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## Developing biocultural indicators for resource manageme

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38 **ABSTRACT**

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

#### 54 **Existing SES frameworks require additional sociocultural detail**

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

69 SES research often seeks to better understand social-ecological resilience, or the ability for  
70 SES to adapt or transform in order to maintain overall function in the face of change (Folke  
71 2006). Resilience thinking has gained interest as SES face unprecedented social, economic,  
72 environmental, and climate change. Although scholars such as Ban et al. (2013) claim that  
73 greater use of SES frameworks will improve interventions, few examples exist that demonstrate  
74 how SES frameworks were successfully used during planning.

75 While SES approaches have made significant progress, critics nevertheless claim that they tend  
76 to treat the social and ecological as 'separate-but-connected' components, which in turn may  
77 reproduce and maintain a false dichotomy between the two (Lauer 2016). Instead, Lauer (2016)  
78 proposes a 'humans-in-nature' conception of the relationship, which acknowledges that all

79 organisms are interdependent and that their connections lead to the codevelopment of both  
80 nature and culture. This conceptualization is compatible with the worldviews of diverse  
81 communities, including those of many Indigenous peoples (Strathern 1980), whose place-based  
82 ecological expertise is increasingly recognized for its contributions to resource management and  
83 conservation science (Berkes 2017).

84 Several frameworks have been developed to examine SESs (Binder et al. 2013). By focusing on  
85 tangible interactions between humans and environment, many SES frameworks ignore other  
86 processes and relations that mediate human-nature interactions, such as power relations and  
87 cultural beliefs and values (Cote & Nightingale 2012). A systematic review of community-based  
88 conservation case studies found that interventions incorporating the local cultural context were  
89 more likely to succeed than those that did not (Waylen et al. 2010). This suggests that the  
90 criticisms of SES frameworks do indeed point to true limitations of current interventions.

91 Although these criticisms have been widely echoed (Fabinyi et al. 2014; McKinnon et al. 2016;  
92 Stojanovic et al. 2016), the limitations of SES frameworks have yet to be fully resolved.

93 Given that many resource management and conservation projects are planned and  
94 implemented by natural scientists, it is not surprising that sociocultural factors have been largely  
95 left out of intervention planning. Intervention planning needs to consider the multidimensional  
96 dynamic of human relationships to nature (especially those that incorporate culture or that are  
97 not tangible) to identify locally appropriate sociocultural components important for conservation  
98 and/or resource management. Then, indicators can be developed for such components and the  
99 most appropriate approaches for measuring these indicators can be determined. This process is  
100 best done using a diverse range of knowledge sources including local knowledge and social  
101 science (Bennett et al. 2016).

102 In the cases where social factors have been included, relatively easily quantified characteristics  
103 that are socioeconomic rather than sociocultural are often selected at the expense of being

104 inadequate and/or inappropriate for the local cultural context (Stojanovic et al. 2016; Sterling et  
105 al. 2017b). For example, “material assets” is an easily measured indicator, commonly used as a  
106 proxy for wealth (McClanahan et al. 2008), yet may not be locally recognized as such  
107 (Copestake et al. 2009). Similarly, social capital is commonly measured as the number of  
108 community groups a household is a part of (McClanahan et al. 2008), yet may not account for  
109 other forms of social connections that may be more common and/or more significant, such as  
110 resource sharing or informal cooperation (Nanau 2011). Additionally, measures of education  
111 tend to focus on the level of formal schooling (Béné et al. 2016), which excludes informal or  
112 non-Western modes of knowledge transmission that play a critical role in childhood  
113 development and learning (Lancy 1996; McCarter & Gavin 2011).

114 The Millennium Ecosystem Assessment (2005) identified Cultural Ecosystem Services (CES)  
115 that may include sociocultural components important to SES, such as “Cultural Heritage Values”  
116 and “Sense of Place”. However, for reasons similar to those mentioned earlier, ecosystem  
117 service assessments have for the most part excluded intangible, meaningful CES (Chan et al.  
118 2012). Efforts have been made to mold and add to CES categories based on the experiences of  
119 local communities in order to identify the CES most relevant for inclusion (Raymond et al. 2009;  
120 Breslow et al. 2016; Pascua et al. 2017).

