

REDISCOVERY OF TRADITIONAL ECOLOGICAL KNOWLEDGE AS ADAPTIVE MANAGEMENT

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Abstract. Indigenous groups offer alternative knowledge and perspectives based on their own locally developed practices of resource use. We surveyed the international literature to focus on the role of Traditional Ecological Knowledge in monitoring, responding to, and managing ecosystem processes and functions, with special attention to ecological resilience. Case studies revealed that there exists a diversity of local or traditional practices for ecosystem management. These include multiple species management, resource rotation, succession management, landscape patchiness management, and other ways of responding to and managing pulses and ecological surprises. Social mechanisms behind these traditional practices include a number of adaptations for the generation, accumulation, and transmission of knowledge; the use of local institutions to provide leaders/stewards and rules for social regulation; mechanisms for cultural internalization of traditional practices; and the development of appropriate world views and cultural values. Some traditional knowledge and management systems were characterized by the use of local ecological knowledge to interpret and respond to feedbacks from the environment to guide the direction of resource management. These traditional systems had certain similarities to adaptive management with its emphasis on feedback learning, and its treatment of uncertainty and unpredictability intrinsic to all ecosystems.

Key words: adaptive management; human ecology; resilience; resource management; social learning; Traditional Ecological Knowledge.

INTRODUCTION

Traditional knowledge, as a way of knowing, is similar to Western science in that it is based on an accumulation of observations, but it is different from science in some fundamental ways. The anthropologist Claude Levi-Strauss (1962:269) argued that these two ways of knowing are two parallel modes of acquiring knowledge about the universe; the two sciences were fundamentally distinct in that “the physical world is approached from opposite ends in the two cases: one is supremely concrete, the other supremely abstract.” Similarly, the philosopher Paul Feyerabend (1987) distinguished between two different traditions of thought: abstract traditions (to which scientific ecology belongs) and historical traditions, which include systems of knowledge possessed by people outside Western science, knowledge that often becomes encoded in rituals and in the cultural practices of everyday life. Other scholars have cautioned against overemphasizing the differences between Western science and traditional

knowledge and questioned if the dichotomy is real (Agrawal 1995).

Interest in Traditional Ecological Knowledge has been growing in recent years, partly due to a recognition that such knowledge can contribute to the conservation of biodiversity (Gadgil et al. 1993), rare species (Colding 1998), protected areas (Johannes 1998), ecological processes (Alcorn 1989), and to sustainable resource use in general (Schmink et al. 1992, Berkes 1999). Conservation biologists, ecological anthropologists, ethnobiologists, other scholars, and the pharmaceutical industry all share an interest in traditional knowledge for scientific, social, or economic reasons.

For a long time, “tradition” was a problematic word for researchers in development and anthropology because, as Warren (1995) put it, “‘traditional’ denoted the 19th-century attitudes of simple, savage and static.” For this reason, some scholars favor the less value-laden term “indigenous knowledge” (Warren 1995). Nevertheless, the use of the term “Traditional Ecological Knowledge” has become established, among others, through the work of the International Conservation Union (IUCN) working group by that name (Johannes 1989, Williams and Baines 1993).

In the course of the development of the field, the

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study of Traditional Ecological Knowledge began with the study of species identifications and classification (ethnobiology), and proceeded to considerations of peoples' understandings of ecological processes and their relationships with the environment (Williams and Baines 1993, Berkes 1999). The analysis of many Traditional Ecological Knowledge systems shows that there is a component of local observational knowledge of species and other environmental phenomena, a component of practice in the way people carry out their resource use activities, and further, a component of belief regarding how people fit into or relate to ecosystems. In short, traditional knowledge is a knowledge–practice–belief complex (Berkes 1999). We have therefore developed a working definition of Traditional Ecological Knowledge as a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment. This definition, evolving from our earlier work (Gadgil et al. 1993, Berkes et al. 1995), further recognizes that Traditional Ecological Knowledge is an attribute of societies with historical continuity in resource use practice (Dei 1993, Williams and Baines 1993). By and large, these are nonindustrial or less technologically advanced societies, many but not all of them indigenous or tribal.

Traditional knowledge may be holistic in outlook and adaptive by nature, gathered over generations by observers whose lives depended on this information and its use. It often accumulates incrementally, tested by trial-and-error and transmitted to future generations orally or by shared practical experiences (Ohmagari and Berkes 1997). Obviously, not all traditional practice and belief systems were ecologically adaptive in the first place; some became maladaptive over time due to changing conditions. Not all traditional practice is ecologically wise. For example, Diamond (1993) notes that even though New Guinea natives possess detailed knowledge of plants and animals, some of the groups had, and continue to have, a heavy impact on their native biota. We do not wish to enter into the debate over aboriginal conservation, but suffice to say, exaggerated claims on behalf of traditional ecological wisdom require a reality check (Chapin 1988, Redford and Stearman 1993). In any case, indigenous notions of conservation are fundamentally different from those of Western conservationists (Alcorn 1993, Dwyer 1994, Roberts et al. 1995).

Nevertheless, growing interest in traditional knowledge since the 1980s is indicative of the need to gain further insights into indigenous and/or local practices of resource use from an ecological perspective, which is the objective of this paper. We explore a diversity of traditional knowledge systems and discuss the usefulness of Traditional Ecological Knowledge in terms

of providing understanding and information complementary to scientific ecology. The synthesis is partly based on the findings of a project on linked social–ecological systems (Berkes and Folke 1998), which sought to mobilize a wider range of considerations and sources of information than those used in conventional resource management (which we define as resource management based on Newtonian science and on the expertise of government managers). The overall objective of the project was to learn from a diversity of locally evolved management systems and their dynamics for improved ecosystem management. Some of the cases came from traditional societies and some from modern societies with locally evolved management systems, as in Maine (Acheson et al. 1998, Hanna 1998). Such nonindigenous examples help emphasize the point that probably none of the examples is purely traditional but incorporate both Western science and local practice. Whether a practice is traditional or contemporary is not the key issue. The important aspect is whether or not there exists local knowledge that helps monitor, interpret, and respond to dynamic changes in ecosystems and the resources and services that they generate.

In this paper, the emphasis is on the role of local or indigenous communities in using Traditional Ecological Knowledge to respond to and manage processes and functions of complex systems. Of special interest are practices by which ecosystems and biological diversity are managed to secure a flow of natural resources and ecological services on which people depend. First, we identify a selection of management practices based on local ecological knowledge. These practices range from monitoring specific resources to ecologically sophisticated practices that respond to and manage disturbance and build resilience (*sensu* Holling 1973, 1986) across temporal and spatial scales. Resilience in this context refers to the capacity to recover after disturbance, absorb stress, internalize it, and transcend it. Resilience is thought to conserve options and opportunity for renewal and novelty (Holling et al. 1995, Gunderson et al. 1997).

Second, we identify a number of social mechanisms behind these practices and organize them sequentially from the generation of knowledge, to the underlying world view and values of the culture in which that knowledge is embedded. We do not address in any detail, the belief or spiritual component of traditional knowledge, as this is largely outside the realm of ecology (but see the discussion on the ecological role of sanctions and taboos by Colding and Folke 1997). Third, we evaluate traditional knowledge systems for the insights they provide for the qualitative (as opposed to quantitative) management of resources and ecosystems (Lugo 1995), and for parallels to adaptive management (Holling 1978, Gunderson et al. 1995).

