions. There have been considerably fewer efforts devoted to actually developing and testing specific indicators that measure sociocultural components deemed relevant to place-based communities. To make indicators context specific, Fabinyi et al. (2014) suggest engaging people on the ground.

In this paper, we ask: What are the relevant sociocultural factors that influence resilience and how can such factors be measured? We present a sample methodology that provides a general road map for how resource managers and conservation practitioners can work with place-based communities to understand the cultural and social factors important to consider when designing interventions. We propose that biocultural approaches are most appropriate for such purposes. Gavin et al. (2015) define biocultural approaches to conservation as "conservation actions made in the service of sustaining the biophysical and sociocultural components of dynamic, interacting, and interdependent social–ecological systems." E. J. Sterling, Filardi, et al. (2017) describe biocultural approaches as starting with and building upon local cultural perspectives to fill existing gaps in indicators required to measure locally defined definitions of success. Biocultural approaches, while still far from being normalized practices, are becoming more common in intervention planning globally (Ens et al., 2015; Maffi & Woodley, 2010; Singh, Pretty, & Pilgrim, 2010). The approach can help develop locally appropriate indicators by identifying sociocultural components linked to resource use that are currently missing from most SES frameworks (Gavin et al., 2015; E. J. Sterling, Filardi, et al., 2017). We use sociocultural to be inclusive of both social and cultural factors including worldviews, values, traditions, and behaviors.

We focus on Pacific Islands, in which Indigenous Pacific Islander communities have been established for centuries or millennia (Kirch, 2017). Across the Pacific, species endemism is high, but biodiversity has experienced considerable decline and extinction due to habitat loss and degradation, invasive species, overexploitation, pollution, disease and human-forced climate change (Jupiter, Mangubhai, & Kingsford, 2014). The Pacific Islands have a long history of both natural and social disturbances, making them especially suited for understanding how social–ecological resilience has been maintained over time (Campbell, 2015). Like many Indigenous communities globally, many Pacific Island worldviews do not conceive of human and nonhuman or natural domains as fundamentally separate (Caillon, Cullman, Verschuuren, & Sterling, 2017; Pyke et al., 2018; Strathern, 1980). Further, it is increasingly acknowledged that Indigenous values, including Pacific Island values, are not equitably recognized in existing frameworks and as such, ecosystem relationships, benefits, and services are not accurately assessed (Jackson, 2006). Thus, an effective understanding of the social–ecological links in these worldviews is vital for intervention success in this region with implications elsewhere.

2 | IDENTIFYING SOCIOCULTURAL COMPONENTS IMPORTANT FOR RESOURCE MANAGEMENT

We assembled a working group (including authors on this paper) to use biocultural approaches for understanding local definitions of resilience in order to develop appropriate indicators of sociocultural factors. Our first activities involved planning and piloting methods to be used in workshops throughout the region (Figure 1, Step 1). We piloted our methods in the Solomon Islands and French Polynesia and refined techniques for prompting participants to think about what resilient communities look like in their places. We conducted six workshops in Fiji, Hawai'i, the Marshall Islands, Solomon Islands, and French Polynesia (Figure 1, Steps 2 & 3). We chose these locations because of existing relationships with local researchers and/or communities. Our sampling design was purposive (Babbie, 2012), in that we invited participants with personal or professional experience in community-based natural resource management and/or local culture (Figure 1, Step 1). The number of participants

