DispatchDate: 28.09.2017 · ProofNo: 349, p.1

nature ecology & evolution

PERSPECTIVE

DOI: 10.1038/s41559-017-0349-6

Biocultural approaches to well-being and sustainability indicators across scales

Eleanor J. Sterling[1]*, Christopher Filardi[1], Anne Toomey[1,2], Amanda Sigouin[1], Erin Betley[1], Nadav Gazit[1], Jennifer Newell[3], Simon Albert[4], Diana Alvira[5], Nadia Bergamini[6], Mary Blair[1], David Boseto[7], Kate Burrows[8], Nora Bynum[5], Sophie Caillon[9], Jennifer E. Caselle[10], Joachim Claudet[11], Georgina Cullman[1], Rachel Dacks[12], Pablo B. Eyzaguirre[6], Steven Gray[13], James Herrera[14], Peter Kenilorea[15], Kealohanuiopuna Kinney[16,17], Natalie Kurashima[18,19], Suzanne Macey[1], Cynthia Malone[1], Senoveva Mauli[20], Joe McCarter[1], Heather McMillen[21], Pua'ala Pascua[22], Patrick Pikacha[4], Ana L. Porzecanski[1], Pascale de Robert[23], Matthieu Salpeteur[9], Myknee Sirikolo[24], Mark H. Stege[25], Kristina Stege[26], Tamara Ticktin[18], Ron Vave[27], Alaka Wali[28], Paige West[29], Kawika B. Winter[24,30] and Stacy D. Jupiter[31]

Monitoring and evaluation are central to ensuring that innovative, multi-scale and interdisciplinary approaches to sustainability are effective. The development of relevant indicators for local sustainable management outcomes, and the ability to link these to broader national and international policy targets, are key challenges for resource managers, policymakers and scientists. Sets of indicators that capture both ecological and social–cultural factors, and the feedbacks between them, can underpin cross-scale linkages that help bridge local and global scale initiatives to increase resilience of both humans and ecosystems. Here we argue that biocultural approaches, in combination with methods for synthesizing across evidence from multiple sources, are critical to developing metrics that facilitate linkages across scales and dimensions. Biocultural approaches explicitly start with and build on local cultural perspectives — encompassing values, knowledges and needs — and recognize feedbacks between ecosystems and human well-being. Adoption of these approaches can encourage exchange between local and global actors, and facilitate identification of crucial problems and solutions that are missing from many regional and international framings of sustainability. Resource managers, scientists and policymakers need to be thoughtful about not only what kinds of indicator are measured, but also how indicators are designed, implemented, measured and ultimately combined to evaluate resource use and well-being. We conclude by providing suggestions for translating between local and global indicator efforts.

Complex global environmental challenges call for innovative, multi-scale and interdisciplinary approaches to research-based policy and action[1,2]. Monitoring and evaluation are central to ensuring these approaches are effective[3–5]. Developing accurate indicators and relevant success criteria to assess the local outcomes of sustainability management actions, and linking them to broader national and international policy targets, remains a key challenge for resource managers, policymakers and scientists[2].

What indicators we decide to measure and how we measure them impact the people and activities that are included in or affected by a given initiative. Efforts to evaluate well-being or resource use that are developed solely on regional or global scales may leave out

[1]Center for Biodiversity and Conservation, American Museum of Natural History, New York, NY 10024, USA. [2]Department of Environmental Studies and Science, Pace University, One Pace Plaza, New York, NY 10038, USA. [3]East Pacific Collection, Australian Museum, Sydney, New South Wales 2010, Australia. [4]School of Civil Engineering, The University of Queensland, St Lucia, Queensland 4072, Australia. [5]Keller Science Action Center, The Field Museum, Chicago, IL 60605, USA. [6]Bioversity International, 00054 Maccarese, Rome, Italy. [7]Ecological Solutions Solomon Islands, PO Box 180, Gizo, Western Province, Solomon Islands. [8]School of Forestry & Environmental Studies, Yale University, New Haven, CT 06511, USA. [9]National Center for Scientific Research, CEFE UMR 5175, 34293 Montpellier, France. [10]Marine Science Institute, University of California Santa Barbara, Santa Barbara, CA 93106, USA. [11]National Center for Scientific Research, CRIOBE, USR 3278 CNRS-EPHE-UPVD, 66860 Perpignan, France and Laboratoire d'Excellence CORAIL, Perpignan, France. [12]Department of Biology, University of Hawai'i at Mānoa, Honolulu, HI 96822, USA. [13]Department of Community Sustainability, Michigan State University, East Lansing, MI 48823, USA. [14]Department of Mammalogy, American Museum of Natural History, New York, NY 10024, USA. [15]Office of the High Representative for the Least Developed Countries, United Nations, New York, NY 10017, USA. [16]Institute of Pacific Islands Forestry, Pacific Southwest Research Station, USDA Forest Service, Hilo, HI 96720, USA. [17]Brown University, Box G-W, 80 Waterman Street, Providence, RI 02912, USA. [18]Department of Botany, University of Hawai'i at Mānoa, Honolulu, HI 96822, USA. [19]Kamehameha Schools, Natural and Cultural Resources, Kailua-Kona, HI 96740, USA. [20]Solomon Islands Community Conservation Partnership, PO Box 2378, Honiara, Solomon Islands. [21]USDA Forest Service, Northern Research Station, NYC Urban Field Station, Bayside, NY 11359, USA. [22]Department of Natural Resource and Environmental Management, University of Hawai'i at Mānoa, Honolulu, HI 96822, USA. [23]Institut de Recherche pour le Développement, UMR PALOC IRD/MNHN, 75231 Paris cedex 05, France. [24]Solomon Islands Ministry of Forests and Research, PO Box G.24, Honiara, Solomon Islands. [25]Marshall Islands Conservation Society, College of the Marshall Islands, PO Box 1258, Majuro, Marshall Islands. [26]MarTina Corporation, PO Box 403, Majuro, Marshall Islands. [27]Fisheries Ecology Research Lab, University of Hawai'i at Mānoa, Honolulu, HI 96822, USA. [28]Science and Education, The Field Museum, Chicago, IL 60605, USA. [29]Department of Anthropology, Barnard College and Columbia University, New York, NY 10027, USA. [30]Limahuli Garden and Preserve, National Tropical Botanical Garden, Kalaheo, HI 96746, USA. [31]Wildlife Conservation Society, Melanesia Program, 11 Ma'afu Street, Suva, Fiji. *e-mail: sterling@amnh.org

indicators critical for local systems. They may discount, mischaracterize, or ignore place-based values, worldviews and knowledge systems[6–8]. Culturally grounded perspectives are missing from many medium- and large-scale efforts developed by governments and other institutions that aim to implement sustainable resource management and monitor goals and targets[9,10]. Disconnects can result in miscommunication, policies that fail to inspire appropriate action and misdirected resources[11]. More worryingly, assessments that lack a place-based cultural context can be harmful to communities, leading to loss of control over place, knowledge, or resources[12,13]. Many types of knowledge and knowledge system — from ways of knowing that reflect in situ, local, place-based cultural values (recognizing that 'culture' is dynamic[8]) to externally derived information from ex situ researchers or policymakers — can contribute to understanding and managing systems sustainably[14–16] (Fig. 1). We use local, place-based and in situ interchangeably to represent culturally grounded actors such as local or indigenous peoples who manage cultural and biological resources and to differentiate from actors — be they 'local' or 'external' to a community — who are not familiar with the cultural practices of a place. We recognize individuals can be 'local' in some contexts and 'external' in others, and in a particular location people self-define with different 'communities' at different times.

