

Weaving knowledge systems in IPBES, CBD and beyond—lessons learned for sustainability

Maria Tengö¹, Rosemary Hill², Pernilla Malmer¹,
Christopher M Raymond³, Marja Spierenburg⁴, Finn Danielsen⁵,
Thomas Elmqvist¹ and Carl Folke^{1,6}



Indigenous peoples and local communities live in, manage and own vast areas often rich in biodiversity and critical for ecosystem services. Bridging indigenous and local knowledge systems with scientific knowledge systems is vital to enhance knowledge, practice, and ethics to move towards sustainability at multiple scales. We focus on international science-policy processes and present a framework for evidence-based guidance on how tasks to mobilise, translate, negotiate, synthesise and apply multiple forms of evidence can bridge knowledge systems. Effective engagement of actors, institutions and knowledge-sharing processes is crucial in each of these tasks. We use examples from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and the Convention on Biological Diversity (CBD) to illustrate and discuss our framework.

Addresses

¹ Stockholm Resilience Centre, Stockholm University, S-106 91 Stockholm, Sweden

² CSIRO Land and Water and James Cook University Division of Tropical Environments and Societies, PO Box 12139, Earlville BC, Cairns 4870, Australia

³ Department of Landscape Architecture, Planning and Management, Swedish University of Agricultural Sciences, PO Box 58, S-230 53 Alnarp, Sweden

⁴ Department of Anthropology and Development Studies, Radboud University Nijmegen, The Netherlands

⁵ NORDECO, Skindergade 23, 3rd floor, DK-1159 Copenhagen K, Denmark

⁶ Beijer Institute of Ecological Economics, Royal Swedish Academy of Sciences, PO Box 50005, S-104 05 Stockholm, Sweden

Corresponding author:

Current Opinion in Environmental Sustainability 2017, **26–27**:17–25

This review comes from a themed issue on **Open issue, part II**

Edited by **Eduardo S Brondizio**, **Rik Leemans** and **William D Solecki**

Received 15 June 2016; Revised 23 November 2016;

Accepted 10 December 2016

<http://dx.doi.org/10.1016/j.cosust.2016.12.005>

1877-3435/© 2017 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

The role for indigenous and local knowledge systems in governance for sustainability

Governance of ecosystems is an enormous challenge in the Anthropocene, characterized by complex interactions and feedbacks of human action and global environmental change [1,2]. Transdisciplinary processes are needed to craft knowledge that is legitimate, credible, and salient, as well as usable for moving towards sustainability [3^{**},4]. Indigenous and local knowledge systems,⁷ and the holders of such knowledge, carry insights that are complementary to science, in terms of scope and content, and also in ways of knowing and governing social-ecological systems during turbulent times and articulating alternative ways forward [5,6^{**},7^{**}]. For example, fisher-farmers in the Amazon delta navigate both gradual and less predictable tidal regime changes and build resilience through generating, innovating, and integrating knowledge of a range of forest, agroforestry, and fishing production systems [8]. Engagement of indigenous peoples and local communities is vital for these knowledge contributions, also as they live in, manage and own vast areas of land often rich in biodiversity and of significance for the generation of critical ecosystem services [9^{*}].

Science-policy arenas and agreements such as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and the Convention on Biological Diversity (CBD) acknowledge the importance of indigenous and local knowledge in their work and explicitly support a diversity of knowledge systems to inform international biodiversity assessments and decision-making [10^{*}]. In sustainability science, research on co-production of knowledge [11,12] has only recently recognized the need for tailoring approaches to meet the particular contexts of diverse knowledge systems [6,13,14]. Engaging with indigenous and local knowledge systems involves encounters of different world views, identities, practices, and ethics, in a context of asymmetries of power and rights [6,15^{**},16]. Tools and approaches that consistently enable engagement towards useable

⁷ Indigenous and local knowledge system: a cumulative body of knowledge, practice and belief, evolving and governed by adaptive processes and handed down and across (through) generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment (see Refs. [10^{*},49,50]).

knowledge for all actors involved in these encounters are not yet available [15**,17**].

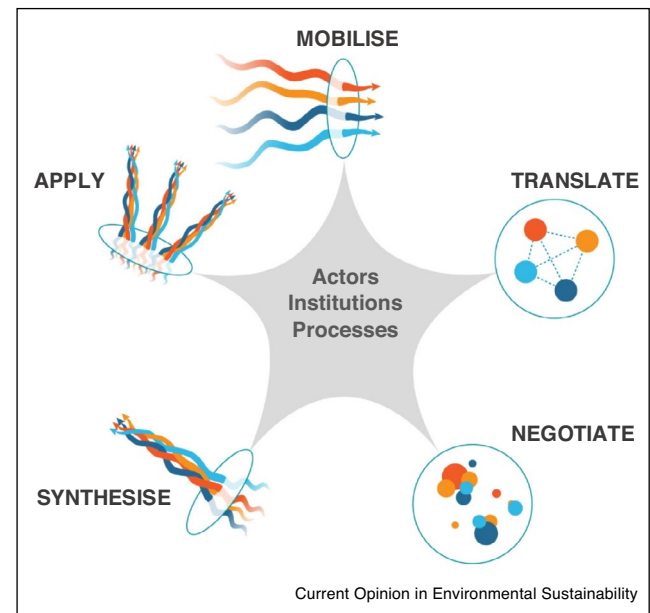
Our aim is to provide guidance for collaborations across knowledge systems in international science-policy processes, based on recent literature from sustainability science, ethnobiology, indigenous studies, conservation, and anthropology. Earlier, we proposed the Multiple Evidence Base, an approach that addresses the implications of going beyond integrating *knowledge* and engaging with diverse *knowledge systems* [17**]. This approach recognises the incommensurability of diverse knowledge systems and the often asymmetric power issues arising when connecting different branches of science with locally-based knowledge systems. Complementarity, validation of knowledge within rather than across knowledge system, and joint assessments of knowledge contributions are key aspects of the approach, which has been promoted by the IPBES and CBD as a suitable approach for working with indigenous and local knowledge in international assessments [10*].

