Environmental Management (2016) 57:798–813
DOI 10.1007/s00267-015-0647-1

Ecological Knowledge Among Communities, Managers and Scientists: Bridging Divergent Perspectives to Improve Forest Management Outcomes

Lucy Rist[1] · Charlie Shackleton[2] · Lily Gadamus[3] · F. Stuart Chapin III[4] · C. Made Gowda[5] · Siddappa Setty[5] · Ramesh Kannan[5] · R. Uma Shaanker[5,6]

Received: 28 December 2014 / Accepted: 28 November 2015 / Published online: 12 December 2015

Abstract Multiple actors are typically involved in forest management, namely communities, managers and researchers. In such cases, suboptimal management outcomes may, in addition to other factors, be symptomatic of a divergence in perspectives among these actors driven by fundamental differences in ecological knowledge. We examine the degree of congruence between the understandings of actors surrounding key issues of management concern in three case studies from tropical, subtropical and boreal forests. We identify commonly encountered points of divergence in ecological knowledge relating to key management processes and issues. We use these to formulate seven hypotheses about differences in the bodies of knowledge that frequently underlie communication and learning failures in forest management contexts where multiple actors are involved and outcomes are judged to be suboptimal. Finally, we present a set of propositions to acknowledge and narrow these differences. A more complete recognition of the full triangulation between all actors involved, and of the influence that fundamental differences in ecological knowledge can exert, may help lead to a more fruitful integration between local knowledge and practice, manager knowledge and practice, and contemporary science in forest management.

Keywords Communication · Conflict · Values · Local knowledge · Participation · Traditional knowledge

✉ Lucy Rist
lucy.rist@slu.se

[1] Department of Forest Ecology and Management, Swedish University of Agricultural Sciences, 90183 Umeå, Sweden

[2] Department of Environmental Science, Rhodes University, Grahamstown 6140, South Africa

[3] Resilience and Adaptation Program, University of Alaska Fairbanks, Fairbanks, AK 99775, USA

[4] Institute of Arctic Biology, University of Alaska Fairbanks, Fairbanks, AK 99775, USA

[5] Ashoka Trust for Research Ecology and the Environment, Royal Enclave, Sriramapura, Jakkur Post, Bangalore 560064, India

[6] Department of Crop Physiology, University of Agricultural Sciences, Bangalore 560056, India

Introduction

It is well accepted that the integration of community and actor groups into natural resource management facilitates planning for sustainable utilisation (Western et al. 1994; Brooks et al. 2012; Gavin et al. 2015), for example, by initiating social learning, reducing conflict and enhancing legitimacy (Gray 2003; Leach et al. 2010; Reed et al. 2010). This recognition has been particularly clear in the context of forests with strong local human influence (Persha et al. 2011). Efforts at such integration have become increasingly common and have been part of a broader attempt to align livelihood improvement and environmental protection goals replacing the protectionist paradigm that previously dominated conservation in many forest locations (Lele et al. 2010). Equally widely acknowledged is that official or externally directed management implemented in many forest areas (and its supporting policy) is often at odds with livelihood objectives or with scientific findings. Thus in many locations, both social and ecological outcomes are judged to be inferior to what is considered possible (Persha et al. 2011; Moen et al. 2014; Torpey-Saboe et al. 2015).

As social-ecological systems, forests can be characterised by governance and decision-making arrangements; property rights; incentive structures; culture and belief systems; power distributions and organisational institutions, in addition to complex and diverse ecological characteristics. The influence of these social and political characteristics on management outcomes is a substantial field of research (Young 2010), with key requirements being identified including trust-building, polycentric institutions, adaptive management and accountable authorities (Nagendra and Ostrom 2012) as well as local rule-making (Persha et al. 2011). There is recognised value in moving beyond why certain contextual factors are important determinants of outcomes, towards identifying specific causal mechanisms such that management and policy can be more effective and appropriate (Brooks et al. 2012).

Communication among different actors involved in forest management is one such causal mechanism (Roux et al. 2006). It is also one receiving growing attention in the natural resource management literature with connections to, for example, social network analysis (Crona and Hubacek 2010; Bodin and Prell 2011; Chang et al. 2012; De Nooy 2013). Communication is a social interaction where meaning or information is conveyed through a shared system, typically language (Barnlund 2008). However, communication does not always lead to agreement and the effects of communication on the sharing of knowledge and values can be moderated by contextual factors such as group identity and the management system current in place (De Nooy 2013). However, even with regular and sustained communication, where fundamentally different views of the forest system exist, solutions may remain harder to reach (e.g. Rist et al. 2010). This is an additional aspect that has received less attention, how the nature of variation in the information itself—specifically how variation in ecological knowledge among actor groups, may also influence management outcomes. We use the term 'knowledge' to encompass knowledge and belief systems in recognition of the "knowledge-practice belief complex" nature of much local or traditional ecological knowledge (Berkes 1999; Pierotti and Wildcat 2000).

In addition to overlooking this aspect, studies have tended to focus on specific pairings within the full range of actors involved, rather than consider all three simultaneously (Fig. 1). There is a substantial literature on traditional ecological knowledge (TEK), an increasing focus on the gap between policy makers and scientists (the "research implementation gap"), and also work on the gap between managers and communities in the arena of participatory management. Yet none of these recognise that there is always a third group of actors involved, thus potential missing the some of the barriers present, as well as the opportunity to consider synergies that may emerge from effective communication among all three groups. Reflection on the full triangulation of actors involved is thus needed to identify the multiple gaps that must be bridged in order to improve management outcomes. Therefore we ask; how do fundamental differences in ecological knowledge between all actors contribute to suboptimal outcomes in forest management, what are common themes within these differences and how might these common challenges be overcome?

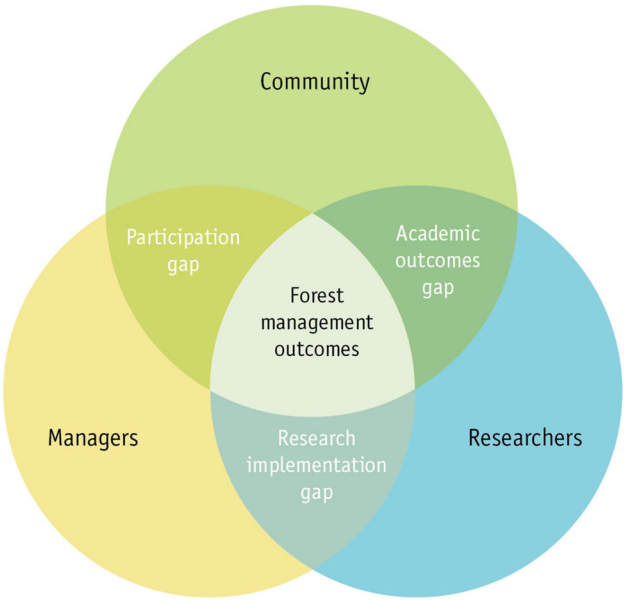

Fig. 1 Actor triangle illustrating knowledge transfer gaps which result, in part, from fundamental differences in actors' beliefs. A failure to triangulate and thus consider all actors, as well as to consider the differences between different groups' ecological knowledge contributes to suboptimal forest management outcomes

Knowledge Framework and Case Studies

Many authors have contrasted local or traditional knowledge with that of western science including breaking down types or elements of knowledge into specific categories (e.g. Stevenson 1996). Such frameworks have also been used to understand, for example, how TEK might be used to complement western science or how it could be better integrated in environmental management (e.g. Orlove et al. 2000; Pierotti and Wildcat 2000). Houde (2007) identified six interconnected and mutually informing "faces" of ecological knowledge that can be used to better identify areas of difference and convergence when attempting to bring two or more ways of thinking and knowing together

Table 1 Characteristics of the six faces of ecological knowledge (Houde 2007)

Face of knowledge	Key components
Factual observations	Empirical observations
	Classifications
	Naming of places
	Descriptions of ecosystem components
	Understanding of interconnections
	Spatial and population patterns
	Ecosystems dynamics and changes
Management systems	Practices adapted to context
	Methods for conservation
	Methods for sustainable resource use
	Methods for adapting to change
	Appropriate and effective technologies
Past and current uses	Land use patterns
	Occupancy
	Harvest levels
	History of the cultural group
	Location of cultural and historical sites
	Location of medicinal plants
Ethics and values	Correct attitudes to adopt
Culture and identity	Links life on the land, language, identity, and cultural survival
Cosmology	Assumptions about how things work
	Beliefs
	Spiritual relationship to the environment

(Table 1). The lower faces are also common to non-TEK contexts, whereas the upper faces are more specific to TEK alone (Houde 2007).