We suggest that different knowledge systems, and the indicators that emerge from these systems, can exist in one of three states:

- As separate and independent reinforcing systems (Fig. 1a)
- As interacting but conflicting systems with externally derived sustainability indicators that may be culturally inappropriate at local levels (Fig. 1b)
- Or as synthesized knowledge systems (Fig. 1c)

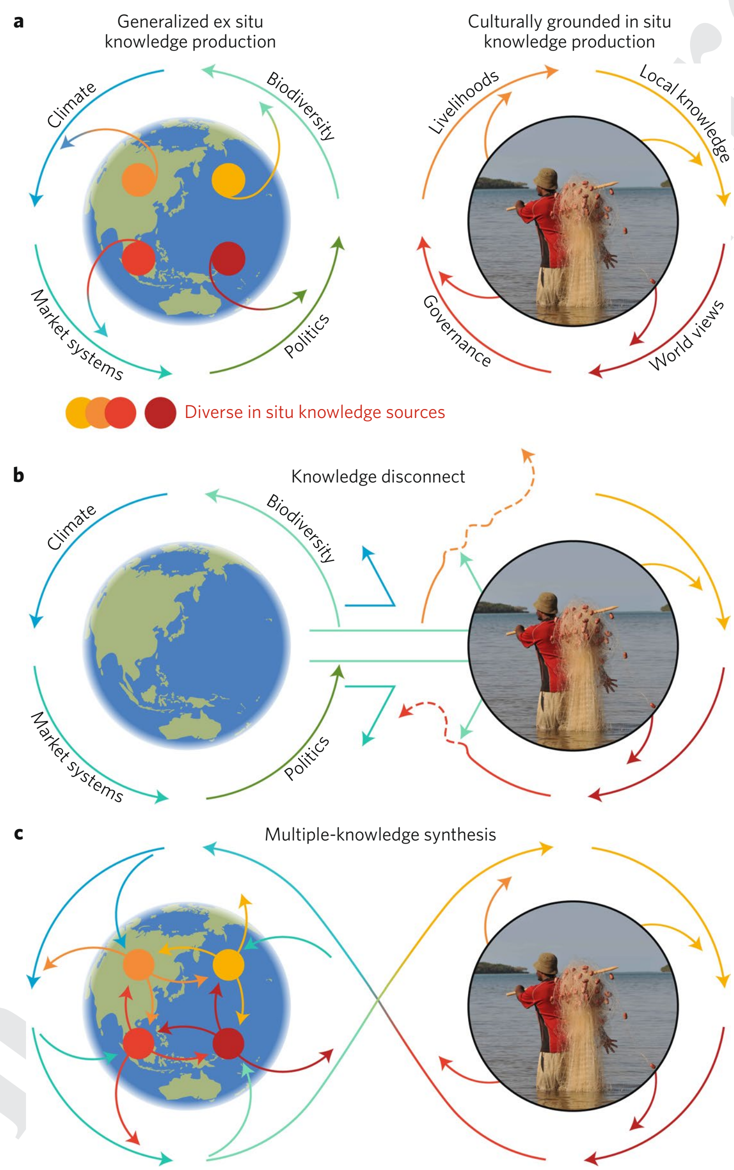

Fig. 1 | Ex situ and in situ knowledge production and synthesis. a, Ex situ and culturally grounded in situ perspectives generate different but complementary knowledge systems that can guide sustainable resource management. **b**, Policy and management driven by ex situ perspectives: approaches that are primarily driven by ex situ perspectives often deliver knowledge in ways that disrupt or conflict with in situ worldviews and well-being, thereby limiting potential for positive interplay between ex situ and in situ knowledge systems. **c**, Policy and management recognizing local perspectives: approaches recognizing and respecting in situ as well as ex situ knowledge systems can lead to more effective syntheses and enduring on-the-ground impact. Credit: photograph, Nicolas Pascal.

Understanding biocultural approaches

Here we argue that biocultural approaches are critical to understanding social–ecological systems and the development of locally relevant indicators. Biocultural (or ecocultural as per ref. [17]) approaches are those that explicitly start with and build on place-based cultural perspectives — encompassing values, knowledges and needs — and recognize feedbacks between ecological state and human well-being[18–22]. These approaches, in combination with methods for synthesizing across evidence from multiple sources[23,24], can also help to develop the indicators that are required to meet current complex challenges[25]. Exchange between in situ and ex situ actors facilitates identification of crucial problems and solutions that are currently missing from many regional and international framings of sustainability[21,22,26]. We suggest that methods that synthesize across culturally grounded and generalized knowledge from multiple sites (Fig. 1c) can foster greater human adaptive capacity and ecological resilience. In doing so, these methods may be more effective than those that rely on a priori frameworks for information synthesis[7,8,27,28].

Historical political and economic forces have resulted in a disproportionate representation and power of people and institutions in the West/global North in shaping 'global' or ex situ knowledge, policy and norms[29]. Yet place-based actors are critical to guide the implementation and monitoring of natural resource management for ethical and practical reasons[13,30]. Indigenous peoples and other in situ communities manage lands and seas that hold significant portions of the planet's biodiversity[31] and carbon stocks[32]. In addition, place-based communities have generated creative resilient responses to global pressures, despite experiencing outsized impacts from them[33,34].

Scholarship and stories stemming from participatory action research[35] and ethnobiology (for example, research into traditional ecological knowledge; TEK) have documented local capacity to respond to stresses[36]. In particular, participatory and community-led resource management approaches have shown that working within place-based social and cultural contexts has the potential to capture connections and drivers of behaviour, such as variation in communal versus individual property rights, that external framing of a system might miss[11,37,38]. However, it is increasingly recognized that local institutions are nested within complex multi-level governance systems[39]. While best practices have been widely developed for community-based governance approaches, new theories and methods are needed to link local goals with sustainable management outcomes that are critical to global policy objectives[10,40,41].

Biocultural approaches to indicator development

International efforts to address complex global concerns (for example, landscape fragmentation, food security) increasingly recognize the importance of feedbacks among social and ecological processes, and that human well-being is linked to ecosystem states and processes[42,43]. For instance, the recently developed sustainable development goals, stemming from the Millennium Ecosystem Assessment[3], theoretically support planning, tracking and reporting that integrate across social and ecological systems[44]. International assessments, such as those emerging from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), incorporate these concepts, although not without some definitional challenges[45,46].

One theory that provides guidance in linking between local and global resource management is social–ecological systems theory[47] (SES). SES provides a priori frameworks for understanding social and ecological feedbacks that characterize the settings within which humans exist and impact policy[25,48]. However, while SES approaches help to conceptualize interactions between elements of a system, they may neglect or under-emphasize the importance of cultural values, beliefs and worldviews to sustainable resource management. For instance, vulnerability assessments identify system weaknesses and emphasize what communities and individuals lack[34,48,49]. This can inadvertently erode local perceptions of well-being and direct blame towards place-based communities, thus fostering a framing of helplessness[50,51]. Furthermore, SES approaches that rely on ex situ values such as the importance of material goods can be problematic. For example, an Amerindian village that had only one television for the whole village had a quality of life indicator measurement below that of other villages where individual families had their own televisions[52]. However, watching one television together was considered *mex* by the inhabitants. *Mex* is a local concept of well-being as 'beauty', valuing not just aesthetics but extended, strong and peaceful social relations[53].