TABLE 1. Social-ecological practices and mechanisms in traditional knowledge and practice (adapted from Folke et al. 1998).

Management practices based on ecological knowledge
Practices found both in conventional resource management and in some local and traditional societies
Monitoring resource abundance and change in ecosystems
Total protection of certain species
Protection of vulnerable life history stages
Protection of specific habitats
Temporal restrictions of harvest
Practices largely abandoned by conventional resource management but still found in some local and traditional societies
Multiple species management; maintaining ecosystem structure and function
Resource rotation
Succession management
Practices related to the dynamics of complex systems, seldom found in conventional resource management but found in some traditional societies—
Management of landscape patchiness
Watershed-based management
Managing ecological processes at multiple scales
Responding to and managing pulses and surprises
Nurturing sources of ecosystem renewal
Social mechanisms behind management practices
Generation, accumulation, and transmission of local ecological knowledge
Reinterpreting signals for learning
Revival of local knowledge
Folklore and knowledge carriers
Integration of knowledge
Intergenerational transmission of knowledge
Geographical diffusion of knowledge
Structure and dynamics of institutions
Roles of stewards/wise people
Cross-scale institutions
Community assessments
Taboos and regulations
Social and religious sanctions
Mechanisms for cultural internalization
Rituals, ceremonies, and other traditions
Cultural frameworks for resource management
World view and cultural values
A world view that provides appropriate environmental ethics
Cultural values of respect, sharing, reciprocity, humility, and other

PRACTICES BASED ON TRADITIONAL ECOLOGICAL KNOWLEDGE

It is often difficult to identify and generalize about indigenous practices that function in resource and ecosystem management. A given practice may be documented from one social group but not the next, or from one time period but not another. As well, researchers who are not trained ecologists may not recognize a practice as having an ecological function or may even misinterpret them. In fact, many of the management practices listed in Table 1 were not previously identified specifically for their role in resource and ecosystem management (Folke et al. 1998). When identifying these practices, we make no claim about their existing use; nor do we make any claims that the people who practiced them would necessarily interpret or explain them as we do. Similar complications apply also to the identification of *social mechanisms* behind management practices.

Practices and mechanisms listed in Table 1 are not

considered separate phenomena but interlinked with one another and coevolving. (Coevolution is interpreted here as a trial-and-error process of self-organization through mutual feedback, see Colding and Folke 1997.) The list is by no means exhaustive but merely a starting point for the further identification of social-ecological linkages and their contribution to the use of locally based ecological knowledge. For analytical purposes, we have clustered these practices into three groups: those found both in conventional resource management and in some local and traditional societies; those largely abandoned by conventional resource management but still found in some local and traditional societies; and those related to the dynamics of complex systems, seldom found in conventional resource management but found in some local and traditional societies.

Table 1 does not list some well known ecological practices, such as territoriality, which can limit the size of local human populations to resource availability

(Dyson-Hudson and Smith 1978) as in other species. Instead, Table 1 deals with variations of territoriality, such as resource rotation and watershed-based management, that may serve different functions. As well, biodiversity conservation is not identified as a practice as such. Many traditional management systems contribute to the conservation of biodiversity through a number of practices, including the use of more varieties, species, and landscape patches than do modern agricultural and food production systems (Nabhan 1985, Warren et al. 1995, Sporrang 1998), and by monitoring and responding to ecosystem change (Berkes et al. 1995). In such cases, biodiversity conservation is not necessarily the objective of the practice but a consequence of it.

Practices found both in conventional resource management and in some traditional societies

Monitoring the status of the resource is a common practice among many groups of traditional users, and is often accompanied with the monitoring of change in ecosystems. The proximity of users to the resource confers an ability to observe day-to-day changes, either by the whole community or by selected individuals, such as community stewards and elders. For example, shamans of the Tukano people of Colombia monitor species abundance by random scheduling of hunting excursions. Thus, shamans determine the number of animals to be hunted and the species that need to be protected, based on field observations (Reichel-Dolmatoff 1976). Many of the cases in Berkes and Folke (1998) provide examples of such monitoring across a range of locally evolved management systems from traditional to modern. For example, herders of the Sahel monitor grazing pressure and the state of the pasture to make decisions about rotating or relocating herds (Niamir-Fuller 1998). Icelandic fishers spend a great deal of time and effort communicating about fish distributions and abundance (Palsson 1998), and coastal communities in Maine monitor clam populations to help determine the areas requiring enhancement (Hanna 1998).

Total protection of certain species is common in some areas. Such practices may vary from avoiding species that are poisonous or are used for medicinal purposes (Begossi 1998) to preserving keystone species in the ecosystem (Colding and Folke 1997). Several practices involve the protection of vulnerable life-history stages of species (Johannes 1978). For example, there are local prohibitions against catching lobsters with eggs in the Maine fisheries (Acheson et al. 1998). In south India, many wading birds are hunted outside the breeding season; they are not hunted in heronries that offer year-round sanctuaries and that may be on trees in the middle of a village (Gadgil et al. 1993).

Sacred groves may serve for the protection of specific habitats, and continue to be important in many

areas, for example in Africa, but have been disappearing as a result of change of rural economies and denigration of local traditions (Dei 1993). Habitats protected by sacred locales may be recruitment areas, for example, for populations of seed-dispersing birds and bats, that are of importance for renewal of surrounding ecosystems (Gadgil et al. 1993). They are also important for birds controlling insect outbreaks on adjacent crop fields, and may serve as seed banks for locally adapted crop varieties and medicinal plants. Even small sacred groves may be surprisingly effective in conserving biodiversity. A botanical survey in a Nigerian sacred grove yielded 330 plant species as compared to only 23 in surrounding nonprotected areas (Warren and Pinkston 1998). Sacred groves are not the only example of culturally protected habitat. Niamir-Fuller (1998) describes the use of buffer areas of Sahelian rangelands, which are normally protected from grazing except in the case of emergencies. Gadgil et al. (1998) suggest that traditional conservation practices in relation to refugia might have originated to serve secular functions, even though they are associated with religious practice.

Temporal restriction of harvest is a common practice in conventional fish and wildlife management, and it is also used in some traditional management systems, for example, among African herders (Niamir-Fuller 1998) and groups of Canadian Amerindian hunters, whose hunting, fishing, and trapping areas are periodically "rested" (Berkes 1999). In the Hindu-Kush Himalayas, there were traditional seasonal and periodic restrictions on gathering from the village commons (Jodha 1998). Zerner (1994) describes how prohibitions on entry, harvest, or hunting in community-controlled areas of many Maluku Islands of Indonesia, are regulated through the practice of *sasi*, a long-standing social institution for restricting access to certain resources.