Drawing on the faces of knowledge as a framework, and using three case studies where, despite efforts at participation and dialogue, suboptimal management outcomes persist, we considered the role of fundamental differences in ecological knowledge in producing these suboptimal outcomes. The three case studies focus on locations with which we collectively have long-term experience conducting social-ecological research (2–15 years). Data collection was based on extracting findings from previous ecological and interdisciplinary research projects (including participatory assessments, workshops, interviews, livelihood surveys and direct observation of events). There were complemented by additional reviewed articles and project reports offering deeper insights into certain aspects of the cases. A multi-case study approach and the use of this framework allowed us to make comparisons between cases and characterise recurrent themes within these divergent beliefs (Yin 2003). In each case, we provide information on the challenges that have been experienced including those in communication between actors. We highlight those management issues where most conflict has arisen between the actors involved and use the knowledge framework to highlight relevant information for comparison (Houde 2007).

The Biligiri Rangaswamy Temple Tiger Reserve, India

The Biligiri Rangaswamy Temple (BRT) Tiger Reserve is located in the state of Karnataka, India. BRT is home to the Soligas, an indigenous community that depend on forest resources for basic subsistence as well as cash income (see Hegde et al. 1996 and Uma Shaanker et al. 2002 for further background). While subject to significant ecological research over the past 20 years (Ganeshaiah and Uma Shaanker 1998), BRT faces a growing number of ecological and social challenges. Efforts to integrate local communities in management and enhance community benefits from the forest have been undertaken, including participatory resource monitoring and value addition for forest products (Shanker et al. 2005; Setty et al. 2008). The Soligas substantial body of ecological knowledge has also been documented, including knowledge of considerable management relevance (Rist et al. 2008; 2010).

Yet despite this local context, progress on integrating specific social and ecological concerns with management goals has remained elusive. In particular, concerns

surrounding the harvest of Non-timber forest products (NTFPs), forest fire, invasive species and changing forest dynamics have been prominent and characterised by conflict. Income from NTFPs has been reduced considerably in recent years, and the population status of many species with livelihood and biodiversity value is of concern (Setty et al. 2008). Strict, top–down rules on forest resource utilisation and local management practices have resulted in general mistrust, antagonism and conflicts between the community and the Karnataka Forest Department (KFD). Conflict remains an episodic occurrence, for example, the KFDs anxiety over implementation of the Scheduled Tribes and Other Forest Dwellers Act (FRA) 2006 and BRT's recent designation as a Tiger Reserve by the National Tiger Conservation Authority (NTCA) with implied relocation of the Soligas (Kothari and Rai 2011). The spread of invasive species, especially *Lantana camara*, as well as incidents of damaging fire are major threats to the area (Sundaram et al. 2012; Ticktin et al. 2012; The Hindu 2010). Knowledge regarding the drivers underlying current management challenges are closely linked to views on the ecological history of the area (Table 2). This has a significant influence on how each group identifies appropriate courses of action for the future (Table 2).

In terms of communication, or lack thereof, there is reciprocal mistrust between managers and communities. Scientists have also been subject to suspicion from both sides, being perceived to be aligned with one or the others agenda. Community members feel that managers do not seek their perspectives, even when the issues under discussion have major livelihood implications. Contact between scientists and the community is rather commonplace, yet typically initiated by scientists. Scientists have learned about TEK from communities but exchanges have typically been a one-way information flow. However, some Soligas assisting with field research have potentially acted as bridges to their communities. Scientists have made efforts to bridge communication gaps through participatory monitoring but this has been narrow in focus. They have also endeavoured to open up dialogue between managers and the community but efforts have not resulted in lasting improvements. Researchers ability to exert pressure on managers or act as community advocates is influenced by the need to obtain research permits. National narratives, particularly those relating to wildlife conservation, have a dominating influence. While the most significant communication and understanding gaps exist between the community and management, the divergent ecological perspectives present suggest significant opportunities for a research agenda with a three-way collaboration and perhaps a logical solution to current challenges.

Tharfield Village, South Africa

Tharfield is a small village of 95 households near the coast in the Eastern Cape, South Africa. Local inhabitants practice diversified livelihoods, including arable and livestock agriculture, opportunistic and migrant wage labour and harvesting of NTFPs for direct consumption and sale. One particular NTFP that has evoked conflict due to contrasting knowledge is *Ischyrolepis eleocharis,* a reed harvested from local forests to make small hand brooms. All households use these brooms on a regular basis, and approximately 10 % sell them in the village and nearest town. The sellers are middle-aged to elderly women, for most of whom this trade is their principle source of cash income (Shackleton et al. 2009). In 2006, Eastern Cape Parks, the statutory provincial conservation agency, banned harvesting of *Ischyrolepis*. They claimed harvesters were causing damage to the dune-forest system by opening up patches in the forest and exposing the underlying dunes to wind and rain erosion, making subsequent restoration difficult (Table 3). Additionally, it was claimed that harvesting was being used as cover to illegally harvest shellfish from the coast (Shackleton et al. 2009). Local harvesters argued that the plant was stimulated by harvesting (recently confirmed by Ruwanza and Shackleton 2015), that they did not harvest in the open patches because in these locations the *Ischyrolepis* shoots were too short to make brooms, and that open patches had always existed in the forest (Table 3).

Scientific research supports the community accounts. Open patches exist in both harvested and unharvested areas and the height of *Ischyrolepis* shoots in open patches is too short for brooms. The causal agents for these patches are unknown, but have been suggested to include death of individual dominant canopy trees, fires, or other disturbance agents. Additionally, the current demand for *Ischyrolepis* by the local community and traders is likely to be within sustainable limits (Shackleton et al. 2009). Lastly, only a small proportion of the shoots are of adequate length to make a hand broom. Harvesters have been observed not to take shorter shoots since they are useless for making a functional broom. Thus, there is also a size refuge operating within their harvesting behaviour such that smaller shoots are spared from harvest. Currently, local harvesters have more knowledge of this species than either officials or local ecologists. Officials have greater capacities and skills to monitor the condition of the larger system, but fail to probe the underlying drivers of ecological changes or to monitor at the appropriate scale.

