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Review article
Contribution of traditional knowledge to ecological restoration: Practices and applications[1]

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Abstract: Traditional knowledge has become a topic of considerable interest within the research and development environment. The contribution of traditional knowledge to conservation and management is increasingly recognized, and implementation endeavours are underway in several countries. The current scale of ecosystem degradation underscores the need for restoration interventions. It is increasingly recognized that successful ecological restoration depends on effective coordination of science and traditional ecological knowledge. This paper synthesizes the literature to evaluate the present and potential contribution of traditional knowledge to ecological restoration. Despite a growing number of articles published on traditional knowledge, only a few have addressed its contributions to ecological restoration *per se*. The main contributions of traditional knowledge to ecological restoration are in construction of reference ecosystems, particularly when historical information is not available; species selection for restoration plantations; site selection for restoration; knowledge about historical land management practices; management of invasive species; and post-restoration monitoring. Traditional knowledge and science are complementary and should be used in conjunction in ecological restoration projects. Incorporation of traditional knowledge can contribute to build a strong partnership for the successful implementation of restoration projects and increase their social acceptability, economical feasibility, and ecological viability.
Keywords: ecological restoration, monitoring, partnership, reference ecosystems, species selection, traditional knowledge.

Résumé : L'intérêt du secteur de la recherche et développement pour les connaissances traditionnelles est considérable. La contribution des savoirs traditionnels à la conservation et à l'aménagement est de plus en plus reconnue et des expériences terrain en ce sens sont en cours dans plusieurs pays. Le niveau de dégradation des écosystèmes justifie le besoin d'interventions de restauration. Il est de plus en plus reconnu que l'intégration des connaissances scientifiques et traditionnelles est nécessaire au succès des efforts de restauration. Cette synthèse évalue les contributions actuelles et potentielles des savoirs traditionnels à la restauration écologique. Malgré qu'un nombre croissant d'articles soient publiés à propos des connaissances traditionnelles, peu concernent la contribution à la restauration écologique. Les principales contributions des connaissances traditionnelles à la restauration écologique sont l'identification d'écosystèmes de référence, en particulier lorsque les informations historiques ne sont pas disponibles; la sélection d'espèces pour les plantations; la sélection de sites pour la restauration; la connaissance de l'historique local des pratiques d'aménagement; la gestion des espèces envahissantes; et le suivi post-restauration. Les connaissances traditionnelles et scientifiques sont complémentaires et devraient être utilisées conjointement dans les projets de restauration écologique. L'inclusion des connaissances traditionnelles peut contribuer à construire un partenariat solide pour le succès de mise en œuvre de projets de restauration et pour en augmenter l'acceptabilité sociale, la faisabilité économique et la viabilité écologique.
Mots-clés : restauration écologique, connaissances traditionnelles, écosystèmes de référence, sélection d'espèces, partenariat, suivi.

Introduction

Traditional people around the world possess considerable knowledge of the natural resources they use (Berkes, 2008; Huntington, 2011). Such knowledge has been found to be important in informing scientific approaches to management, and it is increasingly respected as a source of information that can be used in conservation, management, and sustainable use of natural resources (CBD, online; Gadgil, Berkes & Folke, 1993; Colding, 1998; Charnley, Fischer & Jones, 2007; Uprety *et al.*, 2011). According to Berkes, Colding, and Folke (2000), the integration of traditional ecological knowledge (TEK) and science could contribute to adaptive management. The limited ability of current science to deal effectively with environmental issues

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of increasing magnitude and complexity has also opened the door to the acceptance of alternative sources of knowledge (Stevenson, 2005). In many instances, TEK complements previously gathered ecological data by providing concordant and additional information at a finer geographic scale than scientific data (Moller *et al.*, 2004; Berkes, 2008; Wehi, 2009; Rist *et al.*, 2010).

Interest in ecological restoration is growing, and it is increasingly recognized that ecological restoration should take into account cultural practices as much as ecological processes (SERI, online; Higgs, 2003; Sarr & Puettmann, 2008). Some studies have suggested that TEK, having co-evolved with ecosystems (Long, Tecle & Burnette, 2003), may provide a strong foundation for ecological restoration (Turner, Ignace & Ignace, 2000; Long, Tecle & Burnette, 2003; Higgs, 2005; Shebitz, 2005). However, some scholars are skeptical about the scientific validity of traditional knowledge and its usefulness beyond the local level, while others are concerned about the ethics of exploiting traditional knowledge for academic or policy purposes (Chalmers & Fabricius, 2007). Hence, incorporating traditional knowledge systems into "top-down" approaches to ecological restoration is still a great challenge (He *et al.*, 2009). Nevertheless, community participation is essential during the restoration process, particularly when involving societies with rich traditional knowledge that is integrally linked to biodiversity and natural resources management (Ramakrishnan, 2007a). In landscapes where the influence of traditional people has been recognized, cultural and social aspects of ecological restoration become especially important (Garibaldi & Turner, 2004).