Here, we expand on the approach and present evidence-based guidance on how five tasks—to mobilise, translate, negotiate, synthesise and apply multiple evidence—can bridge indigenous and local knowledge systems and science to enhance governance for sustainability, by enabling engagement of actors and institutions in knowledge-sharing processes that are equitable and empowering. We view the outcome as *weaving—collaborations that respects the integrity of each knowledge system* [cf. 6**]. Emerging from our experiences of practicing co-production of knowledge across knowledge systems in a variety of local to global processes, we present a framework, displayed in Figure 1, which is illustrated and discussed using two examples from global science-policy arenas: IPBES thematic assessment of pollinators, pollination and food production and its piloting of bringing indigenous and local knowledge into assessments; and The Plan of Action on Customary Sustainable Use of Biodiversity under the CBD.

Bridging knowledge systems—actors, institutions, processes

Knowledge has been recognized as “a body of propositions that are adhered to, whether formally or informally, and are routinely used to claim truth” [10*]. Knowledge systems are made up of agents, practices and institutions that organize the production, transfer and use of knowledge [11]. Thus, knowledge is embodied with the actors and in their practices, tools, and technologies, as well as in institutions. Knowledge is inherently dynamic, involving constant evolution of knowledge-based resources and processes for governing those resources [18]. Compared with Western-based science, indigenous and local knowledge systems represent alternative ways of learning from and with the environment, through close and

Figure 1



Conceptual figure illustrating how actors, institutions, and processes are at the core of the five tasks required for successful collaboration across diverse knowledge systems. The circles represent the issue of interest, such as the status of pollinators and pollination (IPBES), or customary sustainable use (CBD). The coloured strands represents contribution from different knowledge systems to the topic, such as from honey hunters (Table 1), published literature on indigenous and local knowledge, as well as from, for example, ecology, agronomy, and entomology in the pollination assessment.

Mobilise means to bring out and articulate knowledge into a form that can be shared with others. **Translate** implies interactions between knowledge systems, indicated by the dotted lines, to enable mutual comprehension of the shared knowledge. **Negotiate** means joint assessment of convergence, divergence and conflicts across knowledge contributions, illustrated here by the combination of some coloured strands (convergence), whereas other may remain contradictory. **Synthesise** concern shaping a broadly accepted common knowledge that maintains the integrity of each knowledge system, illustrated here by braided strands, rather than ‘integrating’ into one knowledge system. **Apply** emphasizes knowledge usable for decision making for all actors involved, at different scales, that can feed back into respective knowledge system, represented here by multiple braids.

continuous observation framed by distinct worldviews with strengths and limitations (like all knowledge systems) [6**]. Thus, in a world dominated by industrialized societies, the issue is not only whether indigenous and local knowledge carry value for sustainability, but also whether collaborative processes to improve sustainability can support *in situ* living knowledge, actors and institutions [5,7**]. The bridging of knowledge systems [23] therefore requires the creation of settings for multiple forms of knowledge exchange and learning across key aspects of the system: its (1) actors, (2) institutions and (3) processes (Figure 1).

Actors embodying and representing knowledge systems

Knowledge systems can be viewed as networks of actors connected by – formal and informal – social relationships that dynamically combine doing, learning, and knowing [18]. Indigenous and local knowledge, similar to scientific knowledge, is produced in a context of power relations. It is not equally distributed; some knowledge may be considered the domain of specialists or persons of specific positions and/or gender [4,20]. Therefore, representation is a challenge, and careful consideration is needed about whom is considered the spokesperson(s) of indigenous and local knowledge systems, how they are appointed, and what forms of representation is allowed for and enabled in science-policy processes [21,22]. Indigenous and local knowledge systems are often represented by researchers who have studied such knowledge ('Experts on ILK'), rather than the knowledge holders themselves representing their knowledge system and its integrity and rights ('ILK holders') [15^{••}]. Nevertheless, some indigenous and local knowledge holders have accumulated experiences in international contexts, such as the CBD, and may act as brokering 'scale-crossing ILK-holders' [23,24].

The institutional context of knowledge

To build social-ecological resilience, knowledge needs to be embedded in an institutional context that enables application and learning from experience over time [25]. Activities and interactions within indigenous and local knowledge systems take place within diverse social contexts, where customary institutions influence knowledge transmission and validation [15^{••},26]. Intellectual and cultural rights are often attached to knowledge, and must be accounted for in decisions about how, when and under what conditions knowledge can be shared [20,27]. The social and historical contexts of colonization, suppression or abuse of cultures and customary laws needs to be taken into account as institutions may need to be revived and/or strengthened to ensure inclusiveness and democratic participation [7^{••},9[•],28]. As Agrawal [29] notes, the key defining characteristic of indigenous and local knowledge is that it is at least constituted, and often both controlled and managed by, indigenous peoples and local communities through formal and informal institutions. Thus, it is critical to recognize that knowledge that is taken out of its context and transformed into new modes may cause harm (as well as benefit) to the knowledge holders and their institutions [7^{••},27,30]. Indigenous methodologies are approaches undertaken by the knowledge holders themselves, and thus firmly embedded in their worldviews, reflecting their reality, history and lived experiences [15^{••},30,31]. Knowledge sharing and learning within can also strengthen indigenous institutions.

Processes for collaboration

To deliver useable new forms of knowledge and avoid harm to already vulnerable communities requires close

attention to design and delivery of knowledge-sharing processes that are equitable and empowering [15^{••}]. Meaningful participation throughout all stages is emphasized in many studies [3^{••},13]. Addressing power asymmetries involves providing space for reshaping the rules and norms governing the relationships of co-production of knowledge [3^{••},6^{••},19[•]], and structures that can distribute decision making power [18,32,33]. Effective knowledge brokerage and arenas that enable building of relationships, trust, and respect is vital [19[•],34,35]. Indigenous governance and Indigenous-driven co-governance can provide conditions that are prospective for effective bridging with Western science [20].