Currently, communication between the three actors is sporadic and unrewarding for all parties. The community criticises unilateral decision-making by managers, and resents the blame they receive for perceived forest degradation. Managers question the community's motives and

Table 2 Management perspectives of indigenous residents of BRT tiger reserve, resource managers, national policy narratives, and regional science, with respect to key forest management issues

Face of knowledge	Forest management actors			
	Community	Managers	National narrative	Regional science
(1) Factual observations, classifications, and system dynamics	Fire is a natural component of forest dynamics (low-intensity fires burn annually), recent intense fires are due to fire suppression and build up of invasive shrubs Suppression of low-intensity/litter fire has had negative ecological implications including the spread of invasive species with many negative repercussions on regeneration of native species (including reduced regeneration of NTFPs), reduced fodder availability for large herbivores and an increased incidence of parasites on wildlife	Fire has negative impacts for conservation, permitted resource use leads to overuse also with negative implications for conservation	Fire has negative impacts in terms of conservation, local resource use must be restricted in the interests of conservation	Fire has negative impacts on forest regeneration, plays a possible positive feedback role in the invasion cycle of *L. camara* but growing recognition of the historical role of low-intensity fire Acknowledgment of significant recent ecological change, problems with invasive species are seen in the context of global invasiveness State a need for continued research to understand causal connections and drivers of change, particularly in relation to fire and invasive species
(2) Management systems	Controlled fire and/or shifting cultivation were traditionally practised. Fire has an essential role in controlling the spread of invasive plant species and in the regulation of both plant and animal parasite populations Small/medium size branch cutting during harvesting of NTFPs promotes tree growth and fruit production (coppicing as a response to cutting) and has additional benefits in terms of removal of invasive mistletoe species	Little support for fire as a management tool outside of roadside clearance and significant portion of limited resources allocated to fire prevention Over harvesting (regardless of harvest method) is also regarded as a potential conservation threat but use continues to be permitted with the use of quotas Conservation via short-term management projects e.g. Lantana clearance programmes. Possible relocation of communities following Tiger Reserve designation	Policy of fire suppression Overharvesting is the priority issue requiring attention to secure sustainable NTFP harvesting Prioritisation as tiger habitat by National Tiger Conservation Authority (NTCA)	Little support for fire as a management tool, judgement that low-intensity fires are no longer possible given the high flammability of lantana Previous efforts to increase community awareness of 'unsustainable' harvesting practices. Initial assumptions regarding impacts of cutting revealed to be flawed in more recent research yet hesitancy in fully supporting the Soliga perspective regarding harvesting methods. Support of participatory resource assessment to help inform quote setting More recent analysis has shown that mistletoes and invasive species are key threats to NTFP populations rather than harvesting, new support for the use of NTFP branch chopping as a management tool to control mistletoes
(3) Factual knowledge regarding past and current uses of the environment	Grass understory maintained by grazing and periodic low-intensity fire, low mistletoe population, long history of resource use, suppression of fire has led to *L. camara* invasion	Ecological implications of long residence of Soligas in the area not recognised	Ecological implications of long residence of Soligas in the area not recognised	Grass understory was maintained by periodic low-intensity fire in the past

Table 2 continued

Face of knowledge	Forest management actors			
	Community	Managers	National narrative	Regional science
(4) Ethics and values	Forest, trees and wildlife are sacred, and being worshiped traditionally. They lead simple life and that contributing to conserving this landscape	Soliga setting of fire in retaliation for bans on NTFP collection	Idea of pristiné forest without human influence remains dominant	Strong focus on conservation and sustainable livelihood
(5) Culture and identity	Strong cultural connection to forest	–	–	–
(6) Cosmology	The Soliga cosmology is an extension of the natural world, sacred sites are identified as composites of the five essential elements. The elements elders are *Devaru (god, sun, light), Maramma (mother, goddess, associated with fire) Veeru (demon), Kallugudi (burial stones, associated with wind), and 'Abbi' (spring/stream, associated with water). There are around 490 sacred sites in the landscape	No cosmological basis for management or protection of the forest.	Biophysical interactions and human interventions determine ecosystem health & dynamics	Biophysical interactions and human interventions determine ecosystem health & dynamics

perceive the extraction of *Ischyrolepis* to be a cover to illegally harvest shellfish. Moreover, this small community and forest is not high on the agency's agenda and thus likely deemed undeserving of the human and financial resources required to actively engage with the community. Regional scientists generally have a good relationship with agency scientists employed locally thus there is a conduit for dialogue, albeit an insecure one. Several regional scientists have a generally trusting relationship with the community, but dialogue is typically project driven. At times this generates community resentment, the agenda being dominated by research priorities rather than emerging from true partnership. Both the community and the agency have expressed an interest in participating in a monitoring and research programme on *Ischyrolepis* harvesting. This is dependent on scientists securing funding but represents an opportunity for all to come together around a common interest. Thus, communication and knowledge gaps exist between all three constituencies, with the largest currently being between the community and management.

Galena and Huslia, Western Alaska

Galena and Huslia are two Koyukon Athabascan communities located in Western Interior Alaska. Residents depend on the forest for subsistence including customary and traditional use of fish, game, furbearers, and berries. The U.S. Fish and Wildlife Service now manage the traditional use areas of these communities as the Koyukuk National Wildlife Refuge. Wildfire is the major issue of concern in this case. Fire in the area causes hardship for Koyukon residents; cabins and traps may be destroyed, downed trees make forest access difficult, cultural sites become unrecognizable, furbearer populations are impacted, and caribou are displaced for decades because lichens, their primary winter food, are slow to recover after fire (Nelson et al. 2008; Ray 2011). Community residents have, however, observed some beneficial effects from wildfire, specifically increased moose browse, which influences moose density; increased density of berry bushes; and decreased brush, thus improved access (Table 4). Residents report that wildfire effects are highly variable, depending on vegetation type, vegetation dryness, and the wind and temperature conditions at the time of burning (Ray et al. 2012). Older Koyukon note changes in the climate and landscape that are influencing the fire regime, as well as changes in the regimes themselves (Ray et al. 2012).

The fire management plan (FMP) for the Refuge focuses on the beneficial effects of wildfire, particularly the potential to improve wildlife habitat and to reduce the risk of catastrophic wildfires. It suggests that residents need education on the beneficial effects of wildfire, and the Refuge's attempts at outreach have caused frustration among locals (Ray et al. 2012). Regional scientific research

Table 3 Management perspectives of residents of Tharfield village, resource managers, national policy narratives, and regional science, with respect to with respect to key forest management issues ("−" indicates where information is not available, this face has not been subject to investigation in previous research)