121 Lessons can also be learned from the well-being field, where considerable progress has been  
122 made in measuring indicators of well-being for assessing outcomes of interventions (McKinnon  
123 et al. 2016). While well-being outcomes have largely been assessed by economic or other  
124 material wealth indicators, there are accepted categories of well-being that include sociocultural  
125 components such as “Culture and Spirituality” and “Social Relations” (McKinnon et al. 2016).  
126 Kaplan-Hallam and Bennett (2017) highlight broad topics under each well-being category that  
127 potentially relate to interventions. There have been considerably fewer efforts devoted to  
128 actually developing and testing specific indicators that measure sociocultural components

129 deemed relevant to place-based communities. To make indicators context specific, Fabinyi et al.  
130 (2014) suggest engaging people on the ground.

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

147 We focus on Pacific Islands, in which Indigenous Pacific Islander communities have been  
148 established for centuries or millennia (Kirch 2017). Across the Pacific, species endemism is  
149 high, but biodiversity has experienced considerable decline and extinction due to habitat loss  
150 and degradation, invasive species, overexploitation, pollution, disease and human-forced  
151 climate change (Jupiter et al. 2014). The Pacific Islands have a long history of both natural and  
152 social disturbances, making them especially suited for understanding how social-ecological  
153 resilience has been maintained over time (Campbell 2015). Like many Indigenous communities



154 globally, many Pacific Island worldviews do not conceive of human and non-human or natural  
155 domains as fundamentally separate (Strathern 1980; Caillon et al. 2017; Pyke et al. 2018).  
156 Further, it is increasingly acknowledged that Indigenous values, including Pacific Island values,  
157 are not equitably recognized in existing frameworks and as such, ecosystem relationships,  
158 benefits, and services are not accurately assessed (Jackson 2006). Thus, an effective  
159 understanding of the social-ecological links in these worldviews is vital for intervention success  
160 in this region with implications elsewhere.

161

### 162 **Identifying sociocultural components important for resource management**

163 We assembled a working group (including authors on this paper) to use biocultural approaches  
164 for understanding local definitions of resilience in order to develop appropriate indicators of  
165 sociocultural factors. Our first activities involved planning and piloting methods to be used in  
166 workshops throughout the region (Fig. 1, Step 1). We piloted our methods in the Solomon  
167 Islands and French Polynesia and refined techniques for prompting participants to think about  
168 what resilient communities look like in their places. We conducted six workshops in Fiji, Hawai'i,  
169 the Marshall Islands, Solomon Islands, and French Polynesia (Fig. 1, Step 2 & 3). We chose  
170 these locations because of existing relationships with local researchers and/or communities.  
171 Our sampling design was purposive (Babbie 2012), in that we invited participants with personal  
172 or professional experience in community-based natural resource management and/or local  
173 culture (Fig. 1, Step 1). The number of participants ranged from four to 34 and included a  
174 combination of cultural practitioners, government and non-governmental organization  
175 employees, and university students and faculty from the host countries as well as countries  
176 across the region, including Vanuatu and Papua New Guinea (see Table S1 for more details  
177 about participants in each step).

178 We used grounded theory methods (Strauss & Corbin 2008) in a participatory approach (Dick  
179 2003). In each workshop, we asked participants to free list (Bernard 2011) characteristics of  
180 resilient Pacific Island communities (Fig. 1, Step 2). Because resilience is a complex concept,  
181 we used a variety of locally relevant questions to approach the concept, with all interpretations  
182 of resilience incorporating ideas of environmental sustainability and long-term human well-  
183 being. For example, in Hawai'i, we asked participants what *'āina momona* (literally translates to  
184 "fat land," and represents a concept of abundant resources) looks like in their places.

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

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

202 response (e.g., transmission of knowledge between generations, access to healthcare,  
203 abundant resources).

204 The resulting dimensions and underlying factors were reviewed by a broader group including  
205 the authors of this paper, participants from our workshops, and other Indigenous and non-  
206 Indigenous conservation professionals who were not involved in the previous steps (Fig. 1, Step  
207 4). Several factors were added in this step under the established dimensions. Finally, a subset  
208 of the working group reviewed all workshop responses to ensure nothing was lost in the iterative  
209 process, added factors based on the published literature, further distilled the factors to minimize  
210 repetition, and created descriptions of the resulting eight dimensions and 93 underlying factors  
211 (Fig. 1, Step 5). This synthesis group also began collecting case studies and literature that  
212 support and further describe the sociocultural factors (Mawyer et al. forthcoming).