Although related conceptually to SES, biocultural approaches differ in that they explicitly start with the specific human practices, local knowledge and cultural beliefs that influence and are influenced by the land- and seascapes of which human communities are a part[19,36,54]. All biocultural approaches are social–ecological in nature, but not all social–ecological approaches frame interactions from locally relevant cultural perspectives. There is a fundamental difference between theoretical conceptions of interactions between social and ecological elements of a system (which externally framed SES can accomplish effectively) and culturally grounded understandings of what factors drive a system (an explicit goal of all biocultural and some SES approaches).

In relation to indicator development for sustainable resource management, biocultural approaches present opportunities that can address some of the challenges (Fig. 1b) by creating space for metrics that facilitate cross-scale linkages. Effective biocultural approaches to indicator development have a number of characteristics. First, they begin with an understanding of locally grounded questions and institutions that communities use when interacting with or managing resources. A clear awareness of who is included in the community, what criteria constitute community membership, diverse opinions within the community, and on what scale and by whom decisions are being made is key[7]. As with development of any indicator, clarity on agency — indicators for what and for whom, chosen by whom, analysed by whom, resulting in actions decided on by whom — is essential[55].

Second, the indicators developed are deeply relevant to people's cultural way of life (Table 1). They encompass cultural values and worldviews that shape people's understandings of their roles within and responsibilities to their environment[56,57]. For instance, within the Reimaanlok national framework for the establishment of community-based conservation areas in the Marshall Islands, traditional knowledge holders guide the selection of targeted resources and threats as well as the mapping of sacred places[18,54].

Third, the ways in which the indicators are measured and monitored are coordinated with existing livelihood strategies or social activities of the people involved in the monitoring[58,59]. For example, the Lutsel K'e Dene First Nation identifies the health of fish based on observations carried out during and immediately after fishing, such as fatness of fish, colour and texture of the flesh, and health of organs[60].

Fourth, biocultural approaches to indicator development are enacted with the explicit intention of using the collected knowledge to guide action of interest to communities[57,61,62,63]. The International Partnership for the Satoyama Initiative, for instance, supports communities in social–ecological production landscapes and seascapes to develop a variety of social, cultural and biological indicators to facilitate local management[63].

Biocultural approaches build on community-based and participatory methods, but more explicitly take a systems perspective, emphasizing feedbacks between ecological and cultural elements in a system. The types of indicator created through biocultural approaches can capture both the ecological underpinnings of a cultural system and the cultural perspectives of an ecological state, and

Table 1 | Examples of United Nations sustainable development goal (SDG) indicators and additional or alternative indicators stemming from biocultural approaches

Issue	Relevant SDG	Example of externally driven metric(s)	Discussion	Examples of indicators derived from biocultural approaches
Food security	Goal 2: "End hunger, achieve food security and improved nutrition and promote sustainable agriculture".	Indicator 2.1.2: "Prevalence of moderate or severe food insecurity in the population, based on the food insecurity experience scale (FIES)". FIES sample question: "During the last 12 months was there a time when your household ran out of food because of a lack of money or other resources?"[102]	Some Pacific island countries have strong cultural obligations to provide family/guests with food[103]. Standardized vulnerability-framed questions about food security may not generate accurate data due to cultural reluctance to admit to food shortages. Biocultural framing would emphasize local knowledge and definitions of resource systems, and innovation for resilience.	(1) Percentage of households in the community that report having a stable food supply throughout the year. Food supply can be subsistence-based, bought, or a result of exchange. (2) Average length of time for which households in the community have a stable, culturally valued food supply after a disaster.
Quality education	Goal 4: "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all".	Indicator 4.1.1: "Proportion of children and young people: (a) in grades 2/3; (b) at the end of primary; and (c) at the end of lower secondary achieving at least a minimum proficiency level in (i) reading and (ii) mathematics, by sex".	Inclusion of place-based ecological knowledge can increase local ownership of school curricula, strengthen management practices and build identity for pupils[17,104].	Vitality (that is, rate of retention over time) of ecological knowledge and practice, vitality of transmission pathways for information about land and sea, innovation in ecological knowledge systems[95].
Access to fresh water	Goal 6: "Ensure availability and sustainable management of water and sanitation for all".	Indicator 6.3.2: "Proportion of bodies of water with good ambient water quality".	The Maori worldview does not distinguish between the spiritual health and ecological state of water sources. Some water sources are considered sacred, or *tapu*. An indicator such as ambient water quality is incomplete in its ability to assess Maori values including the role of particular locations in creation stories, use in access routes and the ability for a site to be used by future generations[83].	The Maori-based cultural health index for streams includes: (1) site status (for example, traditional significance); (2) the intangible and tangible value of a site; and (3) stream health measures that were developed through participatory processes[83].
Issue	**SDG goal**	**Ex situ metric(s)**	**Discussion**	**Revised indicator**
Sustainable tourism	Goal 8: "Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all".	Indicator 8.9.1: "Tourism direct gross domestic product (GDP) as a proportion of total GDP and in growth rate".	GDP is often not measurable or meaningful at the local level. Further, a biocultural framing could capture whether tourism activities are beneficial for place-based communities and supportive of traditional culture[105].	Relative contribution of local tourism revenues within average annual household income as generated from culturally appropriate marketing or demonstration/presentation of traditional knowledge and customary practices (for example, guided interpretive hikes by respected elder; visitor use of traditional navigation).
Protection of marine resources	Goal 14: "Conserve and sustainably use the oceans, seas and marine resources for sustainable development".	Indicator 14.5.1: "Coverage of protected areas in relation to marine areas".	Measuring marine protected area (MPA) coverage does not account for effectiveness of MPA location, design, or management[106]. Percentages are insufficient metrics of sustainability. Moreover, this metric may exclude locally managed marine areas, which often lack legal status but incorporate place-based practice[107]. For example, in Hawai'i, the community-based subsistence fishing areas sets rules based in traditional resource management without the complete closures that might result in a loss of place-based practice[33,108].	(1) Are common marine resources managed sustainably, through locally supported customary management systems? (2) The Micronesia protected area management effectiveness scorecard is designed to measure stakeholder engagement, local knowledge and other aspects of effective protected area management at the community level, although it can also be scalable to national and regional levels[109].

Continued

Table 1 | (continued)

Issue	Relevant SDG	Example of externally driven metric(s)	Discussion	Examples of indicators derived from biocultural approaches
Protection of terrestrial resources	Goal 15: "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss".	Indicator 15.5.1: Red List index.	Red listing evaluation may not reflect local abundance of culturally important species. For example, a highly culturally important species that is in steep local decline, but stable nationally (or globally), would not be identified. Similarly, globally or nationally threatened species that are of local cultural importance may be locally thriving due to sustainable management. Red listing can then have negative local consequences. Alternative metrics could reflect the status of local forest resources as well as interest in maintaining cultural practices.	How long does it take to collect forest resources for cultural practices and how has the amount of time to complete this harvest changed since elders in the community were young?

thus can highlight interactions and feedbacks between humans and their environment. For example, a social indicator may encompass social or cultural practices that in turn explain an observed phenomenon in the population dynamics of a species. A social indicator such as 'trend in percent of elders or parents transmitting traditional knowledge to children' could explain why a harvested species has healthy populations, because intergenerational transmission of TEK regarding the impact of harvest of individuals at different life stages facilitates effective population management. Similarly, biological trends and processes — such as dynamics or status of totem species — may underpin local visions of well-being because people's perceptions of well-being are tied to the health of their totem.