Faces of knowledge	Community	Managers	National narrative	Regional science
Forest management actors				
(1) Factual observations, classifications, and system dynamics	Original ecological state a shifting mix of forest and grassland patches, Reduced use leading to tree encroachment into grassy patches. Thickening of the forest Ischyrolepis is pulled by hand with shoots broken off from a horizontal rhizome. Harvesting of Ischyrolepis is sustainable because very little is removed, it regrows quickly and harvesters have not seen evidence of declines. Most claim that harvesting stimulates the plant	Widespread forest along the coast fragmented and disturbed by injudicious land use and harvesting Conservation protection has reduced damaging impacts, but not entirely. Harvesting of specific species has resulted in degraded patches within the forest and the potential for increased soil erosion of the sensitive dune soils Ischyrolepis is pulled by hand or cut Harvesting is unsustainable at both species and systems levels. The species is in decline, and harvesting causes damage to the forest	Widespread forest along the coast fragmented and disturbed by injudicious land use, clearing and harvesting South Africa has very little forest. Forests are species rich. Coastal forests are particularly threatened because of large-scale land transformation and development in the coastal zone Broadly, most national commentary perceives harvesting of NTFPs by rural communities to be a one-way path to resource demise sooner or later	Shifting mix of forest and grassland patches directed by successional changes along a stabilising dune system Coastal forests are sensitive. Rates of use and change are extremely variable from one forest to another. Ischyrolepis is pulled by hand with shoots broken off from a horizontal rhizome. Harvesting of Ischyrolepis is sustainable because very little is removed, it is likely to regrow rapidly, and there is a physical functional size limit which prevents all the resource being removed
(2) Management systems	Human use/influence plays a role in maintaining the system No specific management is required for this species as harvesting stimulates growth, harvesting should be permitted to continue. Willingness to participate in monitoring and harvesting trials. Forest access should be allowed, because there is no evidence of activities causing damage to the forest structure or composition	Need to control local use and influence Harvesting and future access and use should be discouraged, limited or banned. Any harvesting for commercial purposes should be prohibited, even if it is minimal and practised by poor rural woman with no other sources of income	Forests must be afforded a high conservation status Sustainable use can be allowed based on sound management and scientific principles. Until such principles are known and in place for the specific context, management should err on the side of caution	Natural reforestation possible if land use pressures permit A longer term enquiry is required with participation of community and managers, regarding (i) the effects of harvesting on Ischyrolepis and (ii) the formation and dynamics of the open patches within the forest. In the interim, use should be allowed because there are few signs of significant damage to the species or the forest.
(3) Factual knowledge regarding past and current uses of the environment	–	–	–	–
(4) Ethics and values	Most management philosophies promote human control over environment, some recognising complexity and uncertainty	Management approach promotes human control over environment	Management approach promotes human control over environment	Most management philosophies promote human control over environment, some recognising complexity and uncertainty
(5) Cultural and identity	Ischyrolepis products are viewed as important cultural artefacts within the community and are given as gifts during celebrations	Whilst there is some cultural recognition the bulk of the extraction is for commercial use with products being sold in urban markets	National commentary and policy recognises the cultural use of habitats, spaces and species by local people, but this may need to be regulated in sensitive areas or for scarce or threatened species. Harvesting for personal use is generally tolerated, but harvesting for commercial use typically requires permits or permissions, which may be overlooked if for a small-scale, limited enterprise	The use of Ischrolepis fulfils multiple functions and satisfies the needs of different actors. The cultural role is significant and even much of the small-scale trade is to supply culturally valued products to urban consumers who cannot harvest the resource themselves. Therefore, even though it may be traded, the basis of most of the trade is culturally driven demand
(6) Cosmology	Respect and acknowledgment of the ancestors is part of everyday life as they have influence over the pathways of their descendants. Ancestors reside in natural places such as the forest. Excessive use of the forest may disturb the ancestors, but the ancestors will always heal the forest if needed and in time	No cosmological basis for management or protection of the forest. Species and habitats should be conserved as part of broad-scale national and international initiatives to conserve a portion of the Earth's ecosystems and species. Harvesting in protected areas in an anathema	Biophysical interactions and human interventions determine ecosystem health & dynamics	Biophysical interactions and human interventions determine ecosystem health & dynamics

Table 4 Management perspectives of indigenous residents of Galena/Huslia, resource managers, national policy narratives, and regional science, with respect to key forest management issues

Face of knowledge	Forest management actors			
	Community	Managers	National narrative	Regional science
(1) Factual observations, classifications, and system dynamics	High severity fire has many negative consequences, low to moderate severity fires may have some benefits, but fire effects are largely unpredictable. General drivers of flammability believed to be vegetation, fuels, weather. Fire is a natural part of the system but is now much more unpredictable. Observed increases in landscape flammability due to warmer winters and summers and a drying landscape caused by climate change. Varying responses on the influence of time since wildfire on flammability	Optimistic prediction of multiple resource benefits, little to no recognition of negative consequences of fire. General drivers believed to be vegetation, fuels, weather, topography. Fire management plan implies wildfires reduce risk of future catastrophic wildfire. The role of climate change not seriously considered	Prescribed fire and wildland fire are the most cost-effective and natural methods of returning fire to fire-adapted ecosystems and maintaining ecological resilience. General drivers believed to be fuel, weather, topography. Fire suppression increases risk of catastrophic wildfires due to fuel build up	Fire has not been removed from Alaskan ecosystems by suppression. Wildfires can have positive, negative or unpredictable effects on certain species. Burns have long-term harmful effects on caribou; and possibly furbearers and their prey. General drivers considered to be vegetation, fuel, and weather. Climate change has resulted in increased area burned and large fire seasons. Changing fire severity and burning patterns Boreal flammability driven by climate and ecosystem type, not forest age
(2) Management systems	Burning was a never historically a part of indigenous management in this region. Current widespread support for fire suppression, including in "remote" areas that are important for resource use	1) Allow wildfire to burn in remote areas, wildfire suppression closer to communities; 2) Use fires as a natural ecological process/maintain fire dependent ecosystems; 3) Reduce hazardous fuels/ avoid catastrophic fires; 4) Improve habitat through wildfires and prescribed burns	1) Maintain the natural role of fire as an essential process in fire-adapted ecosystems; 2) Reduce hazardous fuels to lower risk of catastrophic fire to communities and critical resources 3) Wildfire suppression still very important due to wildland-urban interface and risk to life and property	Maintain natural processes such as wildfires to support ecosystem resilience, but recognise that wildfires have moved out of the historical range of variability due to climate change. Continue with variable fire suppression policy that protects communities while supporting natural fire regime
(3) Factual knowledge regarding past and current uses of the environment	In the past, some level of place-tenure: families moved with the seasons but often had spring camps or fish camps in the same place each year. Use areas were larger, populations were smaller, and in the absence of state or federal management there was more flexibility in the case of wildfire, but options were limited by respect for use areas of others. Wildfires were less common, less extensive, less severe, and more limited in location (some areas that burn now used to be wetlands).	Potential misperception that indigenous use was completely nomadic and thus not negatively affected by specific areas burning due to unlimited ability to move to a new area	Concern that wildfire suppression has moved wildfire regime out of historic range of variability	Recognition that this part of Alaska never saw complete wildfire suppression

Table 4 continued

Face of knowledge	Forest management actors			
	Community	Managers	National narrative	Regional science
(4) Ethics and values	Respect for the land, for animals, and for other people guides attitudes and actions. If a use area burns, respect for the use areas of others may make it difficult to find a new use area. Some ethical conflict with the idea of "managing" wildlife populations, with its implications of dominance, since indigenous use focused on respectful human-animal relationships that are more equal. Sports hunters offensive to indigenous tradition of taking only what needed and with respect.	Maintaining historical disturbance regime is critical to ecosystem health. Support for active management such as prescribed burns. Management approach promotes human control over environment. Management goals accommodate non-local stakeholders. For example, interest in prescribed burning related to managing for high moose populations to accommodate sports hunters from other regions as well as local subsistence hunters	Returning fire to the ecosystem is critical to ecosystem health. Most management philosophies promote human control over environment, some recognising complexity and uncertainty	Documenting historical fire regime and considering climate change are critical to deciding appropriate fire regime. Most management philosophies promote human control over environment, some recognising complexity and uncertainty
(5) Knowledge as a vector for cultural identity	Locally based observations, stories, and resulting wisdom define peoples' relationship to the land and their identity. Places tied to subsistence/cultural/family activities. When important areas, such as historic spring camps burn, a sense of cultural loss. A burnt camp or trapline can make it difficult to teach subsistence to grandchildren Strong desire for local knowledge and values to drive land use, thus preserving local autonomy, culture, and values	Scientific knowledge provides the basis for management actions. Managers vested in own authority tied to language of science. Desire to educate others and convert to belief in Western science Measurement systems encourage perception of landscape in terms of numbers (e.g. hectares in different successional stages) rather than places	General scientific understanding provides the basis for management recommendations. Managers vested in own authority tied to language of science. Desire to educate others and convert to belief in Western science Measurement systems encourage perception of landscape in terms of numbers (e.g. hectares in different successional stages) rather than places	Scientific knowledge provides the basis for management actions. Scientists usually vested in own authority tied to language of science. Desire to educate others and convert to belief in Western science Measurement systems encourage perception of landscape in terms of numbers (e.g. hectares in different successional stages) rather than places
(6) Cosmology	Actions determine the "luck" and benefits (ecosystem services) that individuals receive from the land. If these actions are not based on respect, a person will have bad luck in meeting their subsistence needs. A prescribed burn that kills small animals could be considered disrespectful to the animals, violating local beliefs, and causing possible loss of subsistence "luck"	No cosmological basis for management or protection of the forest	Biophysical interactions and interventions by managers determine fire regime and ecosystem health	Biophysical interactions and interventions by managers determine fire regime and ecosystem health