Five tasks to enable bridging of knowledge systems

Emerging from our experiences in a variety of local to global processes, we identify five tasks which appear to be commonly present and critical for successful outcomes for bridging of knowledge systems (Figure 1). A literature review on indigenous and local knowledge systems in ecosystem assessments and related contexts was undertaken to anchor and strengthen our combined theoretical and practical understanding of the tasks and to provide empirical guidance to implement them. In the following, we present and illustrate the tasks using two processes within IPBES and CBD (Box 1). The tasks as applied on the cases are summarized in Tables 1 and 2 and analyses strengths and weaknesses in the two processes respectively. The analysis is based on secondary sources, see Table 1. Identification of sources was guided by expert-selection, reflecting experiences from two of the authors who were closely involved in the actual CBD process and the IPBES assessment respectively.

Mobilise: means to *develop knowledge-based products or outcomes through a process of innovation and/or engaging with past knowledge and experience* [36,37]. Along with the Multiple Evidence Base approach, we emphasize that such mobilization processes should respect validation mechanisms within the knowledge systems involved. In the example on indigenous and local knowledge for customary sustainable use in relation to the CBD, a bridging organization facilitated community led processes of mobilizing the communities' own knowledge, using methods adjusted to the local cultural context. In the honey hunter example, experts from different indigenous groups, supported by an indigenous organisation, came together and documented key features of their knowledge that they viewed as relevant to the IPBES pollination assessment (Table 1).

To increase the relevance, and maintain the integrity and context of the insights included in ecosystem assessments, it is important to secure that knowledge has been clearly and recently legitimated by actors representing the knowledge system, [17^{••},38]. For example,

Box 1 Two examples of engagement with indigenous and local knowledge systems in international science-policy processes.

The IPBES thematic assessment of pollinators, pollination and food production and its piloting of bringing in ILK in IPBES assessments and other functions. IPBES has among its core principles undertaken to recognize and respect the contribution of ILK to the conservation and sustainable use of ecosystems. The first IPBES work programme 2014–2018, adopted at IPBES 2 in late 2013, includes development of procedures, approaches and participatory processes for working with ILKS in IPBES as one of its deliverables. The procedures will be developed through, for example, global dialogues with ILK holders and experts (e.g. http://www.unesco.org/new/fileadmin/MULTIMEDIA/HQ/SC/pdf/IPBES_Pollination-Pollinators_Workshop.pdf). A specific participatory mechanism will be put in place. IPBES also decided to use the thematic assessment of pollinators, pollination and food production for the first piloting of procedures and approaches for working with ILK. The scoping of the pollinators assessment started in 2013, and the pollinator assessment was approved at IPBES 4 in early 2016. For more information see: <http://www.ipbes.net/work-programme/pollination>.

The Plan of Action on Customary Sustainable Use of Biodiversity under the Convention on Biological Diversity (CBD). Its objective is to recognise, promote and support customary sustainable use (CSU) at local, national, regional and international levels, and to ensure the full and effective participation of indigenous peoples and local communities at all stages of implementation of the plan. The nations adhering to the CBD have agreed to protect and encourage customary use of biological resources in accordance with traditional cultural practices that are compatible with conservation or sustainable use requirements. In 2004 it was recognized that there was a scarcity of practical information about and examples of customary sustainable use of biological diversity by indigenous peoples and local communities and how such use can be encouraged. In response to this call for advice, while also fulfilling the desire to document and safeguard their knowledge, indigenous organizations and support organisations from Bangladesh, Suriname, Guyana, Cameroon, Thailand and Venezuela, started to develop case studies to promote customary sustainable use. These case studies became a core stream of evidence contributing to the CBD processes to develop a Plan of Action on Customary Sustainable Use that was finally adopted in 2014 at the 12th Conference of the Parties. For more information see: <http://www.forestpeoples.org/customary-sustainable-use-studies>; <https://www.cbd.int/decision/cop/default.shtml?id=13375>.

indigenous knowledge may be embedded in poems, rituals and practice, and engagement with key knowledge actors, such as elders, is needed to agree what knowledge is relevant and valid and can be shared. There is an emerging literature on community driven mobilization of knowledge as a mean to revitalize, safe-guard and expand knowledge systems [24,39,40]. Johnson *et al.* [6**] summarize participatory methods for mobilising knowledge in collaborations that empower holders of indigenous and local knowledge and their institutions.

Translate: means to *adapt knowledge products or outcomes into forms appropriate to enable mutual comprehension in the face of differences between actors*. Translate involves multi-directional interactions between actors representing all

knowledge systems to enable mutual understanding of respective contributions. It implies communication using a language and terms that can be understood by all actors [37] and clarifying knowledge claims or criteria of credibility in a respectful way [4]. In both cases in Table 1, reports and presentations emerging from the mobilization were shared and discussed at dialogue sessions, engaging ILK holders together with ILK experts and delegates from bridging organizations. Knowledge brokerage is key to foster common understandings, and is supported by use of boundary objects (such as jointly produced maps, pictures or conceptual frameworks) [19*,34,37]. Critical to these processes are boundary organizations (organizations with the specific role of linking science to policy), bridging organizations (organizations which can create connectivity between groups, locations and worldviews) and bridging and bonding networks (structural arrangements between individuals and organizations) [4,19*,34,41,42].