Many cultural aspects are known to affect adaptive capacity[64] and yet are often deemed intangible and thus potentially unmeasurable[65]. Consequently, many assessments rely on indicators that are easier to quantify, compare, aggregate and communicate across scales and arenas, but that may miss out on feedbacks or critical variables at the local level that biocultural approaches could illuminate (Table 1). As noted in ref. [66], conservation and sustainability efforts frequently approach social–cultural aspects as if they are assessing biodiversity: by creating lists of stakeholders, documenting spatial data on land/sea use and converting these into relative costs. These approaches overlook the complex psychological and cultural reasons behind management action or inaction. Indicators can and should measure the perceptions of the effect of ecological change on well-being, as these perceptions can drive behaviour more than factors collected via empirical data on change[41]. Perceptions impact local support (or lack thereof) for management action. Recognition of the role of perceptions within the context of different worldviews is critical to understanding connections and disconnections between international, national and local framing of problems and successes[41,67–69].

An emerging literature has begun to identify innovative methods to address the challenges of capturing cultural aspects of a system, when the creation of metrics is deemed helpful or necessary by all parties in a consultation[65]. For instance, challenges in developing indicators of intangible elements of a system can in part be resolved through the use of ethnographic interviewing techniques that elucidate how the values, beliefs and experiences of individual people affect their understanding of that system[65]. As one example, in exploring the impact of western Lesotho's Metolong Dam on local inhabitants, researchers used audiovisual and global positioning system technology along with interview and group discussion notes to document 'intangible culture' as expressed through the relationships between landscape features and cultural histories and narratives[70].

Overall, indicators need to be meaningful and applicable to practice at local levels, and should be situated within a context of feedbacks between interconnected ecological and cultural components of a system. Given these complex factors, biocultural approaches can assist in developing grounded, accurate, appropriate and relevant indicators.

Managing cross-cultural indicator development

Biocultural approaches can be undertaken by indigenous and other place-based communities without engaging with ex situ entities[71]. These communities might not use the term biocultural to describe their approach, as for them it is a lived experience. Furthermore, biocultural approaches are not exclusively used in the context of indigenous communities or in the 'global South'. High-nature-value, low-intensity farming and other European biocultural initiatives highlight the use of biocultural approaches in non-indigenous settings[72]. However, as communities across the globe face internal and external environmental and economic pressures, they have increasingly engaged with ex situ actors in knowledge exchange and co-creation of indicators[21,23,73]. The process of co-creation of indicators across groups can help to frame questions and solutions that span scales[7] and ensure that indicators are relevant to users[74] (Fig. 1c). Collaborations that seek to understand and embrace the complexity and interrelated nature of different worldviews can lead to improved conservation and management outcomes[75–78].

For example, in coastal British Columbia, a collaborative team of Heiltsuk First Nation youth and leadership and ex situ scientists placed Heiltsuk observations of grizzly bear (*Ursus arctos*) in the context of *Gvi'ilas* — customary law in which bear behaviour is recognized as a voice to guide decision-making about whole ecosystems — to undertake basic bear studies. In this project, the Heiltsuk framed the research questions and led the partnership to carry out data collection and communicate the findings to the broader community. The research relied both on population and landscape genetics and on Heiltsuk ways of knowing. As it was embedded in Heiltsuk governance structures, the research led to changes in bear management objectives, sanctions on trophy hunting and outlines for a multi-nation grizzly bear sanctuary under formal co-management frameworks[79].

Elucidating culturally grounded understandings requires time and skills, to translate between different types of knowledge and scales of governance[21,80]. Collaborators need to observe and listen carefully, and be open to the validity and deep complexity of other ways of knowing[81]. They must also have skills to identify indicators embedded in numerous cultural forms[59]. Indigenous indicators may be integrated within social contexts that are unfamiliar to ex situ scientists[12,82], or that may seem disconnected from environmental management but are inextricably linked for in situ actors. These forms may include stories, songs, ceremonies, oral histories and what ex situ actors might view as 'art'[21,75,82,83]. Including information from different knowledge systems can provide a more complete picture for decision-making[84,85]. For instance, oral histories from Hawai'i informed the development of local indicators of environmental and climate change. These include distribution of pan-Pacific, culturally important trees that were once widespread as described by place names and legends, but are now sparse due to landscape transformations and climate change effects[86].

Cross-cultural knowledge sharing and collaborations require understanding of how to manoeuvre through the diversity of expectations, perceptions and viewpoints within and across communities. Knowledge from different sources may initially seem incompatible[87]. Overcoming this requires ex situ actors to take the time to understand the local context for these knowledges and not dismiss them[88]. With biocultural approaches, the social–cultural context for local knowledge is key, as is explicit recognition of the producers and holders of knowledge. Knowledge extraction without this context and attribution can disempower local knowledge holders and undermine that knowledge's transformative potential for management[10]. Ethnographic research has a key role to play in understanding the politics and process of how knowledge arises and is translated between different groups, and how that can inform decision-making[82,87].

Cross-cultural navigation also involves recognizing different perspectives on the type and depth of knowledge that is sufficient for characterizing critical dimensions of a system for management. For example, both in situ and ex situ actors and managers may have only a partial vision of the larger system. In New Ireland, Papua New Guinea, in situ actors might know the micro-scale behavioural ecology of sandfish (*Holothuria scabra*), but they do not necessarily know the behavioural ecology of species that are intimately connected to the sandfish in the larger system[89]; ex situ actors might know the large-scale dynamics of those reef species in the western Pacific but may not understand the micro-system dynamics of single reef sites (P.W., unpublished observations). Individuals who are steeped in local cultures but have worked or studied, for instance, in international settings can help with ensuring successful co-creation processes[90]. Effective two-way communication between ex situ and in situ actors can facilitate policies that leverage the power of both locally relevant knowledge that has evolved within a place and larger-scale generalizable knowledge[21,26].

Such collaborative cross-cultural work comes with a number of challenges. Involving numerous sources of knowledge can increase potential for conflict, and enhanced complexity can overwhelm decision-makers and scientists[91]. Other points that must be considered include the range of beliefs and biases people bring to an endeavour, competitive funding environments, organizational structures driven by external value systems, timelines for reporting that favour efficiency and speed, ethical issues regarding the dissemination and use of co-produced knowledge, and the arbitrary nature of classifying different types of knowledge[24]. Some of these issues can be overcome if researchers approach cross-cultural work with strategies aimed at fostering true partnerships with in situ groups. Research has shown that when initiatives include diverse actors across all stages, local users are more likely to sustain those initiatives[13,24,55]. Building in enough time and appropriate conditions for iterative reflection in selection of indicators is critical, as is consideration of rights, representation and power dynamics[13,55,92]. The social process of engagement, of working together to reflect on and choose indicators, is a key ingredient of successful indicator development and the discussion itself may lead to improved outcomes. An initiative is more likely to produce practical, actionable knowledge when researchers understand and leverage the interactive nature of knowledge- and decision-making[93]. When synthesizing different knowledges, approaches that are iterative, collaborative, and include methods to evaluate validity and reliability can be helpful[24], as are strategies that use validation processes internal to each system to ensure that the highest calibre knowledge is available for consideration[23,73].