indicates that climate change is associated with an increasing annual average area burned and is linked to changing fire severity and burning patterns in Alaska (Kasischke et al. 2010). Most notably, research indicates that climate and ecosystem type, not forest age or fuel load, drive forest flammability (Johnson et al. 2001; Chapin et al. 2006; Abatzoglou and Kolden 2011). Additionally, research shows that besides the documented positive effects, wildfire can have negative or unpredictable effects on Alaskan wildlife, especially caribou (Rupp et al. 2006; Nelson et al. 2008). This research largely supports local observations and calls into question the FMP's promotion of prescribed fires in a landscape that is already experiencing increased wildfire.

Communication among the three groups generally depends on information delivery rather than dialogue. Agency management plans stress the importance of community education whereas community members feel their perspective is not sought by managers. Scientists have typically focused on the biophysical determinants of the fire regime and to lesser extent on societal impacts (Table 4). They have little community contact, communicating via scientific publications and dialogue with agency fire scientists. Agency scientists communicate effectively with academics and agency managers, but agency managers are torn between listening to local information about Alaskan wildfire and responding to a national narrative that links funding to a paradigm that emphasises the beneficial effects of wildfire (Ray et al. 2012).

Results

Communication and learning failures are, in part, a consequence of differences in actors' knowledge. Characterising some of these differences may help expand and generalise theories used to deal with management challenges (Yin 2003). Thus, based on applying our framework across the three cases (Tables 2, 3, 4), as well as our broader collective experience from working in these contexts, we formulate seven hypothesises or general theoretical propositions that may explain divergent perspectives with regard to forest management in these and similar settings (i.e. those where multiple actors are involved and outcomes are judged to be suboptimal). Several of these hypotheses are interrelated, reflecting important interactions among processes in complex social-ecological systems (Levin 1999).

Actors Possess Different Historical Views of Ecosystem Characteristics and Change

A perspective on the past strongly influences how groups view both present states of nature and management challenges. Managers often fail to acknowledge the long residence times of communities in, and adjacent to, forests and that resource use is not a novel influence. This was particularly problematic in the Indian case. Managers and scientists frequently have a short time period of reference or brief tenure in an area. Additionally both managers and communities can be characterised by the view that "*it has always been that way*" with respect to history of land use and ecological characteristics. Community actors may contest suggestions that patterns of use have changed over time or are subject to outside influences that alter impacts. For example, increasing human population, commercialisation of subsistence resources, or synergistic effects with other drivers of change such as invasive species or climate change, one or more of which was relevant in each of our cases. Such omissions may be unintentional but in other cases are deliberate responses to fears over the security of use rights or residence status.

Different Actors Focus on Different Temporal and Spatial Scales

This appears typical in relation to both causes of management problems and potential solutions. Activities that appear to one group to be unsustainable in the short term may be considered necessary by another for long-term resilience and sustainability. Such differences between actors were common in the Indian and Alaskan cases, in particular with respect to disturbance regimes and ecological variability. Community perspectives can reflect a greater recognition of underlying ecological dynamics, and the acceptance that quick solutions are not possible. In India and Alaska such recognition likely emerges from the long residence times of these communities and their intimate livelihood connections to the forest. A broader difference in attitudes to change can also be distinguished; local people often recognising that change is part of a dynamic and variable system. Managers typically want to constrain change, a possible result of a dominant optimisation/preservation approach, which characterised all three cases. Similarly common to all cases was that scientists tend to be more embracing of change and variability but struggle with incorporating such uncertainty into recommendations directed at policy.

Actors have Different Perspectives on Drivers of Change

Researchers often focus on the impact of livelihood uses, giving less consideration to external pressures and mirroring the challenge above in understanding systems at appropriate scales. In both India and South Africa this

translates to a focus on regulating community activities and on drivers operating at small temporal and spatial scales, to the detriment of drivers at larger scales. Livelihood uses thus tend to receive more attention in relation to their relative impact than do other, possibly more serious, drivers of change. This is perhaps because managers feel they can control resource use, and hence its impacts, but feel powerless against exogenous drivers such as climate change or powerful commercial interests. A notable example being the presence of a coffee plantation inside the BRT sanctuary in India, as well as mining activities on the sanctuary's boarders which have received surprisingly little attention.

Managers and communities often have very divergent views on the appropriate role of people; communities viewing themselves as part of the forest and managers considering people as external influences on a 'natural' system. In the Indian and Alaskan cases this was particularly clear. Both having cosmologies which regard the world of humans and the world of nature as closely related to each other, and rites and rituals based on such belief systems are important for the conservation of nature. Therefore, managers, and to some extent scientists, often ignore or undervalue past human agency and its role in shaping the structure, composition or function of forests. Alternatively, when human agency is recognised, influences are believed to be largely negative and needing constraint. In many cases, local rules and norms that historically regulated use are undermined by new regulatory frameworks, which contribute to conservation losses, this was particularly clear in the Indian case.

Actors have Different Perspectives on the Impact of Resource Use

Scientists and managers frequently assume that use is unsustainable with no prior evidential basis. In our broader experience this is extremely common, based on both old colonial prescriptions and inappropriate knowledge transfers from temperate systems to tropical ones. Worryingly, this perspective remains strongly entrenched in training curricula and conservation policies throughout the developing world, such that much conventional scientific wisdom suggests local utilisation in biodiverse areas is invariably in conflict with conservation objectives. Use is therefore often prohibited or strictly controlled with little account of the high variability that characterises people's interactions with the forest and generalisations about extraction applied across large areas. Generalisations and ignorance of the nuanced variation in social-ecological landscapes is also prevalent; generalisations such as 'fire is damaging' or 'overharvesting is the likely outcome of permitting use' remain common and are clearly evident in all three cases. Many similar examples represent prevalent conservation myths and dogma arrived at inductively with little empirical support.

Actors View the Relative Importance of System Components Differently

Communities attach values to a greater range of species, resources and landscapes than do managers; this was most clearly evident in the Indian case. Managers typically have a conservation objective implemented largely through minimisation of use and disturbance in relation to an area (as was the case in South Africa), a species, or more lately, to ecosystem services (e.g. carbon sequestration). There has been an evolution towards an increasing number of objectives that need to be optimised from the same area of forest. Previously communities were excluded from protected areas where the primary objective was conservation. Nowadays, there is a need to manage for multiple goals, including sustainable use, conservation, and ecosystem service provision; few managers have training equipping them for such a task. While there is growing recognition of the need to manage for multiple objectives, there remains a strong prioritisation of wildlife over plants. It has been reported in other work that large mammals dominate the conservation psyche, even to the detriment of other local biodiversity (Caro 2001), or local livelihoods (e.g. Karanth and Karanth 2012). The same distinction can also be made in other locations where timber species are prioritised over understory plants (Rist et al. 2012).

Actors Prioritise Ecological Processes and Forest Products Differently

Managers may have a greater focus on specific system components (e.g. annual census of tigers or number of fires) than broader ecosystem dynamics and services. Scientists focus on larger-scale processes at the expense of information relating to specific products unless specifically asked to target them. Typically, scientists have been process- or species-orientated, rarely integrating both process and product perspectives in research. There is more to suggest that communities observe and understand both and are much more integrative in their perspectives, a funding also supported by other research (Berkes 1999; Berkes et al. 2000; Nakashima and Roué 2002).