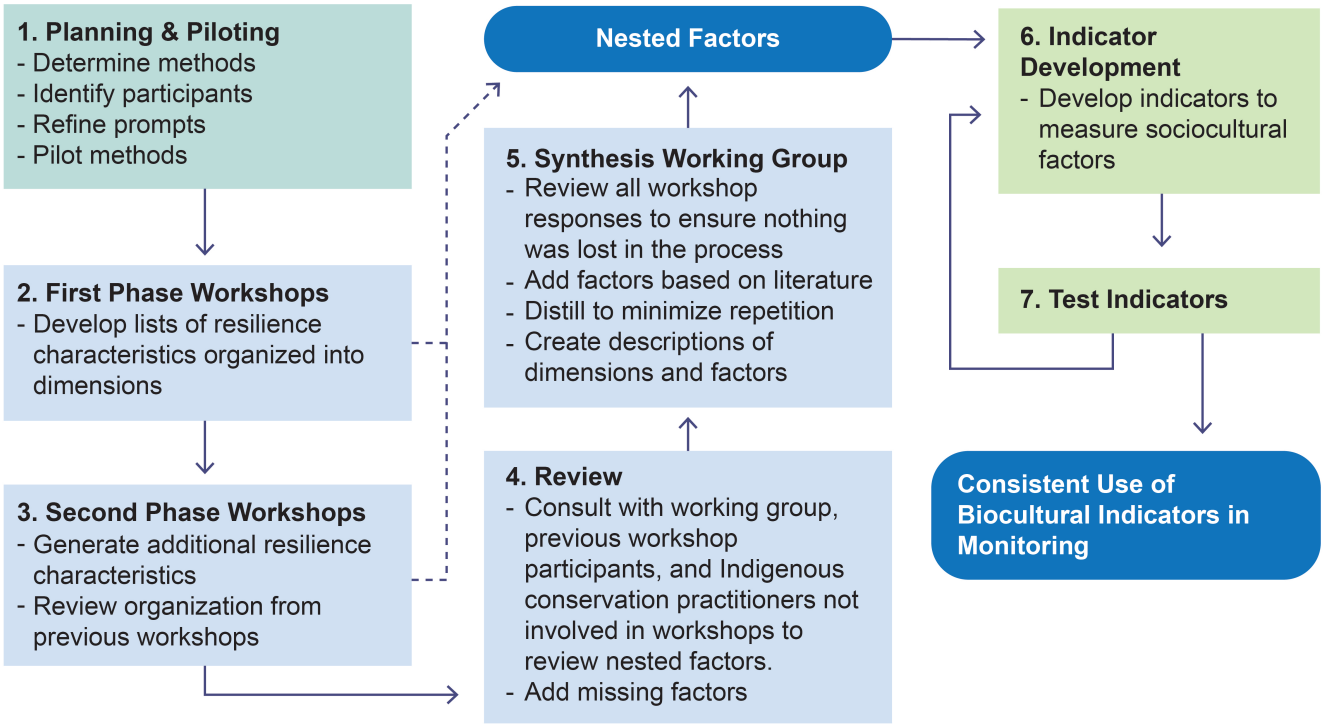

FIGURE 1 Iterative process used to develop the nested factors and biocultural indicators. This paper documents our progress through step six. Example indicators are presented in Table 1 and are currently being tested (step 7)

ranged from 4 to 34 and included a combination of cultural practitioners, government and nongovernmental organization employees, and university students and faculty from the host countries as well as countries across the region, including Vanuatu and Papua New Guinea (see Table S1 for more details about participants in each step).

We used grounded theory methods (Strauss & Corbin, 2008) in a participatory approach (Dick, 2003). In each workshop, we asked participants to free list (Bernard, 2011) characteristics of resilient Pacific Island communities (Figure 1, Step 2). Because resilience is a complex concept, we used a variety of locally relevant questions to approach the concept, with all interpretations of resilience incorporating ideas of environmental sustainability and long-term human well-being. For example, in Hawai'i, we asked participants what *ʻāina momona* (literally translates to "fat land," and represents a concept of abundant resources) looks like in their places.

After creating a free list of resilience characteristics, workshop participants combined their responses and developed dimensions in which all the characteristics could be grouped. The development of dimensions and categorization of responses was done first in small groups and then with all participants of the workshop as an open plenary. We found that having participants create and name dimensions promoted further brainstorming; once dimensions were named, participants thought of additional characteristics that could also be included. In addition, by having participants do the categorizing, we avoided analyzing responses through our filters as outside researchers (Saldaña, 2009). Our method was iterative; we built upon our findings by giving participants in later workshops the dimensions that were developed in previous workshops, had them evaluate whether they agreed with these dimensions, and whether their responses could be classified within them (Figure 1, Step 3).