Bridging global and local policy and management

If we are to monitor and evaluate sustainable resource use and well-being effectively, we need mechanisms that allow for translation between place-based contexts and other scales, including layers of local and regional government. Thus, in addition to being thoughtful on all scales about what kinds of indicator we measure and who is doing the measuring, we need robust, transparent processes to guide how indicators are designed, implemented, analysed, combined or compared and incorporated into decision-making processes. Global efforts should also explicitly consider why and how to standardize, despite the ease of comparing and aggregating standardized information. Indicators capturing information in exactly the same way regardless of local context may not be meaningful. Conversely, measures that are developed on local scales and reflect specific place-based values may not easily translate to other locales or to national and international policy by the very nature of their specificity[82].

There are several non-exclusive ways to bridge the gaps between local and global indicators. For instance, it may be possible to group complementary indicators under a particular dimension, such as governance, that is meaningful on local as well as global scales. Place-based communities could choose from these indicators to suit their cultural and biological setting[43,94]. This type of system has already been designed. The vitality index of traditional environmental knowledge (VITEK) is a locally appropriate, globally applicable index that can be used to measure, assess and compare local ecological knowledge transmission. VITEK defines broad domains of TEK for the overall index, but the actual questions used as indicators are adapted locally[95]. Tools such as the Mauri model provide a flexible process by which communities can quantify their perceptions of the long-term viability of different well-being dimensions and develop benchmarks tailored to local settings[96]; while the indicators relate to a specific location, the indicator groupings and methods for scoring the results are fixed, facilitating comparability across communities[54].

In addition, provincial and national level agencies have an important role to play. National initiatives such as the Melanesian well-being index standardize and quantify well-being using culturally appropriate metrics[97]. Similarly, in Latin America, emerging well-being concepts such as *Buen Vivir* ('living well') use culturally grounded quantitative approaches[98]. One of the earliest efforts to quantify holistic well-being, Bhutan's gross national happiness index, focuses on non-economic development measures and has received much global attention, although these efforts have also been critiqued in relation to exclusion of minority groups[99]. National level understanding of local systems and patterns can lead to better tracking of whether or not global targets are being met and enable policy development and action on the ground to address local issues meaningfully. Initiatives that work with national governments to develop indicator strategies for international conventions, such as the Convention on Biological Diversity's (CBD) National Biodiversity Strategic Action Plan process and the Biodiversity Indicator Partnership, or to assess the current status of biodiversity, such as IPBES[45,46], could help ensure that culturally grounded indicators are developed and used.

Joint efforts in implementation of existing international conventions, such as between the CBD and the United Nations Educational, Scientific and Cultural Organization's Convention for the Safeguarding of the Intangible Cultural Heritage, could lead to shared indicators of progress that would better address combined cultural and biological elements on the local scale. These efforts could also promote information sharing, bridge organizational concerns, and integrate specialized knowledge and actions across multiple scales and sectors[100].

Conclusion

Global targets such as sustainability and well-being are best addressed through multi-level governance[100], and we argue that biocultural approaches can create space for meaningful local metrics while supporting cross-scale application. Future work could find ways to compare results from biocultural approaches to indicator development with those that did not include cultural aspects or feedbacks between humans and their environments, to see if outcomes differ. In addition, more work needs to be done regarding methods for synthesizing across multiple knowledge systems and identifying ways to maintain the richness of local narratives to counter reductionist approaches in decision-making[75,101]. While great strides are being made in better articulating methods for collaboration and not just participation[13,26,30], this remains an ongoing challenge. We believe that by integrating local perspectives and values into global scale indicator development efforts, biocultural approaches can both facilitate development of metrics more appropriate for in situ communities and support the innovative approaches to research-based policy and action necessary to confront complex environmental challenges.

Received: 16 January 2017; Accepted: 20 September 2017;