Negotiate: means to *interact among different knowledge systems to develop mutually respectful and useful representations of knowledge* [3**,4]. It involves joint assessments of convergence, divergence and conflicts across knowledge contributions brought forward through mobilization [17**]. In the pollination assessment, the negotiation of contributed knowledge about honey-hunting to the assessment was done by chapter authors and ILK-experts. In the CBD case, representatives from the five communities participated in the expert meeting discussing an action plan for customary sustainable use and contributed recommendations (Table 1). Different knowledge systems have been shown to produce converging but complementary insights at the same scale, and innovative insights when recognizing knowledge generated at different scales [17**,43]. In many examples, contradictions between different data were resolved when scale and resolution was unpacked [38,43,44]. Conflicts may remain concerning the causality behind an identified pattern, and what management options are appropriate to deal with it [43]. Thus negotiation needs awareness of the dual role of actors, including scientists, as experts and carriers of knowledge as well as stakeholders with vested interests and representing or possessing different, sometimes unequal, levels of power [3**].

Synthesise: means to *shape broadly accepted common knowledge bases for a particular purpose*; it involves building a systems-based understanding of the problem [17**,45], and supporting enlightenment, decision making, or further negotiation of a particular issue [36,41]. In the Summary for Policy Makers emerging from the IPBES pollination assessment, the contributions of practices of honey hunters to enhancing pollinators were recognised, with recommended support for recognition of rights and tenures of indigenous peoples to secure these contributions. The development of the Action Plan included a

Table 1

Description of key task and examples from IPBES and CBD to illustrate how they were manifested. The example from IPBES concerns one case of direct involvement of ILK holders in mobilizing knowledge on pollination and how it was included in the assessment report. The CBD example describes a more extensive process, coordinated by a bridging organization, of communities mobilizing knowledge internally to contribute to the development of an action plan on Customary Sustainable Use

Task description	IPBES example: honey hunters knowledge in pollination assessment	CBD example: community led knowledge contributions for developing a Plan of Action on Customary Sustainable Use.
Mobilise: <i>Develop knowledge-based products through a process of innovation and/or engaging with past knowledge and experience.</i>	Knowledge of 8 honey-hunters from four regions in Indonesia shared in a discussion session on Belitung Island, hosted by an ILK-holder from an Indigenous NGO and an ILK-expert from a research organization. Participants selected by IPBES ILK Taskforce from responses to a global call for nominations based on criteria of relevance, significance and capacity to engage.	Independent community-led mobilization of knowledge in five countries using a joint procedure coordinated by a bridging organization. Community researchers identified in community workshops, and trained in interview techniques, report writing and facilitation. Information on traditional knowledge and customary rules and practices gathered by means of questionnaires, group discussions, interviews, participatory rural appraisals, village walks, and so on, adjusted to local culture and context. ^c
Translate: <i>Adapt knowledge products or outcomes into forms appropriate to enable mutual comprehension in the face of differences between actors</i>	Information from above (e.g. how flowering signals harvest-times, songs required for successful harvests, taboos on felling nest trees) included in joint presentation by ILK-holders and experts at the Panama Global Dialogue which brought together ILK-holders, ILK-experts and Chapter Authors focused on ILK of pollinators and food production, and subsequently published in chapter in the Dialogue Outcomes. ^a	Above case studies (including information about, for example, how forests are categorized and managed by communities for specific purposes, such as rotational cultivation, or safeguarded for wildlife or water protection and spiritual needs) presented by ILK holders and discussed at several preparatory meetings and CBD events attended by bridging organizations, CBD Parties representatives and invited experts.
Negotiate: <i>Interact among different knowledge systems to develop mutually respectful and useful representations of knowledge</i>	Authors and ILK-experts (no ILK-holders) co-produced material included in Chapter 5 of the Pollination Assessment; seven practices in-common among honey-hunters that contribute to fostering bees identified, including taboos and sacred areas; totemic and/or spiritual relationships between people and pollinators; actions to foster pollinator nesting resources. ^{a,b}	Case studies presented and discussed at CBD Expert Meeting on Customary Sustainable Use in 2011. Indigenous peoples and local community representatives from the five communities, and others, participated through CBD nomination process. They contributed recommendations into the Expert Meetings report. ^d
Synthesize: <i>Shape broadly accepted common knowledge bases for a particular purpose</i>	Summary for Policy Makers recognizes the practices of honey-hunters that protect bees and recommends support for recognition of rights and tenures associated with such practices.	CBD Secretariat synthesized draft text based on expert meetings recommendations and submissions from Parties and other actors including additional organizations representing ILK-holders in an open and transparent process. Draft Plan of Action negotiated and further synthesized through additional contributions from Indigenous peoples and local community organizations, during CBD meetings 2011–2013 with ILK holders participating and contributing inputs through the International Indigenous Forum for Biodiversity.
Apply: <i>Use common knowledge bases to make decisions and/or take actions and to reinforce and feedback into the knowledge systems</i>	Panama Global Dialogue Outcomes report returned to honey-hunters; Summary for Decision makers findings considered by CBD in December 2016 and subsequently by national level governments. Evidence from assessment, including ILK, to be included in all relevant decisions in the biodiversity related conventions.	Plan of Action, approved in CBD COP12 2014, ^e recognizes the importance of ILK practices for biodiversity conservation and sustainable use and makes recommendations for governments to include Customary Sustainable Use in National Biodiversity Strategy and Action Plans. Network of indigenous peoples and local communities strengthened and expanding for mobilizing knowledge, more case studies added continuously, and also including contributions to monitoring of Aichi Targets. ^{f,g}

^a Lyver, P, E Perez, M Carneiro da Cunha and M Roue (eds.). 2015. Indigenous and Local Knowledge about Pollination and Pollinators associated with Food Production: Outcomes from the Global Dialogue Workshop (Panama 1-5 December 2014). UNESCO: Paris. Online: http://www.unesco.org/new/fileadmin/MULTIMEDIA/HQ/SC/pdf/IPBES_Pollination-Pollinators_Workshop.pdf.