In the last few decades, the potential contribution of TEK in the conservation, management, and sustainable use of natural resources has been increasingly recognized, documented, and utilized (Berkes, Colding & Folke, 2000; Gadgil *et al.*, 2003). Although the role of TEK in ecological restoration has also been recognized in recent years (Anderson, 2001; Shebitz, 2005; Parks Canada, 2009), its present or potential contribution has not been well studied (Perrow & Davy, 2002; Shebitz, 2005). To date, only a few attempts have been made to convert TEK into ecological restoration tools (*e.g.*, Kimmerer, 2000; Shebitz, 2005; Douterlungne *et al.*, 2010). In this synthesis, we highlight the contribution of traditional knowledge to ecological restoration and discuss how ecological restoration can benefit from traditional knowledge. We briefly introduce some perspectives on traditional knowledge and discuss the concepts of ecological restoration and restoration ecology. We decipher the meanings and implications of a number of related terms in the context of ecological restoration, as these terms are sometimes misunderstood. We then present examples of how TEK has contributed to various ecological restoration projects and practices. From the analysis of these projects, we identify key success elements and important challenges when incorporating traditional knowledge into ecological restoration projects.

Traditional Ecological Knowledge

Over the past 2 decades, several definitions of traditional (ecological) knowledge have been introduced, all giving similar meanings to the concept (*e.g.*, CBD, online; Berkes, Colding & Folke, 2000; Huntington, 2000; Turner, Ignace & Ignace, 2000; Charnley, Fischer & Jones, 2007). Berkes, Colding, and Folke (2000) defined it 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".

Although there are some differences among them, terms such as traditional knowledge, indigenous knowledge, traditional ecological knowledge, traditional ecological knowledge and wisdom, traditional environmental knowledge, local ecological knowledge, etc., are often used interchangeably depending on the context (Gadgil, Berkes & Folke, 1993; Stevenson, 1996; Berkes, Colding & Folke, 2000; Turner, Ignace & Ignace, 2000; Davis & Wagner, 2003; Stevenson, 2005; Charnley, Fischer & Jones, 2007; Berkes, 2008; Davis & Ruddle, 2010; Rist *et al.*, 2010). Traditional ecological knowledge (TEK) is the predominant term used among conservationists and resource managers, as it includes the qualifier "ecological", accounts for the interplay between organisms and their environment, and is not restricted to indigenous peoples alone (Olsson & Folke, 2001; Rist *et al.*, 2010). This kind of knowledge comes from a range of sources and is a dynamic mix of past tradition and present innovation accumulated through trial and error over many years (Drew, 2005; Berkes, 2008; Sillitoe & Marzano, 2009). It is place-based, geographically specific, and largely dependent on local social mechanisms, and therefore it varies within and between societies (Berkes, Colding & Folke, 2000). The growing recognition of TEK started with the documentation of a tremendously rich body of environmental knowledge, not just of species but also of their ecological relations, among a diversity of groups outside the mainstream world (Berkes, 2008). Hence, TEK is not only about particular species but also about ecosystem dynamics.

Although the potential contribution of traditional knowledge was recognized in the early 1970s (Ramakrishnan, 2007a), it was the Brundtland Commission, the Convention on Biological Diversity, the Forest Principles, and Agenda 21 that brought to the public eye the importance of traditional knowledge and provided guidance to the international community for its incorporation into various activities (UNCED, online). Since then, international and national agencies have been actively involved in promoting and facilitating the documentation and use of traditional knowledge in resource management and other development activities (Inglis, 1993; Davis & Wagner, 2003). Not all traditional knowledge is ecologically wise. Neither are all traditional practices and belief systems ecologically adaptive. Some become maladaptive over time due to changing conditions, lose meaning out of context, or become stagnant and irrelevant over time (Berkes, Colding & Folke, 2000; Charnley, Fischer & Jones, 2007). If used with caution, however, traditional knowledge can fill crucial gaps in our ecological understanding.

ECOLOGICAL RESTORATION AND RESTORATION ECOLOGY

The Society for Ecological Restoration International (SERI) defines ecological restoration as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (SERI, online). The ecosystem that requires restoration could be degraded, damaged, transformed, or entirely destroyed as the direct or indirect result of human activities, or, in some cases, these impacts to ecosystems have been caused or aggravated by natural disturbances, to the point where the ecosystem's regenerating capacity is altered, preventing it from recovering its predisturbance state or historic developmental trajectory (SERI, online). Restoration is thus an intentional attempt to bring the system back to some historical state and regain ecological integrity and resilience (Palmer, Falk & Zedler, 2006). It can be viewed as an attempt to recover a natural range of ecosystem composition, structure, and dynamics (Palmer, Falk & Zedler, 2006). Ecological restoration is the ensemble of practices that constitute the entire field of restoration, including restoration ecology and the relevant human and natural sciences, politics, technologies, economic factors, and cultural dimensions (Higgs, 2005). Restoration efforts should attempt to balance functional repair and structural accuracy of the ecosystem and consider the wider cultural context of restoration practices (Higgs, 1997).