References

1. Sterling, E. J., Gómez, A. & Porzecanski, A. L. A systemic view of biodiversity and its conservation: processes, interrelationships, and human culture. *Bioessays* **32**, 1090–1098 (2010).
2. Carpenter, S. R. et al. Science for managing ecosystem services: beyond the Millennium Ecosystem Assessment. *Proc. Natl Acad. Sci. USA* **106**, 1305–1312 (2009).
3. Millennium Ecosystem Assessment *Ecosystems and Human Well-being: Synthesis* (Island, Washington DC, 2005).
4. Mascarenhas, A., Coelho, P., Subtil, E. & Ramos, T. B. The role of common local indicators in regional sustainability assessment. *Ecol. Indic.* **10**, 646–656 (2010).
5. Hinkel, J. 'Indicators of vulnerability and adaptive capacity': towards a clarification of the science–policy interface. *Glob. Environ. Change* **21**, 198–208 (2011).
6. Cunningham, A. B. *Applied Ethnobotany: People, Wild Plant Use and Conservation*. (Earthscan, London, 2001).
7. Fraser, E. D. G., Dougill, A. J., Mabee, W. E., Reed, M. & McAlpine, P. Bottom up and top down: analysis of participatory processes for sustainability indicator identification as a pathway to community empowerment and sustainable environmental management. *J. Environ. Manag.* **78**, 114–127 (2006).
8. Winter, K. & McClatchey, W. Quantifying evolution of cultural interactions with plants: implications for managing diversity for resilience in social–ecological systems. *Funct. Ecosyst. Commun.* **2**, 1–10 (2008).
9. Tallis, H. et al. A global system for monitoring ecosystem service change. *Bioscience* **62**, 977–986 (2012).
10. Mistry, J. & Berardi, A. Bridging indigenous and scientific knowledge. *Science* **352**, 1274–1275 (2016).
11. Cullman, G. Community forest management as virtualism in northeastern Madagascar. *Hum. Ecol.* **43**, 29–41 (2015).
12. West, P. *Conservation is Our Government Now: The Politics of Ecology in Papua New Guinea*. (Duke Univ. Press, Durham, 2006).
13. Sterling, E. J. et al. Assessing the evidence for stakeholder engagement in biodiversity conservation. *Biol. Conserv.* **209**, 159–171 (2017).
14. Smith, L. T. *Decolonizing Methodologies: Research and Indigenous Peoples.* (Zed Books, London, 1999).
15. Chan, K. M. A. et al. Why protect nature? Rethinking values and the environment. *Proc. Natl Acad. Sci. USA* **113**, 1462–1465 (2016).
16. Daniel, T. C. et al. Contributions of cultural services to the ecosystem services agenda. *Proc. Natl Acad. Sci. USA* **109**, 8812–8819 (2012).
17. Thaman, K. H. In: B. Teasdale, Z. Ma Rhea eds. *Local Knowledge and Wisdom in Higher Education* (pp. 43–50. Elsevier, Oxford, 2000).
18. Reimaan National Planning Team. *Reimaanlok: Looking to the Future: National Conservation Area Plan for the Marshall Islands*. (N. Baker, Melbourne, 2008).
19. Gavin, M. C. et al. Defining biocultural approaches to conservation. *Trends Ecol. Evol.* **30**, 140–145 (2015).
20. van Oudenhoven, F. J. W., Mijatović, D. & Eyzaguirre, P. B. Social–ecological indicators of resilience in agrarian and natural landscapes. *Manag. Environ. Quality* **22**, 154–173 (2011).
21. Ens, E. J. In: J. Altman, S. Kerins eds. *People on Country: Vital Landscapes, Indigenous Futures* (pp. 45–64. The Federation Press, Leichhardt, 2012).
22. Preuss, K. & Dixon, M. 'Looking after country two-ways': insights into indigenous community-based conservation from the Southern Tanami. *Ecol. Manag. Restor.* **13**, 2–15 (2012).
23. Tengö, M., Brondizio, E. S., Elmqvist, T., Malmer, P. & Spierenburg, M. Connecting diverse knowledge systems for enhanced ecosystem governance: the multiple evidence base approach. *Ambio* **43**, 579–591 (2014).
24. Raymond, C. M. et al. Integrating local and scientific knowledge for environmental management. *J. Environ. Manag.* **91**, 1766–1777 (2010).
25. Leenhardt, P. et al. Challenges, insights and perspectives associated with using social–ecological science for marine conservation. *Ocean Coast. Manag.* **115**, 49–60 (2015).
26. Ens, E. J., Daniels, C., Nelson, E., Roy, J. & Dixon, P. Creating multi-functional landscapes: using exclusion fences to frame feral ungulate management preferences in remote Aboriginal-owned northern Australia. *Biol. Conserv.* **197**, 235–246 (2016).
27. Jupiter, S. Culture, kastom and conservation in Melanesia: what happens when worldviews collide? *Pac. Conserv. Biol.* **23**, 139–145 (2017).
28. Pascua, P., McMillen, H., Ticktin, T., Vaughan, M. & Winter, K. B. Beyond services: a process and framework to incorporate cultural, genealogical, place-based, and indigenous relationships in ecosystem service assessments. *Ecosyst. Serv.* **26B**, 465–475 (2017).
29. Harding, S. *Science and Social Inequality: Feminist and Postcolonial Issues.* (Univ. Illinois Press, Champaign, 2006).
30. Reed, M. S. et al. A theory of participation: what makes stakeholder and public engagement in environmental management work? *Restor. Ecol.* https://doi.org/10.1111/rec.12541 (2017).
31. Kainer, K. A. et al. Partnering for greater success: local stakeholders and research in tropical biology and conservation. *Biotropica* **41**, 555–562 (2009).
32. Walker, W. et al. Forest carbon in Amazonia: the unrecognized contribution of indigenous territories and protected natural areas. *Carbon Manag.* **5**, 479–485 (2014).
33. McMillen, H. L. et al. Small islands, valuable insights: systems of customary resource use and resilience to climate change in the Pacific. *Ecol. Soc.* **19**, 44 (2014).
34. Campbell, J. Islandness: vulnerability and resilience in Oceania. *Shima* **3**, 85–97 (2009).
35. Chambers, R. Participatory rural appraisal (PRA): challenges, potentials and paradigm. *World Dev.* **22**, 1437–1454 (1994).
36. Berkes, F. *Sacred Ecology: Traditional Ecological Knowledge and Resource Management*. 3rd edn, (Routledge, New York, 2012).
37. Berkes, F., Colding, J. & Folke, C. Rediscovery of traditional ecological knowledge as adaptive management. *Ecol. Appl.* **10**, 1251–1262 (2000).
38. Lawrence, A., Paudel, K., Barnes, R. & Malla, Y. Adaptive value of participatory biodiversity monitoring in community forestry. *Environ. Conserv.* **33**, 325–334 (2006).
39. Berkes, F. Rethinking community-based conservation. *Conserv. Biol.* **18**, 621–630 (2004).
40. Turner, N. J., Gregory, R., Brooks, C., Failing, L. & Satterfield, T. From invisibility to transparency: identifying the implications. *Ecol. Soc.* **13**, 7 (2008).
41. Leonard, S., Parsons, M., Olawsky, K. & Kofod, F. The role of culture and traditional knowledge in climate change adaptation: insights from East Kimberley, Australia. *Glob. Environ. Change* **23**, 623–632 (2013).
42. Steffen, W. et al. Planetary boundaries: guiding human development on a changing planet. *Science* **347**, 1259855 (2015).
43. Hicks, C. C. et al. Engage key social concepts for sustainability. *Science* **352**, 38–40 (2016).
44. Selomane, O., Reyers, B., Biggs, R., Tallis, H. & Polasky, S. Towards integrated social–ecological sustainability indicators: exploring the contribution and gaps in existing global data. *Ecol. Econ.* **118**, 140–146 (2015).
45. Díaz, S., Demissew, S., Carabias, J. & Joly, C. The IPBES conceptual framework—connecting nature and people. *Curr. Opin. Environ. Sustain.* **14**, 1–16 (2015).