After workshops were completed, we (i.e., authors of this paper) coded the responses, in order to group them into more general factors and so that our findings from each workshop could be compiled (Figure 1, Step 4). For example, *laulima* (Hawaiian), *solesolevaki* (Fijian), and *lale dron* (Marshallese) all represent similar concepts of "Cooperation and social cohesion" and were thus coded as such under the dimension "Connectedness to people and place." The code for responses that were not specific to a certain context was generally identical to the original response (e.g., transmission of knowledge between generations, access to healthcare, abundant resources).

The resulting dimensions and underlying factors were reviewed by a broader group including the authors of this paper, participants from our workshops, and other Indigenous and non-Indigenous conservation professionals who were not involved in the previous steps (Figure 1, Step 4). Several factors were added in this step under the established dimensions. Finally, a subset of the working

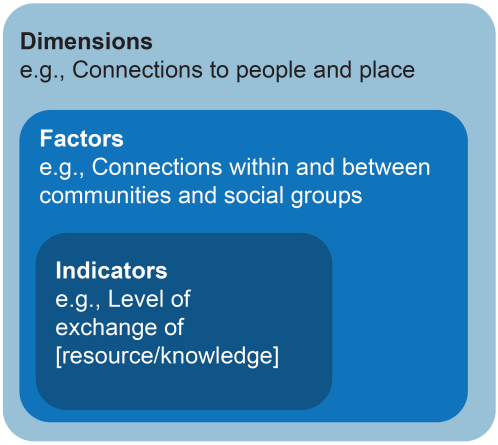

FIGURE 2 Illustration of the nested indicators and factors (adapted from Breslow et al., 2016). A list of the eight dimensions and 93 underlying factors can be found in Table S2. Example indicators are in Table 1

group reviewed all workshop responses to ensure nothing was lost in the iterative process, added factors based on the published literature, further distilled the factors to minimize repetition, and created descriptions of the resulting eight dimensions and 93 underlying factors (Figure 1, Step 5). This synthesis group also began collecting case studies and literature that support and further describes the sociocultural factors.

The dimensions and nested factors (Figure 2) can be found in the Supporting Information (Table S2). In a region as vast and diverse as the Pacific Islands, we acknowledge that the participants were not representative of all communities or stakeholders and as such, consider the nested factors as a reference that will continually evolve over time as we attain additional feedback. However, the general themes that emerged from the workshops and follow-up reviews are consistent with those documented in the literatures of anthropology, sociology, and geography across the region. Moreover, as we reached further in our process, we found that suggested changes to our nested factors were fewer, indicating to us that we were close to theoretical saturation (Bernard, 2011), and at a point at which our work was fit for sharing more broadly.

Once the nested factors were established, we identified select sociocultural factors for which we were unaware of well-established, existing indicators (Figure 2). Based on the responses from the workshops, and our previous knowledge, we then developed indicators to measure the status of these sociocultural factors (Table 1, Figure 1, Step 6). Several authors of this paper have been and/or are currently involved in testing a number of biocultural indicators in projects throughout the Pacific (Figure 1, Step 7).

3 | LOCAL PERCEPTIONS OF KEY COMPONENTS OF RESILIENT SOCIAL–ECOLOGICAL SYSTEMS

All the workshop responses could be grouped under one or more of the following dimensions: (a) Environmental state, (b) Access to natural and cultural resources, (c) Sustainability management, (d) Connectedness to people and place, (e) Indigenous and local knowledges, skills, practices, values and worldviews, (f) Education, (g) Human health, and (h) Access to infrastructure, civic services, and financial resources (Table S2). Many of the responses were cross-cutting and could be organized into more than one dimension. While it may appear there are dimensions that could be condensed, we kept them distinct to represent specific outcomes of our workshop process.

It is not essential to measure every factor in a given dimension. Dimensions are important because, while each underlying factor may not be important to every community, there are a number of factors from each dimension that do apply broadly. For example, certain practices (e.g., transmission of traditional stories, songs, chants, and dances) under the "Indigenous and local knowledges, skills, practices, values and worldviews" dimension may be considered inappropriate to address if they are not in line with the current religious context. Similarly, while "activism in maintenance of place" in the "Connection to People and Place" dimension was powerfully discussed in a couple of the workshops, it is not a factor that surfaced in all workshops and may not resonate with all communities.