^b Hill, R, Kwapong, P, Nates-Parra, G, Breslow, S, Buchori, D, Howlett, B, LeBuhn, G, Maués, MM, Quezada-Euán, JJ, Saeed, S, (2016 (in press)) Chapter 5: Biocultural diversity, pollinators and their socio-cultural values, in: Potts, SG, Imperatriz-Fonseca, VL, Ngo, HT (Eds.), Pollinators, pollination and food production: a global assessment. Contribution of the expert group to the First Assessment Report (Deliverable 3a) of the Intergovernmental Platform on Biodiversity and Ecosystem Services Bonn, Germany. Online: <http://www.ipbes.net/work-programme/pollination>.

^c Forest Peoples Programme. 2011. Customary sustainable use of biodiversity by indigenous peoples and local communities. Examples, challenges, community initiatives and recommendations relating to CBD Article 10(c). A synthesis paper based on case studies from Bangladesh, Cameroon, Guyana, Suriname, and Thailand.

^d CBD 2011. UNEP/CBD/WG8J/7/5/Add.1. Report of the Meeting on Article 10 with a Focus on Article 10(c) as a Major Component of the Programme of Work on Article (j) and Related Provisions of the Convention.

^e CBD Decision XII/12 Annex 1. Plan of Action on Customary Sustainable Use.

^f Ferrari MF, de Jong C, Belohrad VS: Community-based monitoring and information systems (CBMIS) in the context of the Convention on Biological Diversity (CBD). Biodiversity 2015, 16:57–67.

^g CBD 2016. UNEP/CBD/SBI/1/INF/51. Outlooks on Biodiversity: Indigenous Peoples and Local Communities' Contributions to the Implementation of the Strategic Plan for Biodiversity 2011–2020—A Complement to the Fourth Edition of the Global Biodiversity Outlook.

Table 2

Discussion of strength and weaknesses the two examples from IPBES and CBD (see more in [Box 1](#)) in terms of engagement with actors, institutions and knowledge-sharing processes representing diverse knowledge systems across the five tasks.

	IPBES pollination assessment		CBD Action Plan for customary sustainable use	
	Examples of strengths	Examples of weaknesses	Examples of strengths	Examples of weaknesses
Actors: <i>How were diverse knowledge systems' actors engaged in the tasks?</i>	Some ILK-holders and some IPBES authors had opportunity to engage separately and together in mobilise and translate tasks.	ILKS represented mainly through scientific experts. ILK-holders were not directly engaged in negotiate, synthesis or apply tasks. Scale-crossing ILK-holder actors present only for first part of Assessment.	ILK holders, communities, and organizations mobilizing their knowledge, were part of initiating the process, and were represented the whole way through. Transparency in including contributions from different actors and knowledge systems. Indigenous peoples and local communities full and effective participation welcomed and encouraged in CBD meetings and procedures for participation in place.	Limited direct involvement by scientists in mobilization, negotiation, translation; coming in late in process, and mainly in roles of government representatives. Highly formal process requiring skills and resources that are limited for ILK holders.
Institutions: <i>How were diverse knowledge systems' institutions involved (e. g. mechanisms for validating and governing knowledge) in the tasks?</i>	Panama Global Dialogue provided an opportunity for the indigenous territory Guna Yala to explain their governance through a Congress which subsequently authorized use of a Mola image representing pollinators in the Assessment.	The ILK-holders' institutions were directly engaged only to a small extent through their organisations (e.g. Guna Congress) and not at all in the validation of their knowledge in the synthesis of the Summary for Policy Makers.	ILK holders' institutions strongly involved in mobilization. Represented by ILK holders and bridging organizations through the whole process. Self-identification of engagement, that is, indigenous peoples and local communities were welcome to contribute case studies and provide input on process.	Community involvement in mobilization externally supported. Strong involved of ILKS for Customary Sustainable Use, more challenging in other CBD work where link to ILK is less apparent.
Processes: <i>Did the processes provide for equity and power-sharing between and among the diverse knowledge systems?</i>	Some resources made available to ILK-holders for travel and networking with each other helped equalize power imbalances between ILK and science.	No resources for ILK-holders for community mobilization, or engagement in several tasks. IPBES processes dominated by scientific knowledge systems and very short timelines, giving limited space for engagement with ILK holders.	Initiative and continuous engagement from indigenous peoples and local communities in the process. Procedures facilitate full and effective participation of indigenous peoples and local communities representatives. Voluntary fund for participation. Inclusive process enabled usefulness for all involved.	The process from case studies to decision on Plan of Action took almost a decade. Resources remain a bottleneck; ILK holders fundraised for pilot cases and partly also their own participation in the process.

number of steps to foster contributions from, for example, additional community organizations, through encouraging their participation in CBD meetings and written contributions to open calls (Table 1). While synthesis may sometimes imply integration of all knowledge into scientific knowledge, here we emphasize collaborative approaches allowing for diversity and thereby fostering mutual respect and accessibility to knowledge [19^{*},23]. A synthesis may include and illuminate areas of high convergence between knowledge systems as well as contradictory evidence. Co-produced synthesis can also lead to innovation and identification of new questions for further investigation [17^{**}]. We seek to inspire new forms of synthesis which may speak to different cultures and worldviews about human-environment interactions for sustainability, akin to weaving which maintains the integrity of each strand [6^{**},17^{**}].

Apply: means to *use common knowledge bases to make decisions and take actions, and to reinforce and feedback into the knowledge systems*. Applications of synthesised knowledge should be relevant for all actors involved, and may take different forms, for example, for local communities as ‘working knowledge’ in governing their own territories [35,46], and play out at different scales [14]. For both examples in Table 1, it is not straightforward to assess the extent to which the knowledge was actually applied beyond the policy recommendations to governments, in particular for the pollination assessment which was only recently concluded. For customary sustainable use, the Plan of Action is now ready for implementation by CBD Parties. Such implementation may be strengthened by demands from the networks of indigenous peoples and local communities that have developed in the process. The networks are extending and being active in other contexts as well, which can be seen as an application of lessons learned from mobilizing knowledge and empowerment from the recognition of the contributions.