Practices largely abandoned by conventional resource management but still found in some local and traditional societies

These include practices that have fallen out of favor in government resource management, presumably because of production inefficiency. But many of them are being rediscovered, as reflected for example in the growing emphasis on agroecology, integrated farming and aquaculture, and polyculture. Explicitly or implicitly, these rediscoveries continue to be inspired by traditional practices. Many traditional systems use multiple species management, for example, through integrated farming and cultivation systems. A Nigerian case study (Warren and Pinkston 1998) identifies an agroforestry system combining food crops and domesticated trees as the oldest farming practice in the area. Since the beginning of the 20th century, this system has taken the form of a perennial mixed plantation that

includes cash crops such as cocoa, oil palm, and coffee. Many multiple species management approaches result in soil fertility improvement and crop protection through the integration of trees, animals, and crops (Altieri 1994). For example, the Bisnois of the Thar desert of India maintain their resource base through managing a keystone process tree species, *Prosopis cineraria*. This leguminous tree helps fix free nitrogen and enrich the soil, creating ideal conditions for crops that are planted under the shade of these trees. The leaves provide fodder, branches provide fencing material and firewood, and pods are eaten by both cattle and humans (Sankhala 1993).

Many of these systems serve the purpose of maintaining ecosystem process and function. For example, indigenous-inspired forestry practices in northern coastal British Columbia serve to conserve the structure and function of forest ecosystems by the maintenance of both hardwood and coniferous trees, so that species such as alder can help fix nitrogen for the conifers (Pinkerton 1998). Ramakrishnan (1992), Jodha (1998), and Alcorn and Toledo (1998) describe mixed cultivation systems in which some of the species help maintain ecosystem structure and function. For example, *milpa* and *jhum* systems, which are two regional variations of shifting cultivation (swidden) systems found throughout world's tropical forests (Brookfield and Padoch 1994), use tools and techniques that support the processes and functions of the agroforest ecosystem.

The practice of resource rotation, once used in agriculture worldwide, is one of the most widespread tools of traditional resource management systems from the arctic to the tropics. For example, James Bay Cree hunters rotate trapping areas on a four-year cycle (ideally) to allow populations of beaver to recover. They use a similar rotation technique for fishing areas, using the declining catch per unit of effort as the feedback that informs decision-making, basically an optimum foraging model (Berkes 1998). In semiarid regions such as the fringe of Sahel, plant productivity oscillates seasonally and follows the rains. Many of the larger herbivores, as well as the traditional cattle herders, have adapted to this pattern by migrating seasonally. This yearly cycle provides a rotational management system, enabling the recovery of heavily grazed rangelands. In some cases, adjacent grazing areas are rotated in the same season as well (Niamir-Fuller 1998). Variations of this pattern, involving the rotation of herd animal enclosures, may result in landscape-level management in the long term through the production of islands of *Acacia*, a keystone species, by providing nutrient-rich microhabitats suitable for the growth of this tree species (Reid and Ellis 1995).

Appreciated by ecologists only relatively recently (Denevan et al. 1984), succession management is exemplified by the shifting cultivation system, *milpa*, as

used in tropical Mexico. This system is well adapted to the multiple use of the tropical moist forest. While crops are growing, the regenerating vegetation is renewing the site for the next *milpa* cycle, and many of the regrowth species will eventually become trees that provide firewood, construction materials, dyes, craft materials, canoe bodies, medicine, and other resources. Agriculture becomes a sequential harvesting system of crops and nonfood crops (Alcorn and Toledo 1998). There are many variations of this succession management system among different South American groups (e.g., Irvine 1989).

Practices related to the dynamics of complex systems seldom found in conventional resource management

Some of the above-mentioned practices also address the management of complex systems (Costanza et al. 1993), but there seems to exist a class of indigenous practices that may be best appreciated by ecologists with an interest in ecosystem dynamics, adaptive management, and nonequilibrium systems, practices seldom found in the repertory of conventional resource management.

Management of landscape patchiness is practiced by many groups in the African Sahel (Niamir-Fuller 1998). The small-scale movements of Sahelian herders are adapted to the variability and unpredictability of the landscape. In a contemporary adaptation of traditional herding rules, the Maasai of Kenya progressively widen the radius of grazing around wells as the wet season advances, so as to leave enough forage around the wells for the dry season. Sporrang (1998) argues that the scattered agricultural plots of 18th century Swedish farmers of Delacarla was an adaptation for the use of multiple ecological zones in the landscape. In the Eastern Himalayas, tribal groups are intimately familiar with and utilize landscape patchiness by elevation zones to grow different crops (Ramakrishnan 1992).

Watershed-based management systems use biogeographic boundaries to delineate areas controlled and managed by specific groups of people (Berkes et al. 1998). Southeast Asia and Oceania had, and to some extent still have, a wealth of these prescientific ecosystem management practices. Examples include ancient Hawaiian *ahupua'a* (Costa-Pierce 1987), the Yap *tabinau*, the Fijian *vanua*, and the Solomon Islands *puava* (Ruddle et al. 1992). These four terms refer to generically similar watershed-based management systems. In ancient Hawaii, valleys within watersheds were used for integrated farming. The ecosystem unit extended from upland forests protected by taboo, downstream to the coral reef and lagoon. Similarly in the Solomon Islands, a *puava* in the widest sense includes all resources and land in a watershed, from the top of the mainland mountains to the open sea outside the barrier reef (Hviding 1996). In each of these cases, the social group inhabiting the ecosystem unit was con-

sidered to be part of the system, and affiliation with a particular area was considered to be part of a person's identity.

There is some evidence that locally devised systems may be useful in managing ecological processes at multiple scales. *Milpa* is the indigenous Mexican term for shifting cultivation. *Milpa* succession, as described by Alcorn and Toledo (1998), manages food crops on a 1–3 year scale, and some tree crops and products on a 30-year scale. Based on ethnohistorical information and current practice, James Bay Cree hunters seem to be simultaneously managing beaver populations on a 4–6 year scale, lake fish on a 5–10 year scale, and caribou on a 80–100 year scale (Berkes 1998). The holistic forestry described by Pinkerton (1998) is concerned not only with the production of fiber over several square kilometers, but also with the maintenance of ecological processes involving soil bacteria at the spatial scale of a few square meters. In the case of African herders, Niamir-Fuller (1998) recognizes two different sets of practices and rules for the larger scale movements (macro-mobility) and the smaller scale movements (micro-mobility).

An example of responding to and managing pulses and surprises is the establishment of range reserves within the annual grazing areas of African herders. These reserves provide an emergency supply of forage that functions to maintain the resilience of both the ecosystem and the social system of the herders, and serve as buffer when disturbance, such as drought, challenges the dryland ecosystem (Niamir-Fuller 1998). Such practices may be considered ecological adaptations to unpredictable, low-rainfall environments. Livestock gather up energy from the low-production environment, and serve as relatively drought-resistant packages of concentrated energy to buffer against variability (Coughenour et al. 1985). Sacred groves in India absorb disturbance by serving as fire-breaks for cultivated areas and villages (Gadgil et al. 1998). The Warlis of India control pests by placing certain kinds of tree branches in their paddy fields. This practice serves to attract birds for insect control, and buffers against outbreaks of various pest populations (Pereira 1992).