These dimensions appear to be quite similar to the CES categories (Millennium Ecosystem Assessment 2005). However, upon looking further at the nested factors, differences arise, especially within the "Social relations" and "Sense of place" categories that appear most similar to our "Connection to people and place" dimension. Similar to the findings of Pascua et al. (2017), we found that respondents highlighted the reciprocal nature of relationships with human and nonhuman, and living and nonliving entities, an aspect not captured in these established CES categories.

Factors in our "Connection to People and Place" and "Indigenous and local knowledges, skills, practices, values and worldviews" dimensions are consistent with key cultural elements previously identified as lacking from existing SES and CES frameworks (Chan et al., 2012; Cote & Nightingale, 2012; Pascua et al., 2017). As such, we focus on these two dimensions and explain why they are significant in designing and implementing interventions (Table 1). The factors within these two dimensions along with the remaining dimensions, are not necessarily inherently beneficial for conservation and resource management, per se. In other words, their incorporation into planning will not always result in win–win situations and may imply social and ecological trade-offs (Table 1).

TABLE 1 Four sociocultural factors, descriptions of their links to interventions (e.g., conservation, natural resource management, etc.) and corresponding sample indicators. The first two sociocultural factors are classified under Dimension D, "Connectedness to people and place" and the latter two are in Dimension E, "Indigenous and local knowledges, skills, practices, values and worldviews." A full list of dimensions and nested factors can be found in Table S2

Example sociocultural factor	How factor is linked to interventions	How interventions are impacted by factor	How factor can be impacted by intervention	Example indicators	Type of indicator
Connections within and between communities and social groups	Individuals and groups share natural resources and knowledge about natural resources (Bodin, Crona, Thyresson, Golz, & Tengö, 2014)	Knowledge about both sustainable and unsustainable practices can be shared between individuals and groups	If intervention is successful, it can result in additional resources to be shared, potentially maintaining networks. However, interventions may inhibit sharing if harvesting is restricted and connections/networks may be threatened	Perceptions of adequacy of exchange networks of natural resources	Perception
				Level of exchange of [resource/knowledge]	Practice
Knowledge and practice of social and cultural norms related to place-based practices	Harvesting particular resources in particular ways, observing spiritual prohibitions, and transmitting knowledge of specific sites, are all examples of cultural norms that may be associated with specific places (Poepoe, Bartram, & Friedlander, 2007)	If intervention is in line with norms, the intervention is likely to benefit from local support, but if it goes against norms, it is not likely to be supported	If intervention is in line with cultural norms, the intervention can help perpetuate cultural norms related to place-based practices. Cultural norms can be threatened when an intervention is not in line with the norms	Perceptions of the degree to which community members follow [locally appropriate cultural norm]	Perception
				Knowledge of places forbidden for certain persons (e.g., gender, matriclans, family) or certain behaviors	Knowledge
Knowledge and practice of stories, songs, chants, and dance	Language and knowledge about species/ecology may be embedded in cultural performances (Fernández-Llamazares & Cabeza, 2017)	If intervention addresses species/places/ecologies that are mentioned in performances, resource users may be more able to see how intervention is linked to their lives and cultures	If intervention restricts access to resources and/or places, over time, knowledge of that species/place/ecology may dwindle, negatively impacting opportunities for practice of related cultural performances	Trend in the number of people who carry out or perform [a locally important cultural performance with embedded local ecological knowledge]	Practice
				Knowledge of appropriate conditions to engage in cultural performance	Knowledge
Innovation in knowledge and practice based on tradition	New knowledge may develop based on how resources respond to increased harvests or changing environmental or climatic conditions, or new technology. Traditional practices may adapt to correspond with new knowledge (Ticktin, Whitehead, & Fraiola, 2006)	Interventions can be informed by local innovations	Interventions can be the source of new knowledge to guide innovation based on tradition	Attitude according to statement: "Our observations and new knowledge are used to adapt our cultural practices in order to respond to changing environmental and social conditions"	Perception
				Presence of traditional resource use rules or protocols adapted to changing environmental or other conditions	Practice

However, the long-term success of any intervention is more likely when sociocultural factors have been considered.