A range of challenges emerge in knowledge application, such as strategic use of knowledge by actors (including scientists) [47], and institutional barriers to connect knowledge with action at various scales [26]. It is essential for successful application that the actors involved also have the agency and rights to apply new insights through suitable governance arrangements [7^{**},23].

Ways forward for learning about sustainability across knowledge systems

Exercises in bridging between indigenous and local knowledge systems and science in IPBES and CBD involved all the tasks of our framework, resulting in new insights for governance of social-ecological systems in relation to biodiversity and ecosystem management (Table 1). Nevertheless, both strengths and weaknesses can be identified in the extent to which actors, institutions and processes of the diverse knowledge systems were

effectively engaged (Table 2). For example, in the IPBES pilot, ILK-holders were involved to some extent to *mobilise* and *translate*, but were not ‘following’ their knowledge into *negotiate*, *synthesise*, and *apply*. Such limitations may impact negatively on the institutions for knowledge governance [27], but also on existing ecosystem management [7^{**}], and lessen the potential for new and innovative approaches for dealing with environmental challenges [9^{*}].

Mobilisation of indigenous and local knowledge is a key task that has received little attention in IPBES and CBD and related processes [48]. Focusing on dialogue for bridging knowledge as within the IPBES example, assumes that knowledge is accessible and can be easily shared, ignoring the complexities around indigenous and local knowledge systems that are place-based, practical, oral, tacit—and has a local political context. In the CBD example, community-led mobilisation was independently funded and led, and mechanisms were applied to include communities’ contributions into decision-making in a transparent way. Through the processes used, the CBD example was piloting validation of knowledge within indigenous and local knowledge systems [17^{**}]. The importance of scale-crossing actors has been highlighted in both the IPBES and CBD. Networks and organizations such as the International Indigenous Forum on Biodiversity (IIFB) and Forest Peoples Programme (FPP) enabled the inclusion and nurturing of ‘scale-crossing ILK’ holders to contribute to CBD as well as IPBES [24]. However, attention is required to procedures and mechanisms that enable involvement of key actors that do not fit as experts in line with demands for academic or ‘representational’ credentials.

Legitimacy, credibility, and saliency of knowledge is fundamental, but key questions remain about how to ensure that knowledge is usable in efforts toward sustainability, using the words of Clark *et al.* [3^{**}]. As a majority of the Earth’s surface is governed by Indigenous peoples and local communities [9^{*}], knowledge systems need to be bridged in ways that are useful to, and does justice to, their efforts [7^{**}]. This holds also true for insights and innovations from indigenous and local knowledge systems which may strengthen the efforts of industrialised societies in transformations towards stewardship of the biosphere, including navigating the complexity and uncertainty of the Anthropocene. We argue that attention to the roles of actors, institutions and knowledge sharing processes in the five tasks provides the foundation for weaving knowledge that is useable for bodies like the IPBES and CBD, as well as on the ground.

Conclusions

Effective collaboration across knowledge systems is sorely needed to ensure inclusive and equitable pathways for governing ecosystems within planetary boundaries in

the Anthropocene, as is acknowledged in IPBES and other global assessments [9*,10*]. Achieving such collaboration will require moving from studies “into” or “about” indigenous and local knowledge systems, to equitable engagement *with* and *among* these knowledge systems to support mutual investigations into our shared environmental challenges. Numerous examples show how bridging knowledge systems can be constructive and innovative in place-based problem solving contexts [15**,23,32,33,38]. Our review shows that for such experiences to be relevant beyond the local, attention needs to be directed towards engagement of knowledge holders and their institutions, and well-designed processes that build trust and communication across barriers of language, culture, worldviews and experience. Such engagement requires substantial investments of both time and funds for logistics, interpreters, preparation and participation. Furthermore, addressing issues of identification, representation, delegation, and liaison requires recognition of and adaptation to the diverse contexts within which indigenous and local knowledge systems exist. This brief review points to emerging methods and experiences, as well as expanding networks of capacity, which can support solutions to the many challenges.

Insights from the CBD and IPBES processes underpin the framework we present that recognizes actors as knowledge carriers, institutions as critical moderators of knowledge systems, and promotes processes that empower all actors. Such a framework can guide practice as well as further research on successful co-production of knowledge to support sustainability transitions at local as well as at larger scales. There is a great need to investigate how such knowledge, emerging out of joint learning processes that embrace critical connections of people and nature, may lead to innovative ways of addressing the challenges of the Anthropocene.