Disturbances triggered by events such as fire, hurricanes, pest outbreaks, and heavy grazing are inherent to the internal dynamics of ecosystems, and often set the timing of ecosystem renewal processes (Holling et al. 1995). Many traditional societies seem to nurture sources of ecosystem renewal by creating small-scale disturbances. Traditional agroforestry, such as *milpa* and *jhum*, create forest gaps and enable people to produce crops or enhance wild foods without disrupting natural renewal processes (Ramakrishnan 1992, Turner 1994). Lewis and Ferguson (1988) show that aboriginal use of fire in as geographically diverse areas as Canada, Australia, and California had many elements and prin-

ciples in common. It was used effectively to improve habitat for game and to assist in the hunt itself. Herders in Niamir-Fuller (1998) behave like a disturbance by following the migratory cycles of the herbivores from one area to another. The pulses of grazing by herbivores contribute to the capacity of the semiarid grasslands of Africa to function under a wide range of climatic conditions. If this capacity of the ecosystem to deal with pulses is reduced, an event that previously could be absorbed can flip the grassland ecosystem into a relatively unproductive state, which is dominated and controlled by woody plants for several decades (Walker 1993).

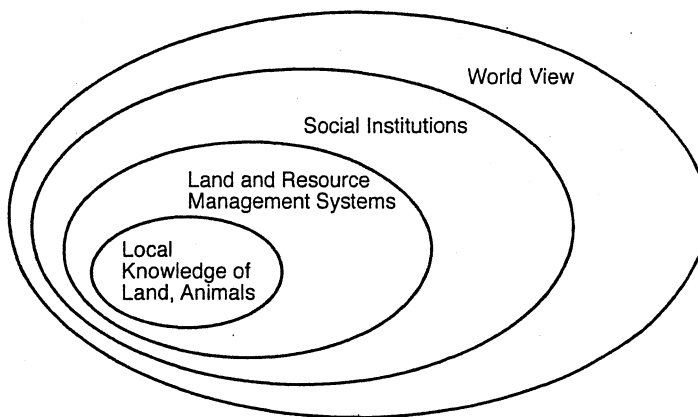
SOCIAL MECHANISMS BEHIND TRADITIONAL PRACTICES

The practice of Traditional Ecological Knowledge differs from that of scientific ecological knowledge in that it is largely dependent on local social mechanisms. These social mechanisms may be thought of as a hierarchy that proceeds from local ecological knowledge to social institutions, to mechanisms for cultural internalization, and to world views. Institutions, in the sense of rules-in-use, provide the means by which societies can act on their local knowledge and use it to produce a livelihood from the environment (Berkes 1989). Both knowledge and institutions require mechanisms for cultural internalization, so that learning can be encoded and remembered by the social group. World view or cosmology gives shape to cultural values, ethics, and the basic norms and rules of a society. Fig. 1 illustrates the idea of Traditional Ecological Knowledge as a knowledge–practice–belief complex. Local observational knowledge of the land, resource management systems, social institutions (or rules-in-use), and the world view can be represented as a hierarchical system. Such a representation falls short of showing the feedbacks among the ellipses, and the close coupling of some parts of the system, especially management systems and social institutions. However, it does convey the idea of embeddedness of local knowledge and rules/norms in the world view of a particular culture.

Generation, accumulation, and transmission of knowledge

The generation, accumulation, and transmission of Traditional Ecological Knowledge proceeds along very different lines than those in scientific ecology. The response of the Cree caribou hunting system, following a resource crisis, illustrates how a society can reinterpret ecological signals for learning, consistent with the model proposed by Gunderson et al. (1995). The disappearance of caribou in the 1910s, following what the Cree themselves considered a wasteful slaughter, became a lesson that later led to a more conservationist approach (Berkes 1999). The redesigned management

FIG. 1. Levels of analysis in traditional knowledge and management systems (adapted from Berkes 1999).



system, encoded in ethical and cultural beliefs of the Cree, was enforced by elders two generations later in the 1980s (Berkes 1999). Another example of such social learning is provided by Finlayson and McCay (1998) in Newfoundland's cod fisheries. Inshore fishers, who had traditionally seen fishery depletions as a natural and transient event, began to realize with the escalation of the offshore fishery, that stock failure could be caused by fishing itself. The irony of the case is that the inshore fishers were unable to convince the resource managers of the impending crisis. The managers were preoccupied with the offshore fishery and missed the signals that the inshore fishers were monitoring and learning from—until the entire stock collapsed (Hutchings et al. 1997).

The reestablishment of beaver management rules by the James Bay Cree provides an example of the revival of local ecological knowledge for restoring a population. Local Cree ethics for beaver conservation were suspended when their territory was overrun by outsiders in the 1920s. The ethics and the territorial management system itself were revived in the 1950s with the departure of the intruders and government protection of Cree land tenure (Feit 1986, Berkes 1998). Such revival requires the presence of strong traditions and institutions, as experienced in some Central American cases (Chapin 1991). In the absence of strong traditions and institutions, other kinds of incentives, including community economic benefits, may become necessary. For example, the redevelopment of ecological refugia in some parts of India has required monetary incentives (Gadgil et al. 1998).

Folklore and knowledge carriers help maintain ecologically sound management practices. These carriers may be local stewards and leaders (Pinkerton 1998), elders (Berkes 1998), or mythical figures in the local culture. For example, tales of the "maize culture hero" are associated with all stages of the *milpa* agroforestry system. The hero warns people of impending doom if people stop making *milpa* properly (Alcorn and Toledo 1998). The hunters' guild among the Yoruba functions as a knowledge carrier to maintain ancient traditions

and indigenous knowledge (Warren and Pinkston 1998); Icelandic fishers serve as carriers of practical knowledge (Pálsson 1998); and among the Gitksan of British Columbia, traditional values and knowledge are carried, and revived, by elders and chiefs (Pinkerton 1998).

Social mechanisms often play a role in the integration of ecological knowledge of different kinds. Maine's soft shell clam fishery is characterized by the integration of informal local knowledge and formal scientific information generated locally (Hanna 1998). Begossi (1998) argues that the mix of traditional and new knowledge of the *caiçaras* and *caboclos* (two groups of mixed-race rural people) of Brazil increases the resilience of their social-ecological systems by combining adaptations from two different cultural traditions, Amerindian and European.

Mechanisms for the intergenerational transmission of knowledge are embedded in social systems. An example of such transmission is the *milpa* script, which is passed on to children and sustained by cultural beliefs, mythologies, and yearly festivals (Alcorn and Toledo 1998). Among the James Bay Cree, successful transmission of bush skills and knowledge depends on the amount of time families spend on the land because of apprenticeship-based knowledge transmission, and the amount of time required for hands-on learning (Ohmagari and Berkes 1997).

Wide-ranging information exchange on rangeland conditions among different pastoralist groups (Niamir-Fuller 1998) illustrates the process of geographical diffusion of ecological knowledge. The similarity of the basic management design in some 30 traditional fishing societies throughout the world suggests geographic transfer of knowledge of marine coastal management systems (Acheson et al. 1998). Similarities become more obvious when regional systems are considered. Johannes' (1978) detailed study of fishery management in Oceania shows the pervasiveness of knowledge diffusion inferred through striking similarities across island groups in the basic design of the reef and lagoon tenure system.