3.1 | Connectedness to people and place

While Ostrom (2009) and others have comprehensively shown the importance of social cohesion to foster collective action for sustainable management of resources, responses in our workshops were often related to the many types of relationships that can exist between individuals, households, and communities and the maintenance of these relationships. Thus, connection to people is related to resource management not only for reasons of collective action, but also because many relationships are based on the circulation of natural resources (e.g., food, planting materials, land) within and between generations, families, and communities. Further, respondents highlighted that connections to people may not always refer to living beings, but could also refer to ancestors, including manifestations of ancestors in living and nonliving components of ecosystems.

"Connectedness to nature" and "sense of place" are two concepts that can explain how connectedness to place is important for social–ecological resilience (Ives et al., 2017; Masterson et al., 2017; Restall & Conrad, 2015). In regions like the Pacific Islands, where even the most recently established communities have been in place for centuries or millennia, connectedness to place is often informed and driven by knowledge of genealogy, historical events, and multi-generational experiences of survival and thriving in place (Morishige et al., 2018). Understanding people's relationship to nature and place is important because such relationships may influence behavior. Connectedness to place may encourage stewardship if people share common values of a place (Chapin & Knapp, 2015). Human-nature connection studies have increased exponentially in the past decade, but most have taken place in Western countries (Ives et al., 2017) and methods and indicators to measure people's connection to place have yet to be well developed (Masterson et al., 2017).

3.2 | Indigenous and local knowledges, skills, practices, values, and worldviews

Indigenous and local knowledge, skills, practices, values and beliefs, related to environmental and ecological states, and resource management, are dynamic, adaptive, and transmitted across and between generations (Bambridge, 2016; Berkes, 2017; Maffi, 2001). They are embedded within a worldview and ethos, and often include spiritual connections to place, including to specific species and landscapes. While factors in this dimension may be linked to conservation, this does not imply that a conservation ethic existed in the past or is a traditional practice (Foale, Cohen, Januchowski-Hartley, Wenger, & Macintyre, 2011). Many of the factors under the "Indigenous and local knowledges, skills, practices, values and worldviews" dimension have been recognized as important aspects in SES (Folke, Colding, & Berkes, 2003), yet they are not consistently developed into indicators for conservation planning purposes.

4 | EXAMPLE BIOCULTURAL INDICATORS

Biocultural indicator development is a complex process that often involves weaving across different worldviews (Austin et al., 2018; E. J. Sterling, Filardi, et al., 2017; Tengö et al., 2017). Since opportunities for communities to participate in indicator development are rare, creating space for communities to identify their resilience characteristics is valuable in itself, as it gives communities a chance to discuss their observations and goals, empowering them to chart their own path forward (McCarter et al., 2018). For example, the development of indicators with communities in Solomon Islands drove the documentation of medicinal plants as well as discussion of taro cultivation methods by previous generations. A set of products that were developed from these efforts sought to reinforce components of place-based well-being that were identified during indicator development.

Based on workshop responses and discussions, we developed a set of example indicators to show how the status of factors locally perceived to be integral to social–ecological resilience can be evaluated and monitored (Table 1). We offer example indicators that measure perceptions, knowledge, and practice (Table 1). Because perception is fundamentally hinged to cultural knowledge and experience (Munhall, 2008), assessing local perceptions may be a significant tool missing from many prior SES frameworks. Indigenous or local knowledge frame how local communities perceive the current state of, or relationships between past and present environmental or ecological contexts, or the status of living or nonliving resources within a context and influence human interactions with the environment (Conklin, 1955; Ingold, 2002). Assessments made by outsiders with different worldviews may be quite different than local perceptions and without perception indicators, vastly different conclusions may result (Bennett, 2016). In addition, perception indicators can allow for assessing individual or community responses to policy, management or governance related to changing environmental or ecological states, with an eye toward enhancing resilience, and sustainability in precarious and rapidly changing contexts (Bryant-Tokalau, 2018; Hermann & Kempf, 2017). Further, because perception indicators are subjective, they measure important dimensions of well-being (Breslow et al., 2016).