46. Pascual, U. et al. Valuing nature's contributions to people: the IPBES approach. *Curr. Opin. Environ. Sustain.* **26**, 7–16 (2017).
47. Ostrom, E. A general framework for analyzing sustainability of social–ecological systems. *Science* **325**, 419–422 (2009).
48. Cinner, J. E. et al. Evaluating social and ecological vulnerability of coral reef fisheries to climate change. *PLoS ONE* **8**, e74321 (2013).
49. Barnett, J., Lambert, S. & Fry, I. The hazards of indicators: insights from the environmental vulnerability index. *Ann. Assoc. Am. Geogr.* **98**, 102–119 (2008).
50. Haalboom, B. & Natcher, D. C. The power and peril of 'vulnerability': approaching community labels with caution in climate change research. *Arctic* **65**, 319–327 (2012).
51. West, P. *Dispossession and the Environment: Rhetoric and Inequality in Papua New Guinea*. (Columbia Univ. Press, New York, 2016).
52. Le Tourneau, F.-M. et al. Assessing the impacts of sustainable development projects in the Amazon: the DURAMAZ experiment. *Sustain. Sci.* **8**, 199–212 (2013).
53. de Robert, P., Lopez Garcés, C., Laques, A.-E. & Coelho-Ferreira, M. A beleza das roças: agrobiodiversidade Mebêngôkre-Kayapó em tempos de globalização. *Boletim do Museu Paraense Emilio Goldi. Ciências Humanas* **7**, 339–369 (2012).
54. Sterling, E. J. *et al.* How do we build culturally-grounded indicators of resilience and adaptation, and address the disconnect between local and global indicators? *Environ. Soc.* (in the press).
55. Estrella, M. & Gaventa, J. *Who Counts Reality? Participatory Monitoring and Evaluation: A Literature Review* IDS Working Paper 70 (Institute of Development Studies, 1998).
56. Cullen-Unsworth, L. C., Hill, R., Butler, J. R. A. & Wallace, M. Development of linked cultural and biophysical indicators for the Wet Tropics World Heritage Area. *Int. J. Sci. Soc.* **2**, 181–194 (2011).
57. Escobar, C. *Community Well-being in Biocultural Landscapes*. (Practical Action Publishing, Rugby, 2014; 42–57.
58. Oba, G. & Kotile, D. G. Assessments of landscape level degradation in southern Ethiopia: pastoralists versus ecologists. *Land Degrad. Dev.* **12**, 461–475 (2001).
59. Åutsÿl K'e Dene Elders and Land-users. et al. *Traditional Knowledge in the Kache Tué Study Region: Phase Three - Towards a Comprehensive Environmental Monitoring Program in the Kakinÿne Region*. (West Kitikmeot Slave Study Society, Yellowknife, 2002).
60. Cobb, D., Berkes, M. K. & Berkes, F. in *Breaking Ice: Renewable Resource and Ocean Management in the Canadian North* (eds Berkes, F., Huebert, R., Fast, H., Mansequ, M. & Diduck, A.) 71–93 (Univ. Calgary Press, Calgary, 2005).
61. Townsend, C. R., Tipa, G., Teirney, L. D. & Niyogi, D. K. Development of a tool to facilitate participation of Maori in the management of stream and river health. *Ecohealth* **1**, 184–195 (2004).
62. Jackson, M. V. et al. Developing collaborative marine turtle monitoring in the Kimberley region of northern Australia. *Ecol. Manag. Restor.* **16**, 163–176 (2015).
63. Bergamini, N. et al. *Indicators of Resilience in Socio-ecological Production Landscapes (SEPLs) UNU-IAS Policy Report*. (United Nations University Institute of Advanced Studies, Yokohama, 2013).
64. Kati, V. & Jari, N. Bottom-up thinking—identifying socio-cultural values of ecosystem services in local blue–green infrastructure planning in Helsinki, Finland. *Land Use Policy* **50**, 537–547 (2016).
65. Satterfield, T., Gregory, R., Klain, S., Roberts, M. & Chan, K. M. Culture, intangibles and metrics in environmental management. *J. Environ. Manag.* **117**, 103–114 (2013).
66. Biggs, D. et al. The implementation crisis in conservation planning: could 'mental models' help? *Conser. Lett.* **4**, 169–183 (2011).
67. Schwarz, A. M. et al. Vulnerability and resilience of remote rural communities to shocks and global changes: empirical analysis from Solomon Islands. *Glob. Environ. Change* **21**, 1128–1140 (2011).
68. Pyhälä, A. et al. Global environmental change: local perceptions, understandings, and explanations. *Ecol. Soc.* **21**, 25 (2016).
69. Bennett, N. J. Using perceptions as evidence to improve conservation and environmental management. *Conserv. Biol.* **30**, 582–592 (2016).
70. Nic Eoin, L., Owens, E. & King, R. Memories of Metolong: the challenges of archiving intangible heritage in development contexts. In *2013 Digital Heritage International Congress* Vol. 2 37–44 (DigitalHeritage, 2013).
71. *Life Plan - Territories of Life - A Video Toolkit for Indigenous Peoples About Land and Rights* (LifeMosaic, Edinburgh, 2015); http://www.lifemosaic.net/eng/tol/life-plan/
72. Kazakova, Y. & Stefanova, V. *High Nature Value Farming in the Western Balkans: Current Status and Key Challenges – A Scoping Document* (European Forum on Nature Conservation and Pastoralism, 2010).
73. Fazey, I. et al. Knowledge exchange: a review and research agenda for environmental management. *Environ. Conserv.* **40**, 19–36 (2013).
74. Izurieta, A. et al. Developing indicators for monitoring and evaluating joint management effectiveness in protected areas in the Northern Territory, Australia. *Ecol. Soc.* **16**, 9 (2011).
75. Peterson, R. B., Russell, D., West, P. & Brosius, J. P. Seeing (and doing) conservation through cultural lenses. *Environ. Manag.* **45**, 5–18 (2010).
76. Ens, E. J., Scott, M. L., Rangers, Y. M., Moritz, C. & Pirzl, R. Putting indigenous conservation policy into practice delivers biodiversity and cultural benefits. *Biodivers. Conserv.* **25**, 2889–2906 (2016).
77. Armitage, D., Berkes, F., Dale, A., Kocho-Schellenberg, E. & Patton, E. Co-management and the co-production of knowledge: learning to adapt in Canada's Arctic. *Glob. Environ. Change* **21**, 995–1004 (2011).
78. Finn, M. & Jackson, S. Protecting indigenous values in water management: a challenge to conventional environmental flow assessments. *Ecosystems* **14**, 1232–1248 (2011).
79. Housty, W. G. et al. Grizzly bear monitoring by the Heiltsuk people as a crucible for First Nation conservation practice. *Ecol. Soc.* **19**, 70 (2014).
80. Ens, E., Burns, E., Russes-Smith, J., Sparrow, B. & Wardle, G. in *Biodiversity and Environmental Change: Monitoring, Challenges and Direction* 83–107 (2014).
81. Sable, T., Howell, G., Wilson, D. & Penashue, P. In: P. Sillitoe ed.. *Local Science vs Global Science: Approaches to Indigenous Knowledge in International Development*. (Berghahn Books, Oxford, 2009).
82. West, P. Translation, value, and space: theorizing an ethnographic and engaged environmental anthropology. *Am. Anthropol.* **107**, 632–642 (2005).
83. Tipa, G. & Teirney, L. D. *A Cultural Health Index for Streams and Waterways: Indicators for Recognising and Expressing Māori Values*. (Ministry for the Environment, Wellington, 2003).
84. Robertson, H. A. & McGee, T. K. Applying local knowledge: the contribution of oral history to wetland rehabilitation at Kanyapella Basin, Australia. *J. Environ. Manag.* **69**, 275–287 (2003).
85. Woodward, E., Jackson, S., Finn, M. & McTaggart, P. M. Utilising indigenous seasonal knowledge to understand aquatic resource use and inform water resource management in northern Australia. *Ecol. Manag. Restor.* **13**, 58–64 (2012).
86. Ka'ūpūlehu Community, McMillen, H., Ticktin, T. & Kurashima, N. *Natural-cultural Resources and Climate Change* (Ka'ūpūlehu Local Ecological Knowledge and Climate Change Portal, 2014); http://hbmpweb.pbrc.hawaii.edu/kaupulehu/cultural-resources
87. Povinelli, E. A. Do rocks listen? The cultural politics of apprehending Australian aboriginal labor. *Am. Anthropol.* **97**, 505–518 (1995).
88. Lauer, M. & Aswani, S. Indigenous ecological knowledge as situated practices: understanding fishers' knowledge in the western Solomon Islands. *Am. Anthropol.* **111**, 317–329 (2009).
89. Aini, J. & West, P. In: G. Cullman ed.. *Resilience Sourcebook: Case Studies of Social–Ecological Resilience in Island Systems*. (Center for Biodiversity and Conservation, American Museum of Natural History, New York, 2014).
90. Gegeo, D. W. & Watson-Gegeo, K. A. "How we know": Kwara'ae rural villagers doing indigenous epistemology. *Contemp. Pacific* **13**, 55–88 (2001).
91. Gray, S., Chan, A., Clark, D. & Jordan, R. Modeling the integration of stakeholder knowledge in social–ecological decision-making: benefits and limitations to knowledge diversity. *Ecol. Model.* **229**, 88–96 (2012).
92. Carter, J. L. Thinking outside the framework: equitable research partnerships for environmental research in Australia. *Geogr. J.* **174**, 63–75 (2008).
93. Clark, W. C., van Kerkhoff, L., Lebel, L. & Gallopin, G. C. Crafting usable knowledge for sustainable development. *Proc. Natl Acad. Sci. USA* **113**, 4570–4578 (2016).
94. *Toolkit for the Indicators of Resilience in Socio-ecological Production Landscapes and Seascapes (SEPLS)* (UNU-IAS, Bioversity International, IGES and UNDP, 2014).
95. Zent, S. & Maffi, L. *Final Report on Indicator No. 2: Methodology for Developing a Vitality Index of Traditional Environmental Knowledge (VITEK) for the Project 'Global Indicators of the Status and Trends of Linguistic Diversity and Traditional Knowledge'* (Terralingua, 2009).
96. Morgan, T. Decision-support tools and the indigenous paradigm. *P. I. Civil. Eng.-Eng. Su.* **159**, 169–177 (2006).
97. *Alternative Indicators of Well-being for Melanesia: Vanuatu Pilot Study Report* (Malvatumauri National Council of Chiefs, 2012).
98. Guardiola, J. & García-Quero, F. *Buen vivir* (living well) in Ecuador: community and environmental satisfaction without household material prosperity? *Ecol. Econ.* **107**, 177–184 (2014).
99. Mason Meier, B. & Chakrabarti, A. The paradox of happiness: health and human rights in the kingdom of Bhutan. *Health Hum. Rights* **18**, 193–208 (2016).
100. Berkes, F. Community-based conservation in a globalized world. *Proc. Natl Acad. Sci. USA* **104**, 15188–15193 (2007).