Structure and dynamics of institutions for implementation of knowledge

Ecological knowledge does not function in isolation. It is embedded in institutions and local social norms (North 1990). The structure and dynamics of institutions are critical for implementation of management practices based on ecological understanding in any society (Hanna et al. 1996). The coordination of appropriate resource use practices is often entrusted with traditional leaders. For example, the collective leadership of stewards of different hunting areas is the key common-property resource management institution among the Cree. A hunting leader may act as the steward of resources on behalf of the community, as well as a social leader (Berkes 1998). Similarly, senior Ara hunters are custodians of their sacred areas as well as communal areas. The traditional guild of Ara hunters is headed by the chief of the hunters, and guided by an Ogun priest who performs ritual duties (Warren and Pinkston 1998). Pinkerton (1998) describes how a clan chief developed and pursued his vision of the future Gitksan forest, a telling case of the key role of stewards/wise people in bringing about a revival of local knowledge.

Several examples are available of cross-scale institutions, those that operate at more than one temporal or spatial scale. In the Maine soft shell clam fisheries, management rights held at different levels, from the citizen to the state, are nested in ascending levels of authority, providing for a cross-scale management institution appropriate for comanagement or the sharing of resource management power and responsibility (Hanna 1998). The "tenurial shell" created by the Mexican state that supports the traditional belief structure of the Huastec, which in turn supports ecologically sustainable land use (Alcorn and Toledo 1998), and the nested territorial rights of tribes, sub-tribes, and clans in south-central Sudan are other examples of institutions that operate cross-scale (Niamir-Fuller 1998).

Many tribal task groups engage once a year in a large-scale communal hunt, a group-level or community assessment of available resources. Such a group exercise may serve the purpose of monitoring or evaluating the status of prey populations and their habitats; this in turn may help adjust resource harvesting strategies (Gadgil et al. 1993). In the Maine clam fishery, the time and effort needed to develop and implement management plans are proportionally shared by the major beneficiaries of the resource through the inclusion of users in resource surveys and other assessments, and through rotating membership on shellfish conservation committees (Hanna 1998).

Taboos and other regulations are critical social mechanisms for resource conservation, and have the potential of building resilience in ecosystems (e.g., Johannes 1978, Chapman 1985, Colding and Folke 1997, Colding 1998). Food taboos on game and fish are part of *caboclos* and *caícaras* cultures, in which species are

avoided due to toxic, medicinal, or ecological reasons (Begossi 1998). In pre-colonial Ara, Nigeria, there were sacred forests and sacred trees of various types, as in India (Gadgil et al. 1998) and elsewhere. Such trees and forests were believed to be occupied by spirits, and their use was forbidden by taboos (Warren and Pinkston 1998).

Taboos are merely one form of a larger set of social and religious sanctions, which may be used in conservation and resource management. The Gitksan of British Columbia sanction those who do not follow the norms and rules of the community by questioning their right to use their Gitksan name and social status (Pinkerton 1998). Acheson et al. (1998) provide a contemporary application of sanctions in the Maine lobster fishery: one must be a member of a "harbor gang" to participate. Members are expected to obey local rules, and a person who violates them will be sanctioned. Territories are held by "harbor gangs"; this limits the number of fishers in each territory and helps conserve the lobster resource.

Other institution-related social mechanisms not listed in Table 1, include coping mechanisms or short-term responses to environmental surprises and other unexpected events; institutional flexibility or the ability to reorganize under changing circumstances, which may involve discontinuities in the status of the resource or in user populations; and incipient institutions that may "kick in" following certain kinds of stresses (Berkes and Folke 1998).

Mechanisms for cultural internalization

A third category of social mechanisms concerns mechanisms for cultural internalization, which include rituals, ceremonies, and other traditions. Rituals help people remember the rules and appropriately interpret signals from ecosystem change. Chapin (1991) argues that where traditions remain strong, people see no need to make special efforts to preserve knowledge; they simply practice their culture. Alcorn and Toledo (1998) show how religious institutions reinforce community cohesion in indigenous and mestizo communities across Mexico. Ritual obligations, rights to community resources, and management obligations are all interlinked. Other examples of management systems with interlinked rituals concern the tribes of the Pacific Northwest, among whom the "first-salmon ceremony" provided the means to internalize proper management practices (Child and Child 1993).

An example of cultural frameworks for resource management is the *milpa* shifting cultivation system in Mexico. Alcorn and Toledo (1998) characterize *milpa* as a "cultural script," an internalized plan consisting of a series of routine steps with alternative subroutines, decision nodes, and room for experimentation. Ecological knowledge is encoded in the local variation of the *milpa* script, derived from experiences and exper-

iments of farmers over generations. Cultural support buffers the script from disruption by new economic demands, introduction of new technologies, or other changes (Alcorn and Toledo 1998). The *sasi* system is another example of cultural frameworks for managing resources. Zerner (1994) has described how improved resource management has been achieved in contemporary Maluku Islands of Indonesia, through the re-establishment and adjustment of *sasi* institutions. Local support for the institution was high because people saw *sasi* as providing historical and cultural continuity and understanding.

World views and cultural values

A fourth category of social mechanisms concerns world views and cultural values. World view or cosmology includes basic beliefs pertaining to religion and ethics, and structures observations that produce knowledge and understanding. It rounds out the knowledge-practice-belief complex that describes traditional knowledge (Fig. 1). Thus, an essential component for traditional knowledge and practice for ecologically sustainable outcomes is a worldview that provides appropriate environmental ethics. The pervasive cosmology of traditional societies may be characterized as a "community of beings" world view in which humans are part of an interacting set of living things, a view that was also common in Europe up until Medieval times (Callicott 1994). Such a cosmology does have similarities to a holistic ecological view of the world, as opposed to the Newtonian mechanical model (Capra 1996), except that traditional world views often also have a spiritual component, which may be interpreted as a way to deal with uncertainty.

Also outside the sphere of ecology, but relevant to indigenous knowledge, are cultural values as a social mechanism behind traditional practice. Cultural values such as respect (for humans as well as for nature), sharing, reciprocity, and humility characterize a diversity of systems of traditional knowledge and practice, including those of American aboriginal groups (Alcorn and Toledo 1998), Africans (Dei 1993, Niamir-Fuller 1998), and Pacific Island peoples (Roberts et al. 1995). Some of these values, such as reciprocity, also characterize local systems of management that seem to be operating sustainably in contemporary communities (Hanna 1998).

QUALITATIVE APPROACHES FOR ADAPTIVE MANAGEMENT

The two ways of knowing, scientific ecology and Traditional Ecological Knowledge, are potentially complementary. Here we focus on two areas, and evaluate traditional knowledge systems for the insights they provide for the qualitative (as opposed to quantitative) management of resources and ecosystems, and for parallels to adaptive management.