Acknowledgements

This work was funded by the Swedish Research Council [VR 2015-03441]. Support is also acknowledged from the Northern Australia Environmental Resources Hub of Australia's National Environmental Science Program and CSIRO Land and Water and from a core grant to the Stockholm Resilience Centre by Mistra. We would also like to thank the various networks and organizations of indigenous peoples and local communities from local to global that are engaging in the processes of CBD and IPBES respectively, and Jerker Lokrantz at Azote for the illustration.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- of special interest
 - of outstanding interest
1. Steffen W, Richardson K, Rockström J, Cornell SE, Fetzer I, Bennett EM, Biggs R, Carpenter SR, de Vries W, de Wit CA *et al.*: **Planetary boundaries: guiding human development on a changing planet.** *Science* 2015, **347**:1259855.
 2. Homer-Dixon T, Walker B, Biggs R, Crépin AS, Folke C, Lambin EF, Peterson GD, Rockström J, Scheffer M, Steffen W *et al.*: **Synchronous failure: the emerging causal architecture of global crisis.** *Ecol Soc* 2015, **20**.
 3. Clark WC, van Kerkhoff L, Lebel L, Gallopin GC: **Crafting usable knowledge for sustainable development.** *Proc Natl Acad Sci* 2016, **113**:201601266.
- The paper firmly places studies of co-production of knowledge in the context of generating useable knowledge for sustainability— adding usable to the often cited trioka of legitimate, credible, and salient knowledge – and addresses co-production relationships from the perspective of innovation system, complex systems, adaptive systems and political systems. The focuses is on what science and researchers need to learn about co-production of knowledge to turn knowledge into practice.
4. Cash DW, Clark WC, Alcock F, Dickson NM, Eckley N, Guston DH, Jäger J, Mitchell RB: **Knowledge systems for sustainable development.** *Proc Natl Acad Sci U S A* 2003, **100**:8086-8091.
 5. Reyes-García V, Fernández-Llamazares Á, Guèze M, Garcés A, Mallo M, Vila-Gómez M, Vilaseca M: **Local indicators of climate change: the potential contribution of local knowledge to climate research.** *Wiley Interdiscip Rev Clim Chang* 2016, **7**:109-124.
 6. Johnson JT, Howitt R, Cajete G, Berkes F, Louis RP, Kliskey A: **Weaving indigenous and sustainability sciences to diversify our methods.** *Sustain Sci* 2015, **11**:1-11.
- The paper introduces a special issue on Weaving Indigenous and Sustainability Science and sets the scene in terms of challenges, methodologies to move forward as well as the potential for collaboration between indigenous and sustainability science.
7. Mistry J, Berardi A: **Bridging indigenous and scientific knowledge.** *Science* 2016, **352**:1274-1275.
- Provides a convincing argument for why local ecological knowledge should be placed at the centre of environmental governance and what the costs may be with failure of bridging knowledge systems
8. Vogt N, Pinedo-Vasquez M, Brondizio ES, Rabelo FG, Fernandes K, Almeida O, Riveiro S, Deadman PJ, Dou Y: **Local ecological knowledge and incremental adaptation to changing flood patterns in the Amazon delta.** *Sustain Sci* 2016, **11**:611-623.
 9. Brondizio ES, Le Tourneau F-M: **Environmental governance for all.** *Science* 2016, **352**:1272-1273.
- Outlines the extensive role of indigenous and local communities in managing biodiversity and ecosystem across the globe and the ethical as well as pragmatic reasons for effective inclusion of people in environmental governance.
10. Díaz S, Demissew S, Carabias J, Joly C, Lonsdale M, Ash N, Larigauderie A, Adhikari JR, Arico S, Baldi A *et al.*: **The IPBES Conceptual Framework—connecting nature and people.** *Curr Opin Environ Sustain* 2015, **14**:1-16.
- The IPBES conceptual framework including how it deals with knowledge and diverse knowledge systems.
11. Cornell S, Berkhout F, Tuinstra W, Tàbara JD, Jäger J, Chabay I, de Wit B, Langlais R, Mills D, Moll P *et al.*: **Opening up knowledge systems for better responses to global environmental change.** *Environ Sci Policy* 2013, **28**:60-70.
 12. Mauser W, Klepper G, Rice M, Schmalzbauer BS, Hackmann H, Leemans R, Moore H: **Transdisciplinary global change research: the co-creation of knowledge for sustainability.** *Curr Opin Environ Sustain* 2013, **5**:420-431.
 13. Reid RS, Nkedianye D, Said MY, Kaelo D, Neselle M, Makui O, Onetu L, Kiruswa S, Kamuaru NO, Kristjansson P *et al.*: **Knowledge Systems for Sustainable Development Special Feature Sackler Colloquium: evolution of models to support community and policy action with science: Balancing pastoral livelihoods and wildlife conservation in savannas of East Africa.** *Proc Natl Acad Sci U S A* 2009, **113**:4579-4584.
 14. Galvin KA, Reid RS, Fernández-Giménez ME, ole Kaelo D, Baival B, Krebs M: **Co-design of transformative research for rangeland sustainability.** *Curr Opin Environ Sustain* 2016, **20**:8-14.
 15. Whyte KP, Brewer JP, Johnson JT: **Weaving Indigenous science, protocols and sustainability science.** *Sustain Sci* 2015, **11**:25-32.

Provides tools and examples for successful bridging of Indigenous and sustainability science, and bring forward caretaking and stewardship as characterizing Indigenous science protocols for sustainability.