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

222 Once the nested factors were established, we identified select sociocultural factors for which we  
223 were unaware of well-established, existing indicators (Fig. 2). Based on the responses from the  
224 workshops, and our previous knowledge, we then developed indicators to measure the status of  
225 these sociocultural factors (Table 1, Fig. 1, Step 6). Several authors of this paper have been

226 and/or are currently involved in testing a number of biocultural indicators in projects throughout  
227 the Pacific (Fig. 1, Step 7).

### 228 **Local perceptions of key components of resilient social-ecological systems**

229 All the workshop responses could be grouped under one or more of the following dimensions:  
230 A) Environmental state, B) Access to natural and cultural resources, C) Sustainability  
231 management, D) Connectedness to people and place, E) Indigenous and local knowledges,  
232 skills, practices, values and worldviews, F) Education, G) Human health, and H) Access to  
233 infrastructure, civic services, and financial resources (Table S2). Many of the responses were  
234 cross-cutting and could be organized into more than one dimension. While it may appear there  
235 are dimensions that could be condensed, we keep them distinct to represent specific outcomes  
236 of our workshop process.

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

246 These dimensions appear to be quite similar to the CES categories (Millennium Ecosystem  
247 Assessment 2005). However, upon looking further at the nested factors, differences arise,  
248 especially within the “Social relations” and “Sense of place” categories that appear most similar  
249 to our “Connection to people and place” dimension. Similar to the findings of Pascua et al.

250 (2017), we found that respondents highlighted the reciprocal nature of relationships with human  
251 and non-human, and living and non-living entities, an aspect not captured in these established  
252 CES categories.

253 Factors in our CPP and ILK dimensions are consistent with key cultural elements previously  
254 identified as lacking from existing SES and CES frameworks (Chan et al. 2012; Cote &  
255 Nightingale 2012; Pascua et al. 2017). As such, we focus on these two dimensions and explain  
256 why they are significant in designing and implementing interventions (Table 1). The factors  
257 within these two dimensions along with the remaining dimensions, are not necessarily inherently  
258 beneficial for conservation and resource management, per se. In other words, their  
259 incorporation into planning will not always result in win-win situations and may imply social and  
260 ecological trade-offs (Table 1). However, the long-term success of any intervention is more  
261 likely when sociocultural factors have been considered.

#### 262 *Connectedness to people and place (CPP)*

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

273 “Connectedness to nature” and “sense of place” are two concepts that can explain how  
274 connectedness to place is important for social-ecological resilience (Restall et al. 2015; Ives et  
275 al. 2017; Masterson et al. 2017). In regions like the Pacific Islands, where even the most  
276 recently established communities have been in place for centuries or millennia, connectedness  
277 to place is often informed and driven by knowledge of genealogy, historical events, and multi-  
278 generational experiences of survival and thriving in place (Morishige et al. 2018). Understanding  
279 people’s relationship to nature and place is important because such relationships may influence  
280 behavior. Connectedness to place may encourage stewardship if people share common values  
281 of a place (Chapin & Knapp 2015). Human-nature connection studies have increased  
282 exponentially in the past decade, but most have taken place in Western countries (Ives et al.  
283 2017) and methods and indicators to measure people’s connection to place have yet to be well  
284 developed (Masterson et al. 2017).

#### 285 *Indigenous and local knowledges, skills, practices, values, and worldviews (ILK)*

286 Indigenous and local knowledge, skills, practices, values and beliefs, related to environmental  
287 and ecological states and resource management, are dynamic, adaptive and transmitted across  
288 and between generations (Maffi 2001; Bambridge 2016; Berkes 2017). They are embedded  
289 within a worldview and ethos, and often include spiritual connections to place, including to  
290 specific species and landscapes. While factors in this dimension may be linked to interventions,  
291 this does not imply that a conservation ethic existed in the past or is a traditional practice (Foale  
292 et al. 2011). Many of the factors under the ILK dimension have been recognized as important  
293 aspects in SES (Folke et al. 2003), yet they are not consistently developed into indicators for  
294 conservation planning purposes.