Conventional resource management has come under criticism because it is equilibrium-based or has an underlying assumption of ecological stability (Holling 1986, Gunderson et al. 1995, Holling et al. 1998). Resource management from a stability point of view may be characterized in terms of rules and regulations made by technical experts, often from a central bureaucracy, and enforced by agents who are not themselves resource users; emphasis on steady states and the maintenance of predictable yields, such as maximum sustainable yield; focus on controlling the resource to increase the predictability of yields; and the use of primarily quantitative techniques, such as stock assessment. Such management appears to cause a gradual loss of resilience as well as reduction of variability and opportunity, thus moving the ecosystem toward thresholds and surprises (e.g., Regier and Baskerville 1986, Ludwig et al. 1993). Loss of resilience is often masked by the development of fossil-fuel-dependent technologies to maintain yields, such as bigger fishing vessels or synthetic fertilizers. It can also be masked through support from socioeconomic infrastructures that make it possible to maintain a business-as-usual strategy when faced with ecological disturbance. Examples include capital markets that provide loans and financial insurance to fishermen and farmers in periods of resource crisis, thereby removing incentives for building an ecological knowledge base.

By contrast, there are lessons from systems of Traditional Ecological Knowledge and practice that may be characterized as "resource management from a resilience point of view," such as: (1) management may be carried out using rules that are locally crafted and socially enforced by the users themselves; (2) resource use tends to be flexible, using area rotations, species-switching, and other practices summarized in Table 1; (3) the users have accumulated an ecological knowledge base that helps respond to environmental feedbacks, such as changes in the catch per unit of effort that help monitor the status of the resource; (4) a diversity of resources are used for livelihood security, keeping options open and minimizing risk; and (5) it is carried out using qualitative management wherein feedbacks of resource and ecosystem change indicate the direction in which management should move (more exploitation/less exploitation) rather than toward a quantitative yield target.

Such qualitative management is not a result of indigenous managers being more "noble" than conventional resource managers. We have argued elsewhere that it is a consequence of historical experience with disturbance and ecological surprise, and of not having access to modern technology and socioeconomic infrastructures with which disturbance can be exported in time and space (Holling et al. 1998). Traditional Ecological Knowledge can be viewed as a "library of information" on how to cope with dynamic change in

complex systems. It may help connect the present to the past and reestablish resilience (Gunderson et al. 1997). Building ecological knowledge to understand qualitative changes in complex systems has been a means for improving a group's chances of survival.

Such a qualitative management approach is consistent with a number of emergent alternative management models. For example, Lugo (1995) has suggested that if the objective is to conserve tropical forests, a strategy of focusing on resilience, through a knowledge of regeneration cycles and ecological processes such as plant succession, may be the key to tropical forest sustainability, adding that "management does not require a precise capacity to predict the future, but only a qualitative capacity to devise systems that can absorb and accommodate future events."

Many of the prescriptions of traditional knowledge and practice are generally consistent with adaptive management as an integrated method for resource and ecosystem management (Holling 1978, Gunderson et al. 1995). It is adaptive because it acknowledges that environmental conditions will always change, requiring societies to respond by adjusting and evolving. Adaptive management, like some traditional knowledge systems, emphasizes processes (including resource use) that are part of ecological cycles of renewability. As well, adaptive management, like many traditional knowledge systems, assumes that nature cannot be controlled and yields cannot be predicted. Uncertainty and unpredictability are characteristics of all ecosystems, including managed ones. In both cases, social learning appears to be the way in which societies respond to uncertainty. Often this involves learning not at the level of the individual but social learning at the level of society or institutions; adaptive management is designed to improve on trial-and-error learning.

In this sense, adaptive management can be seen as a rediscovery of traditional systems of knowledge and management. Even though there are no doubt major differences between the two, adaptive management may be viewed as the scientific analogue of Traditional Ecological Knowledge because of its integration of uncertainty into management strategies and its emphasis on practices that confer resilience. By responding to and managing feedbacks from ecosystems, instead of blocking them out, adaptive management seeks to avoid ecological thresholds at scales that threaten the existence of social and economic activities, as do some traditional knowledge systems. Drawing on management practices based on Traditional Ecological Knowledge, and understanding the social mechanisms behind them, may speed up the process of designing alternative resource management systems.

Among the cases considered in this paper, one can identify a number of promising examples of Traditional Ecological Knowledge that can inspire adaptive management solutions. These include the monitoring of pas-

ture status and initiating small- and large-scale movements of cattle herds in semiarid ecosystems, to respond to spatial and temporal variations in rangeland productivity (Niamir-Fuller 1998). A second example is the maintenance of multiple reproductive year classes in James Bay Cree fisheries, by the thinning out of the full size range of adult fish. This practice conserves reproductive resilience and contrasts with the conventional commercial fishery management practice in Northern Canada of harvesting only the largest fish, thus truncating the year class structure of the population (Berkes 1998). A third example is the maintenance of multiple tree species and age classes by maintaining a diversity of uses of the forest ecosystem, rather than clear-cutting large areas or selectively removing only the most economically valuable species (Pinkerton 1998).

In some cases, circumstances dictate the greater use of local ecological knowledge, and adaptive management can provide a framework for its use. For example, given the pressing needs for inshore fisheries management in Oceania and the scarcity of resources, alternative management models have been proposed in which traditional knowledge, in combination with information from marine protected areas, substitutes for stock assessment data (Johannes 1998). More generally, fishers' knowledge can complement limited scientific information for small-scale fishery management in developing countries (Mahon 1997).

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LITERATURE CITED

- Acheson, J. M., J. A. Wilson, and R. S. Steneck. 1998. Managing chaotic fisheries. Pages 390–413 in F. Berkes and C. Folke, editors. *Linking social and ecological systems: management practices and social mechanisms for building resilience*. Cambridge University Press, Cambridge, UK.
- Agrawal, A. 1995. Indigenous and scientific knowledge: some critical comments. *Indigenous Knowledge and Development Monitor* 3:(3)3–6.
- Alcorn, J. B. 1989. Process as resource. *Advances in Economic Botany* 7:63–77.
- Alcorn, J. B. 1993. Indigenous peoples and conservation. *Conservation Biology* 7:424–426.
- Alcorn, J. B., and V. M. Toledo. 1998. Resilient resource management in Mexico's forest ecosystems: the contribution of property rights. Pages 216–249 in F. Berkes and C. Folke, editors. *Linking social and ecological systems: management practices and social mechanisms for building resilience*. Cambridge University Press, Cambridge, UK.
- Altieri, M. A. 1994. *Biodiversity and pest management in agroecosystems*. Food Products Press, New York, New York, USA.
- Begossi, A. 1998. Resilience and neotraditional populations: The *caícaras* of the Atlantic forest and *caboclos* of the