16. Robinson CJ, Maclean K, Hill R, Bock E, Rist P: **Participatory mapping to negotiate indigenous knowledge used to assess environmental risk.** *Sustain Sci* 2016, **11**:115-126.
17. Tengö M, Brondizio ES, Elmqvist T, Malmer P, Spierenburg M:
 - **Connecting diverse knowledge systems for enhanced ecosystem governance: the multiple evidence base approach.** *Ambio* 2014, **43**:579-591.
 Presents the Multiple Evidence Base approach to collaborations among knowledge systems which this review builds and expands upon.
18. van Kerkhoff L, Szlezák NA: **The role of innovative global institutions in linking knowledge and action.** *Proc Natl Acad Sci U S A* 2016, **113**:4603-4608.
19. Rathwell KJ, Armitage D, Berkes F: **Bridging knowledge systems to enhance governance of environmental commons: a typology of settings.** *Int J Commons* 2015, **9**:851-880.
 - A review of settings for bridging knowledge systems and implications for understanding change in social-ecological systems.
20. Hill R, Grant C, George M, Robinson CJ, Jackson S, Abel N: **A typology of indigenous engagement in Australian environmental management: implications for knowledge integration and social-ecological system sustainability.** *Ecol Soc* 2012, **17**.
21. Beck S, Borie M, Chilvers J, Esguerra A, Heubach K, Hulme M, Lidskog R, Lövbrand E, Marquard E, Miller C, Nadim T, Neßhöver C, Settele J, Turnhout E, Vasileiadou E, Görg C: **Towards a reflexive turn in the governance of global environmental expertise the cases of the IPCC and the IPBES.** *GAIA* 2014, **23**(2):80-87.
22. Voß J, Bornemann B: **The politics of reflexive governance: challenges for designing adaptive management and transition management.** *Ecol Soc* 2011, **16**.
23. Hill R, Davies J, Bohnet IC, Robinson CJ, Maclean K, Pert PL: **Collaboration mobilises institutions with scale-dependent comparative advantage in landscape-scale biodiversity conservation.** *Environ Sci Policy* 2015, **51**:267-277.
24. Ferrari MF, de Jong C, Belohrad VS: **Community-based monitoring and information systems (CBMIS) in the context of the Convention on Biological Diversity (CBD).** *Biodiversity* 2015, **16**:57-67.
25. Berkes F, Folke C: **Linking social and ecological systems. Management Practices and Social Mechanisms for Building Resilience.** Cambridge: University Press; 1998.
26. Wyborn CA: **Connecting knowledge with action through coproductive capacities: adaptive governance and connectivity conservation.** *Ecol Soc* 2015, **20**:11.
27. Williams T, Hardison P: **Culture, law, risk and governance: contexts of traditional knowledge in climate change adaptation.** *Clim Change* 2013, **120**:531-544.
28. Gómez-Baggethun E, Reyes-García V: **Reinterpreting change in traditional ecological knowledge.** *Hum Ecol Interdiscip J* 2013, **41**.
29. Agrawal A: **Indigenous knowledge and the politics of classification.** *Int Soc Sci J* 2002, **54**:287-297.
30. Smith LT: *Decolonizing Methodologies: Research and Indigenous Peoples.* Zed Books; 1999.
31. Kealiikanakaoleohailani K, Giardina CP: **Embracing the sacred: an indigenous framework for tomorrow's sustainability science.** *Sustain Sci* 2016, **11**:57-67.
32. Funder M, Ngaga Y, Nielsen M, Poulsen M, Danielsen F: **Reshaping conservation: the social dynamics of participatory monitoring in Tanzania's Community-managed forests.** *Conserv Soc* 2013, **11**:218.
33. Danielsen F, Topp-Jørgensen E, Levermann N, Løvstrøm P, Schiøtz M, Enghoff M, Jakobsen P: **Counting what counts: using local knowledge to improve Arctic resource management.** *Polar Geogr* 2014, **37**:69-91.
34. Wyborn C: **Connectivity conservation: boundary objects, science narratives and the co-production of science and practice.** *Environ Sci Policy* 2015, **51**:292-303.
35. Robinson CJ, Wallington TJ: **Boundary work: engaging knowledge systems in co-management of feral animals on indigenous lands.** *Ecol Soc* 2016, **17**:16.
36. Raymond CM, Fazey I, Reed MS, Stringer LC, Robinson GM, Evely AC: **Integrating local and scientific knowledge for environmental management.** *J Environ Manage* 2010, **91**:1766-1777.
37. Fazey I, Evely AC, Reed MS, Stringer LC, Kruijsen J, White PCL, Newsham A, Jin L, Cortazzi M, Phillipson J et al.: **Knowledge exchange: a review and research agenda for environmental management.** *Environ Conserv* 2012, **40**:19-36.
38. Danielsen F, Jensen PM, Burgess ND, Coronado I, Holt S, Poulsen MK, Rueda RM, Skielboe T, Enghoff M, Hemmingsen LH et al.: **Testing focus groups as a tool for connecting indigenous and local knowledge on abundance of natural resources with science-based land management systems.** *Conserv Lett* 2014, **7**:380-389.
39. Kealiikanakaoleohailani K, Giardina CP: **Embracing the sacred: an indigenous framework for tomorrow's sustainability science.** *Sustain Sci* 2016, **11**:57-67.
40. Davidson-Hunt IJ, Michael O'Flaherty R: **Researchers, indigenous peoples, and place-based learning communities.** *Soc Nat Resour* 2007, **20**:291-305.
41. Clark WC, Tomich TP, van Noordwijk M, Guston D, Catacutan D, Dickson NM, McNie E: **Boundary work for sustainable development: natural resource management at the Consultative Group on International Agricultural Research (CGIAR).** *Proc Natl Acad Sci U S A* 2016, **113**:4615-4622.
42. Hahn T, Olsson P, Folke C, Johansson K: **Trust-building, knowledge generation and organizational innovations: the role of a bridging organization for adaptive comanagement of a wetland landscape around Kristianstad, Sweden.** *Hum Ecol* 2006, **34**:573-592.
43. Moller H, Berkes F, Lyver POB, Kislalioglu M: **Combining science and traditional ecological knowledge: monitoring populations for co-management.** *Ecol Soc* 2004, **9**:2.
44. Gagnon CA, Berteaux D: **Integrating traditional ecological knowledge and ecological science: a question of scale.** *Ecol Soc* 2009, **14**:19.
45. 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* 2011, **21**:995-1004.
46. Barber M, Jackson S, Shellberg J, Sinnamon V: **Working Knowledge: characterising collective indigenous, scientific, and local knowledge about the ecology, hydrology and geomorphology of Oriners Station, Cape York Peninsula, Australia.** *Rangel J* 2014, **36**:53-66.
47. Spierenburg M: **Getting the message across biodiversity science and policy interfaces—a review.** *GAIA Ecol Perspect Sci Soc* 2012, **21**:125-134.
48. Ford JD, Cameron L, Rubis J, Maillet M, Nakashima D, Willox AC, Pearce T: **Including indigenous knowledge and experience in IPCC assessment reports.** *Nat Clim Change* 2016, **6**:349-353.
49. Berkes F: *Sacred Ecology.* Routledge; 2008.
50. Gadgil M, Berkes F, Folke C: **Indigenous knowledge for biodiversity conservation.** *Ambio* 1993, **22**:151-156.