#### 295 **Example biocultural indicators**

296 Biocultural indicator development is a complex process that often involves weaving across  
297 different worldviews (Sterling et al. 2017b; Tengö et al. 2017; Austin et al. 2018). Since

298 opportunities for communities to participate in indicator development are rare, creating space for  
299 communities to identify their resilience characteristics is valuable in itself, as it gives  
300 communities a chance to discuss their observations and goals, empowering them to chart their  
301 own path forward (McCarter et al. 2018). For example, the development of indicators with  
302 communities in Solomon Islands drove the documentation of medicinal plants as well as  
303 discussion of taro cultivation methods by previous generations. A set of products that were  
304 developed from these efforts sought to reinforce components of place-based wellbeing that  
305 were identified during indicator development.

306 Based on workshop responses and discussions, we developed a set of example indicators to  
307 show how the status of factors locally perceived to be integral to social-ecological resilience can  
308 be evaluated and monitored (Table 1). We offer example indicators that measure perceptions,  
309 knowledge, and practice (Table 1). Because perception is fundamentally hinged to cultural  
310 knowledge and experience (Munhall 2008), assessing local perceptions may be a significant  
311 tool missing from many prior SES frameworks. Indigenous or local knowledge frame how local  
312 communities perceive the current state of, or relationships between past and present  
313 environmental or ecological contexts, or the status of living or non-living resources within a  
314 context and influence human interactions with the environment (Conklin 1955; Ingold 2002).  
315 Assessments made by outsiders with different worldviews may be quite different than local  
316 perceptions and without perception indicators, vastly different conclusions may result (Bennett  
317 2016). In addition, perception indicators can allow for assessing individual or community  
318 responses to policy, management or governance related to changing environmental or  
319 ecological states, with an eye toward enhancing resilience and sustainability in precarious and  
320 rapidly changing contexts (Hermann & Kempf 2017; Bryant-Tokalau 2018). Further, because  
321 perception indicators are subjective, they measure important dimensions of wellbeing (Breslow  
322 et al. 2016).

323 Changing contexts, whether related to changing social, ecological, and/or climatic conditions  
324 drive Indigenous knowledge systems (including associated cultural practices) to evolve over  
325 time (Berkes 2017). As such, knowledge and practice not only serve as options in an individual  
326 and/or community's adaptive capacity portfolio, but also represent adaptation over time (Maffi  
327 2001; Berkes et al. 2003; Granderson 2017). We note that although knowledge and practice  
328 indicators may appear similar, they measure different aspects. For example, just because an  
329 individual knows of their totem does not equate to them having an active relationship with that  
330 species.

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

342 In some cases, a biocultural approach can be used to determine how existing indicators can be  
343 adapted to become biocultural indicators. For example, a biocultural indicator may be the trend  
344 in harvest per unit effort of culturally important species. A similar indicator that is widely used in  
345 fisheries is catch per unit effort (CPUE). In this case, the biocultural indicator may be a subset of  
346 what is already being collected and a biocultural approach would be needed to determine the  
347 culturally important species. This occurred in the Solomon Islands, where some of the authors



348 have been engaged in participatory approaches with communities that include discussions on  
349 the connections between culture, food, and health. As a result of these efforts, communities  
350 have identified culturally important species of marine invertebrates that are now being monitored  
351 by local rangers as part of a marine resource management plan that was developed with a non-  
352 governmental organization.

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

363 Another example of an indicator that may measure both biophysical and sociocultural conditions  
364 is “Level of exchange of a particular resource or type of knowledge within or across  
365 communities,” an indicator of “Connections within and between communities and social groups”  
366 (Table 1). If this indicator is measured over time, the trend may indicate changing social  
367 conditions if households change their sharing behaviors. The indicator can also indicate a  
368 change in ecological state if there are fewer resources available to share. Some of the authors  
369 tested this indicator by asking about resource sharing within communities. The questions used  
370 to measure this indicator worked well in household surveys in Fijian communities. They found  
371 differences in both levels of resource sharing and types of resources shared between urban and  
372 rural communities (Dacks 2018). This indicator was also used to test for relationships to

373 measures of marine resource use (Dacks et al. 2018) and terrestrial biodiversity (Ticktin et al.  
374 2018).

375 Biocultural indicators are beginning to be measured (Ens et al. 2016; Sterling et al. 2017a;  
376 Morishige et al. 2018) and with increased use will come additional insight on the types and  
377 combinations of indicators that work best in given contexts.