101. West, P. An anthropology for 'the assemblage of the now'. *Anthropol. Forum* **26**, 438–445 (2016).
102. Ballard, T. J., Kepple, A. W. & Cafiero, C. *The Food Insecurity Experience Scale: Developing a Global Standard for Monitoring Hunger Worldwide* (FAO, 2013).
103. Ravuvu, A. *Vaka i Taukei: The Fijian Way of Life* (Institute of Pacific Studies of the University of the South Pacific, 1983).
104. Brayboy, B. M. J. & Castagno, A. E. Self-determination through self-education: culturally responsive schooling for indigenous students in the USA. *Teaching Educ.* **20**, 31–53 (2009).
105. Tilley, C. Performing culture in the global village. *Crit. Anthropol.* **17**, 67–89 (1997).
106. Wood, L. J., Fish, L., Laughren, J. & Pauly, D. Assessing progress towards global marine protection targets: shortfalls in information and action. *Oryx* **42**, 340–351 (2008).
107. Jupiter, S. D., Cohen, P. J., Weeks, R., Tawake, A. & Govan, H. Locally-managed marine areas: multiple objectives and diverse strategies. *Pac. Conserv. Biol.* **20**, 165–179 (2014).
108. Friedlander, A. M., Stamoulis, K. A., Kittinger, J. N., Drazen, J. C. & Tissot, B. N. in *Advances in Marine Biology* (eds Johnson, M. L. & Sandell, J.) 153–203 (Academic, Oxford, 2014).
109. Isechal, A. L., Victor, S. & (eds) *Micronesia Protected Area Management Effectiveness: A Guide to Administering the MPAME Tool* (Micronesia Conservation Trust, 2013).

Acknowledgements
We thank F. Arengo, T. Milton, K. Careaga, M. Gueze, L. Sebastien and M. Roué for contributions. The material is based on work supported by the National Science Foundation under grant numbers EF-1427091 and 1444184. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. Support for this project also comes from the Gordon and Betty Moore Foundation, Lynette and Richard Jaffe, and the Jaffe Family Foundation.

Author contributions
E.J.S., C.F., J.N., S.D.J., A.T. and J.M. conceptually framed the manuscript. E.J.S. and C.F. led the development of the manuscript and integration of content. A.S., E.B., G.C., A.T. and N.G. synthesized literature. All remaining authors contributed equally to generating ideas and drafting and revising the manuscript.

Competing interests
The authors declare no competing financial interests.

Additional information
Reprints and permissions information is available at www.nature.com/reprints.

Correspondence and requests for materials should be addressed to E.J.S.

Publisher's note: Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

QUERY FORM

Nature Ecology & Evolution	
Manuscript ID	**[Art. Id: 349]**
Author	**Eleanor J. Sterling**

AUTHOR:

The following queries have arisen during the editing of your manuscript. Please answer by making the requisite corrections directly in the e.proofing tool rather than marking them up on the PDF. This will ensure that your corrections are incorporated accurately and that your paper is published as quickly as possible.

Query No.	*Nature of Query*
Q1:	Author surnames have been highlighted - please check these carefully and indicate if the first name or surname have been marked up incorrectly. Please note that this will affect indexing of your article, such as in PubMed.
Q2:	Please check city name in aff. 4, 11 and 30.
Q3:	Affiliation numbering has been amended - please check all affiliations are still correct.
Q4	Please provide postal/zip codes for affiliations 7, 20, 24, 25, 26 and 31, if applicable.
Q5	regarding affiliation 11, are these two separate affiliations/addresses (i.e. National Center for Scientific Research, CRIOBE and Laboratoire d'Excellence CORAIL?) If so, please provide full addresses for each and list them separately.
Q6	Please note, it is against style to use italics for emphasis or for commonly used Latin/foreign terms, so the text has been amended accordingly throughout.
Q7	If applicable, please reduce the length of any subheadings that spill onto two lines so that they fit onto a single line.
Q8	Please note, it is against style to include author names, so the text has been amended accordingly throughout.
Q9	'peoples" changed to 'people's' (i.e. plural of 'people') throughout, OK?]
Q10	Can we delete the quote marks in the second and third columns of Table 1?
Q11	correct definition of 'MPA' added in Table 1?]
Q12:	Reference 62 was not originally cited in text. Please confirm citation of this reference after the sentence 'Fourth, biocultural approaches …' is ok.
Q13	'Hawai'i Island' changed to simply 'Hawai'i' in the sentence beginning 'For instance, oral...', OK?
Q14	'PW n.d.' changed to 'P.W., unpublished observations' in the sentence beginning 'In New Ireland,...', assuming this is what is meant (where 'P.W.' refers to author Paige West), OK?
Q15	Is 'Mauri model' correct, or should it be ' Maori model' in the sentence beginning 'Tools such as...'?
Q16	Please provide a page range in refs 40 and 68, unless the number given is an article number.
Q17	In ref. 53, please advise whether the journal 'Boletim do Museu Paraense Emilio Goldi. Ciências Humanas' has an abbreviated name.

QUERY FORM

Nature Ecology & Evolution	
Manuscript ID	**[Art. Id: 349]**
Author	**Eleanor J. Sterling**

AUTHOR:

The following queries have arisen during the editing of your manuscript. Please answer by making the requisite corrections directly in the e.proofing tool rather than marking them up on the PDF. This will ensure that your corrections are incorporated accurately and that your paper is published as quickly as possible.

Query No.	*Nature of Query*
Q18	Any update on the publication of ref. 54? Please provide a doi (the one originally provided does not work).
Q19	Please provide city location of publisher for refs 55, 72, 86, 95, 97, 101, 102 and 108.
Q20	Please provide editor name(s) for the book in ref. 57.
Q21	Please provide editor name(s) for the conference proceedings and city location of publisher for ref. 70.
Q22	Changes OK in ref. 71?
Q23	Please provide editor name(s) for the book, and name and city location of publisher for ref. 80.
Q24	Please provide page range of referenced chapter for refs 81 and 89.
Q25	Please provide author name(s) (if different from publisher names) and city location of publication for ref. 94.
Q26	References and citations have been renumbered from 101 onwards - please check.
Q27	is there an editor name missing in ref. 109?