- Amazon (Brazil). Pages 129–157 in F. Berkes and C. Folke, editors. *Linking social and ecological systems: management practices and social mechanisms for building resilience*. Cambridge University Press, Cambridge, UK.
- Berkes, F., editor. 1989. *Common property resources: ecology and community-based sustainable development*. Belhaven, London, UK.
- Berkes, F. 1998. Learning to design resilient resource management: indigenous systems in the Canadian subarctic. Pages 98–128 in F. Berkes and C. Folke, editors. *Linking social and ecological systems: management practices and social mechanisms for building resilience*. Cambridge University Press, Cambridge, UK.
- Berkes, F. 1999. *Sacred ecology. Traditional ecological knowledge and resource management*. Taylor and Francis, Philadelphia and London, UK.
- Berkes, F., and C. Folke, editors. 1998. *Linking social and ecological systems: management practices and social mechanisms for building resilience*. Cambridge University Press, Cambridge, UK.
- Berkes, F., C. Folke, and M. Gadgil. 1995. Traditional ecological knowledge, biodiversity, resilience and sustainability. Pages 269–287 in C. Perrings, K.-G. Mäler, C. Folke, C. S. Holling, and B.-O. Jansson, editors. *Biodiversity conservation*. Kluwer Academic Publishers, Dordrecht, The Netherlands.
- Berkes, F., M. Kislalioglu, C. Folke, and M. Gadgil. 1998. Exploring the basic ecological unit: ecosystem-like concepts in traditional societies. *Ecosystems* 1:409–415.
- Brookfield, H., and C. Padoch. 1994. Appreciating agrodiversity: a look at the dynamism and diversity of indigenous farming practices. *Environment* 36(5):6–11, 37–45.
- Callicott, J. B. 1994. *Earth's insights. A survey of ecological ethics from the Mediterranean Basin to the Australian Outback*. University of California Press, Berkeley, California, USA.
- Capra, F. 1996. *The web of life*. Anchor Books, New York, New York, USA.
- Chapin, M. 1988. The seduction of models: *Chinampa* agriculture in Mexico. *Grassroots Development* 12(1):8–17.
- Chapin, M. 1991. Losing the way of the Great Father. *New Scientist* 131:40–44.
- Chapman, M. 1985. Environmental influences on the development of traditional conservation in the South Pacific region. *Environmental Conservation* 12:217–230.
- Child, A. B., and I. L. Child. 1993. *Religion and magic in the life of traditional peoples*. Prentice Hall, Englewood Cliffs, New Jersey, USA.
- Colding, J. 1998. Analysis of hunting options by the use of general food taboos. *Ecological Modelling* 110:5–17.
- Colding, J., and C. Folke. 1997. The relation between threatened species, their protection, and taboos. *Conservation Ecology* 1(1):6 [online: <http://www.consecol.org/vol1/iss1/art6>].
- Costa-Pierce, B. A. 1987. Aquaculture in ancient Hawaii. *BioScience* 37:320–331.
- Costanza, R., L. Wainger, C. Folke, and K.-G. Mäler. 1993. Modeling complex ecological economic systems. *BioScience* 43:545–555.
- Coughenour, M. B., J. E. Ellis, D. M. Swift, D. L. Coppock, K. Galvin, J. T. McCabe, and T. C. Hart. 1985. Energy extraction and use in a nomadic pastoral ecosystem. *Science* 230:619–625.
- Dei, G. J. S. 1993. Indigenous African knowledge systems: local traditions of sustainable forestry. *Singapore Journal of Tropical Geography* 14:28–41.
- Denevan, W. M., J. M. Treacy, J. B. Alcorn, C. Padoch, J. Denslow, and S. F. Paitan. 1984. Indigenous agroforestry in the Peruvian Amazon: Bora Indian management of swidden fallows. *Interciencia* 9:346–357.
- Diamond, J. 1993. New Guineans and their natural world. Pages 251–271 in S. R. Kellert and E. O. Wilson, editors. *The biophilia hypothesis*. Island Press, Washington, D.C., USA.
- Dwyer, P. D. 1994. Modern conservation and indigenous peoples: in search of wisdom. *Pacific Conservation Biology* 1:91–97.
- Dyson-Hudson, R., and E. A. Smith. 1978. Human territoriality: an ecological assessment. *American Anthropologist* 80:21–41.
- Feit, H. A. 1986. James Bay Cree Indian management and moral considerations of fur-bearers. Pages 49–65 in *Native people and resource management*. Alberta Society of Professional Zoologists, Edmonton, Alberta, Canada.
- Feyerabend, P. 1987. *Farewell to reason*. Verso, London, UK.
- Finlayson, A. C., and B. J. McCay. 1998. Crossing the threshold of ecosystem resilience: the commercial extinction of northern cod. Pages 311–337 in F. Berkes and C. Folke, editors. *Linking social and ecological systems: management practices and social mechanisms for building resilience*. Cambridge University Press, Cambridge, UK.
- Folke, C., F. Berkes, and J. Colding. 1998. Ecological practices and social mechanisms for building resilience and sustainability. Pages 414–436 in F. Berkes and C. Folke, editors. *Linking social and ecological systems: management practices and social mechanisms for building resilience*. Cambridge University Press, Cambridge, UK.
- Gadgil, M., F. Berkes, and C. Folke. 1993. Indigenous knowledge for biodiversity conservation. *Ambio* 22:151–156.
- Gadgil, M., N. S. Hemam, and B. M. Reddy. 1998. People, refugia and resilience. Pages 30–47 in F. Berkes and C. Folke, editors. *Linking social and ecological systems: management practices and social mechanisms for building resilience*. Cambridge University Press, Cambridge, UK.
- Gunderson, L., C. S. Holling, and S. Light, editors. 1995. *Barriers and bridges to the renewal of ecosystems and institutions*. Columbia University Press, New York, New York, USA.
- Gunderson, L. H., C. S. Holling, L. Pritchard, and G. Peterson. 1997. Resilience in ecosystems, institutions, and societies. *Beijer Discussion Papers* 95. Beijer International Institute of Ecological Economics, Royal Swedish Academy of Sciences, Stockholm, Sweden.
- Hanna, S. 1998. Managing for human and ecological context in the Maine soft shell clam fishery. Pages 190–211 in F. Berkes and C. Folke, editors. *Linking social and ecological systems: management practices and social mechanisms for building resilience*. Cambridge University Press, Cambridge, UK.
- Hanna, S., C. Folke, and K.-G. Mäler, editors. 1996. *Rights to nature*. Island Press, Washington, D.C., USA.
- Holling, C. S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4:1–23.
- Holling, C. S., editor. 1978. *Adaptive environmental assessment and management*. Wiley, London, UK.
- Holling, C. S. 1986. The resilience of terrestrial ecosystems: local surprise and global change. Pages 292–317 in W. C. Clark and R. E. Munn, editors. *Sustainable development of the biosphere*. Cambridge University Press, London, UK.
- Holling, C. S., F. Berkes, and C. Folke. 1998. Science, sustainability, and resource management. Pages 342–362 in F. Berkes and C. Folke, editors. *Linking social and ecological systems: management practices and social mechanisms for building resilience*. Cambridge University Press, Cambridge, UK.
- Holling, C. S., D. W. Schindler, B. H. Walker, and J. Roughgarden. 1995. Biodiversity in the functioning of ecosystems: an ecological synthesis. Pages 44–83 in C. A. Perrings, K.-G. Mäler, C. Folke, C. S. Holling, and B.-O. Jans-