378

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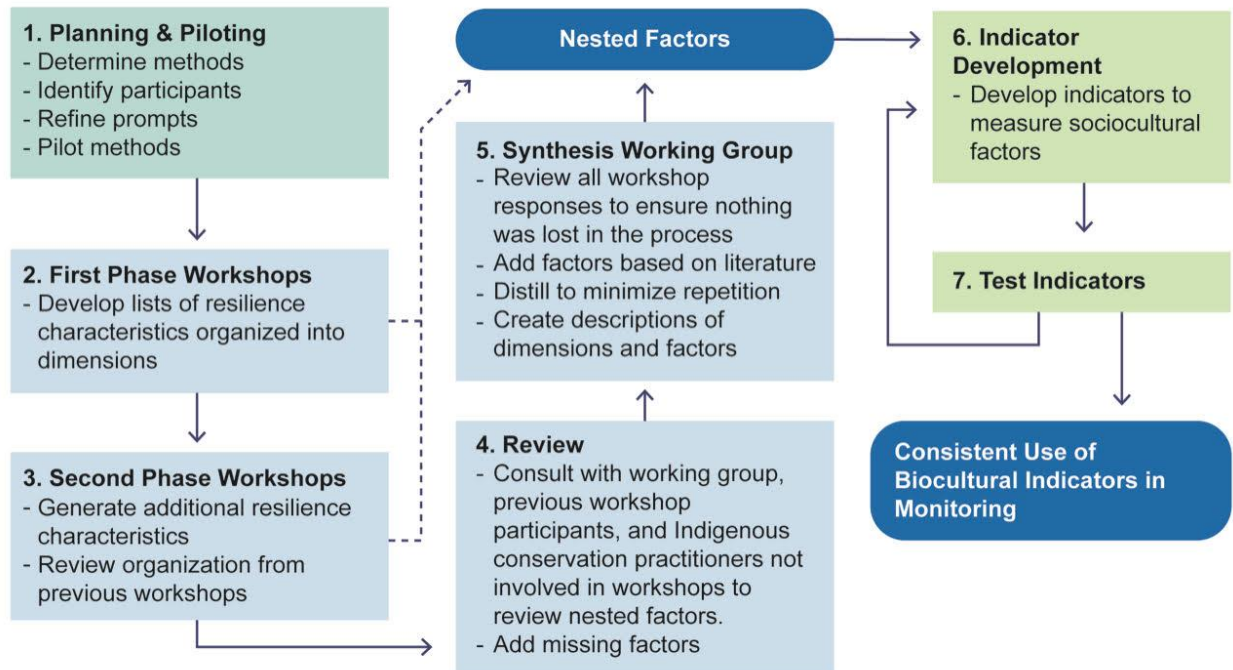
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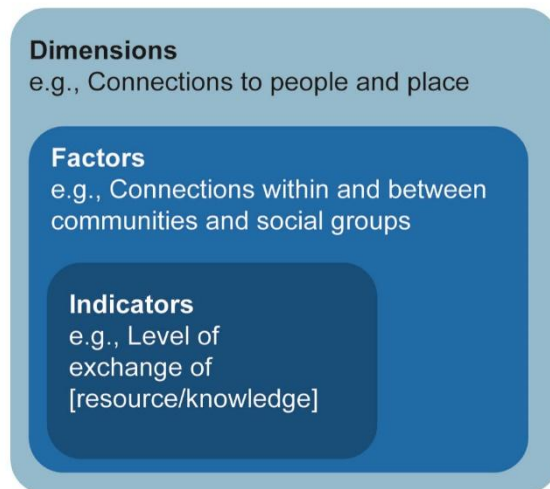
Table 1. Four sociocultural factors, descriptions of their links to interventions (e.g., conservation, natural resource management, etc.) and corresponding sample indicators. The first two sociocultural factors are classified under Dimension D, “Connectedness to people and place” and the latter two are 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	Supporting citations	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	Bodin et al. 2014	Individuals and groups share natural resources and knowledge about natural resources.	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	Poepoe et al. 2007	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.	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	Fernández-Llamazares & Cabeza 2017	Language and knowledge about species/ecology may be embedded in cultural performances.	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	Ticktin et al. 2006	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.	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



592

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



596

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