Changing contexts, whether related to changing social, ecological, and/or climatic conditions drive Indigenous knowledge systems (including associated cultural practices) to evolve over time (Berkes, 2017). As such, knowledge and practice not only serve as options in an individual and/or community's adaptive capacity portfolio, but also represent adaptation over time (Berkes, Colding, & Folke, 2003; Granderson, 2017). We note that although knowledge and practice indicators may appear similar, they measure different aspects. For example, just because an individual knows of their totem does not equate to them having an active relationship with that species.

While our indicators can serve as a starting point for use with place-based communities, indicators need to be locally adapted (even across communities in the Pacific Islands). For example, before asking about "religious or spiritual connections to entities," the types of connections that exist in the local context have to be known. In some communities in Fiji where totem species are locally relevant, questions about totem species worked well in our surveys. Thus, "trend in the number of people who know their totem species" could potentially be used as an indicator where relevant. In other communities in the Pacific, relationships with specific species may be uncommon or less relevant than a local equivalent of "religious or spiritual connections." When indicators are locally adapted, it is important that efforts are devoted to using appropriate terms in the local vernacular to ensure that indicators resonate with local communities.

In some cases, a biocultural approach can be used to determine how existing indicators can be adapted to become biocultural indicators. For example, a biocultural indicator may be the trend in harvest per unit effort of culturally important species. A similar indicator that is widely used in fisheries is catch per unit effort. In this case, the biocultural indicator may be a subset of what is already being collected and a biocultural approach would be needed to determine the culturally important species. This occurred in the Solomon Islands, where some of the authors have been engaged in participatory approaches with communities that include discussions on the connections between culture, food, and health. As a result of these efforts, communities have identified culturally important species of marine invertebrates that are now being monitored by local rangers as part of a marine resource management plan that was developed with a nongovernmental organization.

Due to the coupled nature of SES, some indicators measure both biophysical and sociocultural conditions, for example, the trend in the presence of certain types of local knowledge, such as the location of a certain species. If the knowledge about this species within a community changes over time, this may indicate change in species abundance and/or distribution, change in the frequency of use of this species, or a change in the transmission of this type of knowledge (Maffi, 2001, 2005; Maffi & Woodley, 2010). To tease out the problem of having an indicator potentially measuring multiple conditions, multiple indicators need to be analyzed together. For example, to identify the driver of the change in local knowledge of a species, one would need to ask about frequency of use of that species, actual or perceived change in that frequency, as well as transmission of knowledge, and perceived or actual change in transmission.

Another example of an indicator that may measure both biophysical and sociocultural conditions is "Level of exchange of a particular resource or type of knowledge within or across communities," an indicator of "Connections within and between communities and social groups" (Table 1). If this indicator is measured over time, the trend may indicate changing social conditions if households change their sharing behaviors. The indicator can also indicate a change in ecological state if there are fewer resources available to share. Some of the authors tested this indicator by asking about resource sharing within communities. The questions used to measure this indicator worked well in household surveys in Fijian communities. This study found differences in both levels of resource sharing and types of resources shared between urban and rural communities (Dacks, 2018). This indicator was also used to test for relationships to measures of marine resource use (Dacks, Ticktin, Jupiter, & Friedlander, 2018) and terrestrial biodiversity (Ticktin et al., 2018).

Biocultural indicators are beginning to be measured (Ens, Daniels, Nelson, Roy, & Dixon, 2016; Morishige et al., 2018; E. Sterling, Ticktin, et al., 2017) and with increased use will come additional insight on the types and combinations of indicators that work best in given contexts.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

R. D. drafted the manuscript. T.T. and A.M. assisted with the framing of manuscript. R.D., A.M., T.T., S.W., E.S., J.M., and P.P. worked on data analysis. All authors collected data and contributed to the manuscript writing.

DATA ACCESSIBILITY

Workshop responses are not made available due to their confidentiality. Aggregated responses in the form of factors are listed in the Supplementary Information.

ETHICS STATEMENT

This study was approved by the University of Hawai'i (CHS-20991) and the American Museum of Natural History (FWA00006768) Institutional Review Boards. All data was recorded anonymously with free and prior informed consent.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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