Actors are Influenced by External Narratives, Local Observations or Place-Based Research to Different Extents

An early focus in the non-timber forest product (NTFP) literature on overharvesting has undoubtedly played a role

in general hypotheses being applied in forest management, overlooking the local context and resulting in flawed assumptions about the impacts of local use (most starkly illustrated by the Indian case). By definition, communities are less influenced by external narratives. Conversely, managers may have a strong reliance on external narratives, but these are not updated particularly frequently. Thus, they rely on external learning and direction as advocated by experienced colleagues within the organisational culture and agenda, with infrequent injections of new ideas when overarching policy frameworks are revised. This was particularly clear in the context of fire as a management issue in Alaska. Scientists have constant exposure to external narratives, but require meaningful insight into local conditions and dynamics to temper external narratives with place-based nuances.

Discussion

Problems of communication between actor groups typically arise when there are strikingly different understandings of concepts of meaning and identity arising from different values and beliefs.

Ecological knowledge (encompassing both values and beliefs) has a direct impact on the management actions that different actors consider appropriate (Berkes 1999). Many researchers identify failures in communication and social learning as part of the reason for limited progress in contexts such as those described in this paper (Shanley and López 2009; Bodin and Prell 2011; De Nooy 2013). Yet, other than contrasting, verifying or validating local knowledge relative to scientific knowledge, there has been less attention to differences in the actual bodies of knowledge (values and beliefs) themselves that underlie failures, and less still to applying such insights. The existence of different 'interpretations of reality', differences in how people perceive and understand history, landscapes, resources and ecological dynamics, is known (e.g. Dalhberg 2005), but research and practice are not taking adequate account. In fact there is a current trend to focus on proximate causes, i.e. the policy process, rather than on the ultimate causes, one of which we argue, is fundamentally different views of the system; including both explanations for the current situation and visions for the future. We posit that limited progress in many forests is symptomatic of a need to pay more detailed attention to points of divergence, and specifically to a lack of integration of ecological knowledge in the full triangulation of actors in these efforts. Forest systems are more likely to have sustainable outcomes when local users participate in rulemaking (Persha et al. 2011; Gavin et al. 2015) and build social capital (Pretty 2003), arguably such participation can be facilitated by enhancing the communication and integration of knowledge and vice versa. Thus, such efforts can be informed by greater appreciation of possible sources of contention such as those identified in our hypotheses.

While actors have different priorities and thus views on management, in some instances there can be agreement on objectives, it is rather their articulation and ideas about how to reach them that diverge. Without explicit attention to differences in ecological knowledge such subtleties are overlooked. We suggest several propositions that might help acknowledge and narrow these differences, identifying related barriers to progress where appropriate. Our focus is weighted towards where scientists can take action.

Respectful Dialogue

Actors should seek opportunities to engage in respectful dialogue about the identity of key system components under scrutiny, the scales over which these components interact, and critical drivers of change (hypotheses 1–3). This can involve informal exchange of stories and experiences, or more formal methods for making different understandings explicit (Jones et al. 2011). Methods for eliciting detailed perspectives on resource use include the Q-method (Ray 2011), fuzzy cognitive mapping (Ozesmi and Ozesmi 2004), and cultural consensus analysis (Stone-Jovicich et al. 2011). Another approach may be the development of scenarios or futures visioning (Peterson et al. 2003). Respectful dialogue is required rather than delivery of information and opinion. Where existing knowledge can resolve differences, discussion may allow knowledge to be shared and used as the basis of new policies. However, divergent views may persist, for example, conditioned by historical baggage, ethics or cosmology. Where one group is ignorant of or prejudiced against another's context the problem is not really one of meaning but rather one involving the lack of sympathetic attitudes. Thus, dialogue alone does not guarantee that communication or social learning will occur (Cundill and Rodela 2012). Scientists should seek regular and sustained engagement with communities and managers on an equal footing and thus learn about, rather than diagnose, the local context. For example, it is important that scientists are mindful of a tendency to address problems with a "rational" focus and do not try to "solve" situations by providing additional information and rearranging factual beliefs and existing knowledge. Values (unlike beliefs) are not subject to rational discussion about truth and falsification. Thus, many mistakes have been made by addressing issues of values as though they were issues of rational explanation and objectivity, such approaches just leading to the oppression of others' values (Nordby 2008). The

opportunity to capitalise on the potential of acknowledging these needs requires supporting reforms including changes in scientific training and education and skill development (Kimmerer 2002) as well in the incentive and reward systems associated with research to allow time for such processes (Shanley and López 2009). In terms of community-manager interactions, inherent power differences perhaps represents the greatest challenge to establishing the dialogue required (Hajjar et al. 2012).

Collaborative Research

Where new research is required to provide clarity, collaborative research and social learning may lead to outcomes perceived as legitimate by all groups (Reed et al. 2010). In Alaska, scientists, managers, and communities disagreed about the number of whales migrating annually (Huntington 2000). Native knowledge of under-ice migration that was not monitored by agencies or scientists led to a co-designed monitoring program that showed populations were significantly higher than scientists had thought. This new information led to more liberal harvest limits meeting both the subsistence needs of communities and the conservation objectives of managers. Change in prior beliefs as a result of participation in collaborative research processes can occur in all three groups. In addition, the processes of repeated interaction benefit communication given the opportunities provided for actors with different social and cultural backgrounds to share knowledge and beliefs. This can reduce problems of understanding that typically arise when ideas about shared beliefs are mistaken or if it is unclear how one should interpret another person's beliefs. However, collaborative research processes require financial support and the commitment of time by those with the required skills, in addition to a social and political context that supports such processes (Armitage et al. 2007).

Citizen Science and Adaptive Management

Science need not be solely the domain of formally trained scientists. There is increasing evidence of the value of citizen science and adaptive management in augmenting conventional science, especially in relation to monitoring, mapping and restoration (Dickinson et al. 2010). This not only increases the data available to scientists, but leads to mutual respect and conservation awareness in communities (Evans et al. 2008) and the building of social capital (Gutiérrez et al. 2011). Regional zoning of alternative approaches could be treated as experiments to test their consequences; areas near communities being managed to test a community perspective on key drivers of change and alternative perspectives tested in areas with less immediate impact on communities. The potential for such an adaptive management approach has already been discussed in the context of BRT in India (Rist 2009).

Acknowledge Dynamic Change

While forests are dynamic systems, some actors tend to view them statically. When systems and drivers of change are rapidly shifting it may be useful for actors to discuss multiple potential contributing factors, trajectories and outcomes, without any group claiming to represent the truth. As above, progress can be made, depending on whether existing or new knowledge can clarify reasons for change and the relative desirability of such changes. Collaborative development of an ecosystem history, as per Houde's (2007) third knowledge face, may be one tool in such a process, which can lead to shared understandings towards future cooperation. For example, recognising the role of climate change in affecting fire frequencies and intensities led to shared knowledge of drivers, some of which can be managed and some of which cannot. Similarly, in South Africa, realising that open patches occur in even unharvested forests and these change through time cleared the allegation that it was the harvesters who caused such patches.

In general there is a need to further investigate how climate variability and other events will affect the joint development of management outcomes and the application of all groups' knowledge in this context, moving towards a broader approach that pays greater attention to ecosystem dynamics and environmental change.