- son, editors. Biodiversity loss: economic and ecological issues. Cambridge University Press, Cambridge, UK.
- Hutchings, J. A., C. Walters, and R. L. Haedrich. 1997. Is scientific inquiry incompatible with government information control? *Canadian Journal of Fisheries and Aquatic Sciences* 54:1198–1210.
- Hviding, E. 1996. Guardians of Marovo Lagoon: practice, place and politics in Maritime Melanesia. University of Hawaii Press, Honolulu, Hawaii, USA.
- Irvine, D. 1989. Succession management and resource distribution in an Amazonian rain forest. Pages 223–237 in D. A. Posey and W. L. Balee, editors. *Resource management in Amazonia: indigenous and folk strategies*. New York Botanical Garden, Bronx, New York, USA.
- Jodha, N. S. 1998. Reviving the social system-ecosystem links in the Himalayas. Pages 285–310 in F. Berkes and C. Folke, editors. *Linking social and ecological systems: management practices and social mechanisms for building resilience*. Cambridge University Press, Cambridge, UK.
- Johannes, R. E. 1978. Traditional marine conservation methods in Oceania and their demise. *Annual Review of Ecology and Systematics* 9:349–364.
- Johannes, R. E., editor. 1989. *Traditional ecological knowledge: a collection of essays*. International Conservation Union (IUCN), Gland, Switzerland.
- Johannes, R. E. 1998. The case for data-less marine resource management: examples from tropical nearshore fisheries. *Trends in Ecology and Evolution* 13:243–246.
- Levi-Strauss, C. 1962. *La pensée sauvage*. Librairie Plon, Paris, France. (English translation 1966, *The savage mind*, University of Chicago Press, Chicago, Illinois, USA).
- Lewis, H. T., and T. A. Ferguson. 1988. Yards, corridors and mosaics: how to burn a boreal forest. *Human Ecology* 16: 57–77.
- Ludwig, D., R. Hilborn, and C. Walters. 1993. Uncertainty, resource exploitation and conservation: lessons from history. *Science* 260:1736.
- Lugo, A. 1995. Management of tropical biodiversity. *Ecological Applications* 5:956–961.
- Mahon, R. 1997. Does fisheries science serve the needs of managers of small stocks in developing countries? *Canadian Journal of Fisheries and Aquatic Sciences* 54:2207–2213.
- Nabhan, G. P. 1985. *Gathering the desert*. Arizona University Press, Tucson, Arizona, USA.
- Niamir-Fuller, M. 1998. The resilience of pastoral herding in Sahelian Africa. Pages 250–284 in F. Berkes and C. Folke, editors. *Linking social and ecological systems: management practices and social mechanisms for building resilience*. Cambridge University Press, Cambridge, UK.
- North, D. C. 1990. *Institutions, institutional change and economic performance*. Cambridge University Press, Cambridge, UK.
- Ohmagari, K., and F. Berkes. 1997. Transmission of indigenous knowledge and bush skills among the Western James Bay Cree women of subarctic Canada. *Human Ecology* 25: 197–222.
- Palsson, G. 1998. Learning by fishing: practical engagement and environmental concerns. Pages 48–66 in F. Berkes and C. Folke, editors. *Linking social and ecological systems: management practices and social mechanisms for building resilience*. Cambridge University Press, Cambridge, UK.
- Pereira, W. 1992. The sustainable lifestyle of the Warlis. Pages 189–204 in G. Sen, editor. *Indigenous vision: peoples of India attitudes to the environment*. Sage Publications, New Delhi/Newbury Park/London, UK.
- Pinkerton, E. 1998. Integrated management of a temperate montane forest ecosystem through wholistic forestry: a British Columbia example. Pages 363–389 in F. Berkes and C. Folke, editors. *Linking social and ecological systems: management practices and social mechanisms for building resilience*. Cambridge University Press, Cambridge, UK.
- Ramakrishnan, P. S. 1992. *Shifting agriculture and sustainable development. an interdisciplinary study from North-Eastern India*. Unesco/Parthenon, Paris, France.
- Redford, K. H. and A. M. Stearman. 1993. Forest-dwelling native Amazonians and the conservation of biodiversity. *Conservation Biology* 7:248–255.
- Regier, H. A., and G. L. Baskerville. 1986. Sustainable redevelopment of regional ecosystems degraded by exploitive development. Pages 75–101 in W. C. Clark and R. E. Munn, editors. *Sustainable development of the biosphere*. Cambridge University Press, Cambridge, UK.
- Reichel-Dolmatoff, G. 1976. Cosmology as ecological analysis: a viewpoint from the rainforest. *Man (N.S.)* 11:307–318.
- Reid, R. S., and J. E. Ellis. 1995. Impacts of pastoralists in south Turkana, Kenya: livestock-mediated tree recruitment. *Ecological Applications* 5:978–992.
- Roberts, M., W. Norman, N. Minhinnick, D. Wihongi, and C. Kirkwood. 1995. Kaitiakitanga: Maori perspectives on conservation. *Pacific Conservation Biology* 2:7–20.
- Ruddle, K., E. Hviding, and R. E. Johannes. 1992. Marine resources management in the context of customary tenure. *Marine Resource Economics* 7:249–273.
- Sankhala, K. 1993. *Prospering from the desert*. Pages 18–22 in E. Kempf, editor. *Indigenous peoples and protected areas*. Earthscan, London, UK.
- Schmink, M., K. H. Redford, and C. Padoch. 1992. Traditional peoples and the biosphere: framing the issues and defining the terms. Pages 3–13 in K. H. Redford and C. Padoch, editors. *Conservation of neotropical forests: working from traditional resource use*. Columbia University Press, New York, New York, USA.
- Sporrong, U. 1998. Dalecarlia in Central Sweden before 1800: a society of social and ecological resilience. Pages 67–94 in F. Berkes and C. Folke, editors. *Linking social and ecological systems: management practices and social mechanisms for building resilience*. Cambridge University Press, Cambridge, UK.
- Turner, N. J. 1994. Burning mountain sides for better crops: aboriginal landscape burning in British Columbia. *International Journal of Ecoforestry* 10:116–122.
- Walker, B. H. 1993. Rangeland ecology: understanding and managing change. *Ambio* 22:80–87.
- Warren, D. M. 1995. Comments on article by Arun Agrawal. *Indigenous Knowledge and Development Monitor* 4:(1)13.
- Warren, D. M., and J. Pinkston. 1998. Indigenous African resource management of a tropical rain forest ecosystem: a case study of the Yoruba of Ara, Nigeria. Pages 158–189 in F. Berkes and C. Folke, editors. *Linking social and ecological systems: management practices and social mechanisms for building resilience*. Cambridge University Press, Cambridge, UK.
- Warren, D. M., L. J. Slikkerveer, and D. Brokensha, editors. 1995. *The cultural dimension of development: indigenous knowledge systems*. Intermediate Technology Publications, London, UK.
- Williams, N. M., and G. Baines, editors. 1993. *Traditional ecological knowledge: wisdom for sustainable development*. Centre for Resource and Environmental Studies, Australian National University, Canberra, Australia.
- Zerner, C. 1994. Transforming customary law and coastal management practices in the Maluku Islands, Indonesia, 1870–1992. Pages 80–112 in D. Western and R. M. Wright, editors. *Natural connections: perspectives in community-based conservation*. Island Press, Washington, D.C. and Covelo, California, USA.