Place-Based Decision-Making

Community engagement or collaborative research is less likely to be successful where management decisions are made at a higher level of authority than those responsible for, or affected by, their implementation. For example, where national or provincial/state narratives drive decisions, discussions between local managers and communities are unlikely to resolve conflicts as local managers have limited powers to make changes. Where management plans must follow top-down prescriptive narratives to attain approval or funding this is particularly problematic. An incentive structure that prioritises place-based research supported by local actors and the fostering of local institutions with more decentralised governance may narrow this gap. Such a focus is also supported by research highlighting the critical importance of prominent community leaders and robust social capital in co-management efforts (Gutiérrez et al. 2011).

Targeting of Issues or Acknowledge Impasses

When differences cannot be resolved by sharing knowledge or co-producing new knowledge, it may be useful to explore management options that are relatively insensitive to points of disagreement. For example, managers may disagree with scientists and communities about the importance of climate in changed wildfire dynamics. Since climate cannot be directly managed, this may be a less important issue than different opinions about fuel loading, leading to a more targeted discussion and set of experiments to enhance understanding. Such targeting may allow for issues characterised by lesser communicative challenges to be dealt with first.

Situations where groups cannot come together in an environment of mutual respect and learning are unlikely to lead to favourable outcomes. For example, if managers lack respect for the cultural worldview or cosmology of communities, or communities fear loss of harvesting, access or property rights, then discussions are unlikely to lead to mutually agreeable solutions. In such situations where interaction and dialogue takes place, it should first be constructed around small and non-contentious issues, which can provide the foundation for building of trust and respect before identifying and addressing more contentious issues. In other contexts the social and political context may be a firm barrier to progress and the management may need to be envisioned as a process with a focus on political empowerment, the securing of rights and the building of local institutions (Armitage et al. 2007).

The usefulness of these propositions will differ depending on where misunderstandings occur among the three pairings. In addition, while we have to a degree treated the different actors as unitary groups this may often not be the case, for example, researchers often come into conflict with each other due to different views on ecological theory and how it can be applied in practice, communities also show diversity in particular views or perspectives for action. These communicative challenges within actor groups also will need to be navigated. However, as a first start, awareness of the particular areas of disagreement, and their placement within the actor triangle, will aid in defining the action arena where solutions can be sought, including identifying synergistic opportunities for communication among all three groups. Ecological knowledge provides the linkage between an ecosystem and the management that it is subjected to. Thus, greater recognition of gaps in knowledge and divergent views is required to develop viable management policies and plans from national to local scales. Failure to do so can at the very least, result in suboptimal attainment of ecological and social outcomes, and at the worst, serious and overt conflict between actors. A more complete recognition of the full triangulation of communities, managers and scientists (rather than specific actor pairings), and of the potential influence that fundamental differences in ecological knowledge can exert on communication, may help lead to a more fruitful integration between local knowledge and practice, manager knowledge and practice, and contemporary science.

Acknowledgments Ramesh Kannan sadly passed away before the final publication of this manuscript; his enthusiasm and friendship will be greatly missed by his colleagues. We thank two anonymous reviewers for comments that improved the manuscript. LR was supported in this work by an Alice Horsman Travelling Fellowship from Oxford University and by Future Forests, a multi-disciplinary research programme supported by the Foundation for Strategic Environmental Research (MISTRA), the Swedish Forestry Industry, the Swedish University of Agricultural Sciences (SLU), Umeå University, and the Forestry Research Institute of Sweden. CS was supported the by Indian Council for Cultural Relations. We gratefully thank actors at all three locations for sharing their time and knowledge.

References

Abatzoglou JT, Kolden CA (2011) Climate change in western US deserts: potential for increased wildfire and invasive annual grasses. Rangel Ecol Manag 64:471–478

Armitage D, Berkes F, Doubleday N (2007) Adaptive co-management collaboration, learning, and multi-level governance. UBC Press, Vancouver

Barnlund DC (2008) A transactional model of communication. In: Mortensen CD (ed) Communication theory, 2nd edn. Trans, New Brunswick, New Jersey, pp 47–57

Berkes F (1999) Sacred ecology: traditional ecological knowledge and resource management. Taylor & Francis, Philadelphia

Berkes F, Colding J, Folke C (2000) Rediscovery of traditional ecological knowledge as adaptive management. Ecol Appl 10:1251–1262

Bodin Ö, Prell C (2011) Social networks and natural resource management: uncovering the social fabric of environmental governance. Cambridge University Press, Cambridge

Brooks JS, Waylen KA, Mulder MB (2012) How national context, project design, and local community characteristics influence success in community-based conservation projects. PNAS 109:21265–21270

Caro TM (2001) Species richness and abundance of small mammals inside and outside an African national park. Biol Conserv 98:251–257

Chang C, Allen JC, Dawson SE, Madsen GE (2012) Network analysis as a method for understanding the dynamics of natural resource management in rural communities. Soc Nat Resour 25:203–208

Chapin FS, Oswood MW, Van Cleve K, Viereck LA, Verbyla DL (2006) Alaska's changing boreal forest. Oxford University Press, New York

Crona B, Hubacek K (2010) The right connections: how do social networks lubricate the machinery of natural resource governance? Ecol Soc 15:18

Cundill G, Rodela R (2012) A review of the assertions about the processes and outcomes of social learning in natural resource management. J Environ Manage 113:7–14

Dahlberg AC (2005) Local resource use, nature conservation and tourism in Mkuze wetlands, South Africa: a complex weave of dependence and conflict. Dan J Geogr 105:43–55

De Nooy W (2013) Communication in natural resource management: agreement between and disagreement within stakeholder groups. Ecol Soc 18:44

Dickinson JL, Zuckerberg B, Bonter DN (2010) Citizen science as an ecological research tool: challenges and benefits. Annu Rev Ecol Syst 41:149–172

Evans SM, Gebbels S, Stockill JM (2008) 'Our shared responsibility': participation in ecological projects as a means of empowering communities to contribute to coastal management processes. Mar Pollut Bull 57:3–7

Ganeshaiah KN, Uma SR (1998) BRT sanctuary: a biogeographic bridge of the Deccan Plateau. In: Ganeshaiah KN, Uma SR (eds) Biligiri Rangaswamy Temple wildlife sanctuary: natural history, biodiversity and conservation. ATREE and VGKK, India, pp 4–6

Gavin MC, McCarter J, Mead A, Berkes F, Stepp JR, Peterson D, Tang R (2015) Defining biocultural approaches to conservation. Trends Ecol Evol 30:140–145

Gray B (2003) Framing of environmental disputes. In: Lewicki R, Gray B, Elliott M (eds) Making sense of environmental conflicts. Island Press, Washington, pp 11–35

Gutiérrez NL, Hilborn R, Defeo O (2011) Leadership, social capital and incentives promote successful fisheries. Nature 470:386–389

Hajjar RF, Kozak RA, Innes JL (2012) Is decentralization leading to "real" decision-making power for forest-dependent communities? Case studies from Mexico and Brazil. Ecol Soc 17:12

Hegde R, Suryaprakash S, Achoth L, Bawa KS (1996) Extraction of non-timber forest products in the forests of Biligiri Rangan Hills, India. 1. Contribution to rural income. Econ Bot 50:243–251

Houde N (2007) The six faces of traditional ecological knowledge: challenges and opportunities for Canadian co-management arrangements. Ecol Soc 12:34

Huntington HP (2000) Using traditional ecological knowledge in science: methods and applications. Ecol Appl 10:1270–1274

Johnson EA, Miyanashi K, Bridge SRJ (2001) Wildfire regime in the boreal forest and the idea of suppression and fuel buildup. Conserv Biol 15:1554–1557

Jones NA, Ross H, Lynam T, Perez P, Leitch A (2011) Mental models: an interdisciplinary synthesis of theory and methods. Ecol Soc 16:1

Karanth KU, Karanth KK (2012) A tiger in the drawing room: can luxury tourism benefit wildlife. Econ Political Wkly 38:38–43

Kasischke ES, Verbyla DL, Rupp TS, McGuire AD, Murphy KA, Jandt R, Barnes JL, Hoy EE, Duffy PA, Calef M, Turetsky MR (2010) Alaska's changing fire regime-implications for the vulnerability of its boreal forests. Can J For Res 40:1313–1324

Kimmerer RW (2002) Weaving traditional ecological knowledge into biological education: a call to action. Bioscience 52:432–438

Kothari A, Rai N (2011) Biligiri tiger reserve: include Soligas in conservation plan. The Deccan Herald. In: Published online 9th Feb 2011. http://www.deccanherald.com/content/136029/biligiri-tiger-reserve-include-soligas.html

Leach M (2008) Pathways to sustainability in the forest? Misunderstood dynamics and negotiation of knowledge, power and policy. Environ Plan 40:1783–1795

Leach M, Scoones I, Stirling A (2010) Dynamic sustainabilities: technology, environment, social justice. Earthscan, London

Lele S, Wilshusan P, Brockington D, Seidler R, Bawa K (2010) Beyond exclusion: alternative approaches to biodiversity conservation in the developing tropics. Curr Opin Environ Sustain 2:94–100

Levin SA (1999) Fragile dominion: complexity and the commons. Perseus, Cambridge

Moen J, Rist L, Bishop K, Chapin FS, Ellison D, Kulluvainen T, Petersson H, Puettmann KJ, Ryaner J, Warkentin IG, Bradhaw CJ (2014) Eye on the taiga. Conserv Lett 7:408–441

Nagendra H, Ostrom E (2012) Polycentric governance of multifunctional forested landscapes. Int J Common 6:104–133

Nakashima DJ, Roué M (2002) Indigenous knowledge, peoples and sustainable practice. In: Timmerman P (ed) Encyclopedia of global environmental change 5: social and economic dimensions of global environmental change. Wiley, Chichester, pp 314–324

Nelson JL, Zavaleta E, Chapin FS (2008) Boreal fire effects on subsistence resources in Alaska and adjacent Canada. Ecosystems 11:156–171

Nordby H (2008) Values, cultural identity and communication: a perspective from philosophy of language. J Intercult Commun 17

Orlove BS, Chiang JCH, Cane MA (2000) Forecasting Andean rainfall and crop yield from the influence of El Niño on Pleiades visibility. Nature 403:68–71

Ostrom E (1990) Governing the commons: the evolution of institutions for collective action. Cambridge University Press, Cambridge

Ozesmi U, Ozesmi SL (2004) Ecological models based on people's knowledge: a multi-step fuzzy cognition mapping approach. Ecol Model 176:43–64

Persha L, Agrawal A, Chhatre A (2011) Social and ecological synergy: local rulemaking, forest livelihoods and biodiversity conservation. Science 331:1606–1608

Peterson GD, Cumming GS, Carpenter SR (2003) Scenario planning: a tool for conservation in an uncertain world. Conserv Biol 17:358–366

Pierotti R, Wildcat D (2000) Traditional ecological knowledge: the third alternative. Ecol Appl 10:1333–1340

Pretty J (2003) Social capital and the collective management of resources. Science 302:912–1914

Ray L (2011) Using Q-methodology to identify local perspectives on wildfires in two Koyukon Athabascan communities in rural Alaska. Sustain: Sci Pract Policy 7:18–29

Ray L, Kolden CA, Chapin FS (2012) A case for developing place-based fire management strategies from traditional ecological knowledge. Ecol Soc 17:37

Reed MS, Evely AC, Cundill G, Fazey I, Glass J, Laing A, Newig J, Parrish B, Prell C, Raymond C, Stringer LC (2010) What is social learning? Ecol Soc 15:1

Rist L (2009) Assessing a threat to sustainable NTFP harvest using ecological data and traditional ecological knowledge. PhD thesis, Imperial College London

Rist L, Uma Shaanker R, Milner-Gulland EJ, Ghazoul J (2008) Managing mistletoes: the value of local practices for a non-timber forest resource. For Ecol Manage 255:1684–1691

Rist L, Uma Shaanker R, Milner-Gulland EJ, Ghazoul J (2010) The use of traditional ecological knowledge in forest management: an example from India. Ecol Soc 15:3

Rist L, Shanley P, Sunderland T, Sheil D, Ndoye O, Liswanti N, Tieguhong J (2012) The impacts of selective logging on non-timber forest products of livelihood importance. For Ecol Manage 268:57–69

Roux DJ, Rogers KH, Biggs HC, Ashton PJ, Sergeant A (2006) Bridging the science-management divide: moving from unidirectional knowledge transfer to knowledge interfacing and sharing. Ecol Soc 11:4

Rupp TS, Olson M, Henkelman J, Adams L, Dale B, Joly K, Collins W, Starfield AM (2006) Simulating the influence of a changing fire regime on caribou winter foraging habitat. Ecol Appl 16:1730–1743

Ruwanza S, Shackleton CM (2015) Density and regrowth of a forest restio (*Ischyrolepis eleocharis*) under harvest and non-harvest treatments in dune forests of Eastern Cape province, Economic Botany: South Africa

Setty RS, Bawa K, Ticktin T, Gowda CM (2008) Evaluation of a participatory resource monitoring system for non-timber forest

products: the case of amla (Phyllanthus spp.) fruit harvest by Soligas in south India. Ecol Soc 13:19

Shackleton CM, Parkin F, Chauke MI, Downsborough L, Olsen A, Brill G, Weideman C (2009) Conservation, commercialisation and confusion: harvesting of Ischyrolepis in a coastal forest, South Africa. Environ Dev Sustain 11:229–240

Shanker K, Hiremath A, Bawa K (2005) Linking biodiversity conservation and livelihoods in India. PLoS Biol 3:394

Shanley P, López C (2009) Out of the loop: why research rarely reaches policy makers and the public and what can be done. Biotropica 41:535–544

Stevenson MG (1996) Indigenous knowledge in environmental assessment. Arctic 49:278–291

Stone-Jovicich SS, Lynam T, Leitch A, Jones NA (2011) Using consensus analysis to assess mental models about water use and management in the crocodile river catchment, South Africa. Ecol Soc 16:45

Sundaram B, Krishnan S, Hiremath AJ (2012) Ecology and impacts of the invasive species, *Lantana camara*, in a social-ecological system in South India: perspectives from local knowledge. Hum Ecol 40:931–942

The Hindu (2010) Trees on hundreds of acres burnt in fire in BRT sanctuary. Published online March 10, 2010. http://www.hindu.com/2010/03/10/stories/2010031058950300.htm

Ticktin T, Ganesan R, Paramesha M, Setty S (2012) Disentangling the effects of multiple anthropogenic drivers on the decline of two tropical dry forest trees. J Appl Ecol 49:774–784

Torpey-Saboe N, Andersson K, Mwangi E, Persha L, Salk C, Wright G (2015) Benefit sharing among local resource users: the role of property rights. World Dev 72:408–418

Uma Shaanker R, Ganeshaiah KN, Reddy BVC, Krishnan V, Rajagoplan R, Aravind J, Kumar A, Vanaraj G, Rao D (2002) Enhancing the role of forest fruits. Ecol Soc 15:3

Western D, Wright M, Strum S (eds) (1994) Natural connections: perspectives in community-based conservation. Island Press, Washington

Yin R (2003) Case study research: design and methods, 3rd edn. Sage, London

Young O (2010) Institutional dynamics: resilience, vulnerability and adaptation in environmental and resource regimes. Glob Environ Change 20:378–385