Correspondingly, restoration ecology is the discipline of scientific inquiry dealing with the restoration of ecological systems (Palmer, Falk & Zedler, 2006). Restoration ecology provides clear concepts, models, methodologies, and tools for practitioners in support of their practice (SERI, online). Restoration ecologists can contribute to the advance of ecological theory by using restoration project sites as experimental areas (SERI, online). Hence, restoration ecology is *theory* and ecological restoration is *practice* (Egan & Howell 2001). Ecological restoration requires multiple efforts, long-term commitment, and thoughtful deliberation (Higgs, 2003; Palmer, Falk & Zedler, 2006; Choi *et al.*, 2008). It is a multidisciplinary intervention based on traditional or local knowledge as well as scientific understanding of previous (reference) conditions. Strategic, integrated identification and implementation of conservation and restoration activities can help to ensure the protection and recovery of species and ecosystems and the ongoing delivery of ecological goods and services at levels required for a healthy planet. The principles of good ecological restoration practice include (after SERI & IUCN, 2004):

1. Ecological systems
   - Incorporating biological and environmental spatial variation into the design.
   - Allowing for linkages within the larger landscape.
   - Emphasizing process repair over structural replacement.
   - Allowing sufficient time for self-generating processes to resume.
   - Treating the causes rather than the symptoms of degradation.
   - Including monitoring protocols to allow for adaptive management.
2. Social systems
   - Ensuring all stakeholders are aware of the full range of possible alternatives, opportunities, costs, and benefits offered by restoration.
   - Empowering all stakeholders, especially disenfranchized resource users.
   - Engaging all relevant sectors of society and disciplines, including the displaced and powerless, in planning, implementation, and monitoring.
   - Involving relevant stakeholders in the definition of boundaries for restoration.
   - Considering all forms of historical and current information, including scientific and indigenous and local knowledge, innovations, and practices.
   - Providing short-term benefits leading to the acceptance of longer-term objectives.
   - Providing for the accrual of ecosystem goods and services.

Hence, ecological restoration requires knowledge about ecosystems and their dynamics, including their relationships to societal values, activities, and patterns of resource use. A good restoration requires an expanded view that includes historical, social, cultural, political, aesthetic, and moral aspects (Higgs, 1997). Higgs (2005) argues that restoration requires scientific and technological insights, but he also insists on the importance of the support of local communities, effective policies, appropriate legislation, and long-term funding for durable restoration. According to Parks Canada (2009), ecological restoration should be *effective* (in restoring and maintaining ecological integrity), *efficient* (in using practical and economic methods to achieve functional success), and *engaging* (through implementing inclusive processes and by recognizing and embracing interrelationships between culture and nature), which is possible by integrating ecological and social science with traditional knowledge.

OTHER RELATED CONCEPTS

The difficulty of achieving full restoration is recognized (Palmer, Falk & Zedler, 2006). Restoration of predamaged conditions might not be attainable, because the sequence of previous climatic and biological events is unlikely to be repeated (Cairns, 2003; Lamb & Gilmour, 2003). Therefore, some critics have opposed use of the term "restoration", preferring "rehabilitation" instead (Cooke, 2005; Chazdon, 2008). Rehabilitation, in this context, means to rebuild or return a site to a previous condition such that the original productivity or structure is regained along with some, but not all, of the original biodiversity (Higgs, 2003; Lamb & Gilmour, 2003). The term is almost synonymous with restoration but also includes reclamation projects with a strong ecological focus. According to Adams (2002), rehabilitation, reclamation, enhancement, ecological recovery, and mitigation are related terms. Some mitigation measures can be used for "mitigative restoration" on relatively undamaged ecosystems (Cairns, 2003). According to Egan and Howell (2001), reclamation and mitigation are the roots of ecological restoration. Aronson *et al.* (1993) claim that the term reclamation has been used synonymously with both restoration and reallocation. However, Cairns (2006) argues that restoration is different from reclamation and rehabilitation, since restoration is a holistic process not achieved through the isolated manipulation of individual elements. Higgs (2003) emphasizes that "concern for historical conditions is one of the main attributes of restoration separating it from related practices such as reclamation and rehabilitation".

The restored ecosystem often requires continuing management to counteract the invasion of opportunist species, the impacts of various human activities, climate change, and other, unforeseeable events. In this respect, a restored ecosystem is no different from an undamaged ecosystem of the same kind, and both are likely to require some level of management (SERI, online). Although ecosystem restoration and ecosystem management form a continuum and often employ similar sorts of intervention, ecological restoration aims at assisting or initiating recovery, whereas ecosystem management is intended to guarantee the continued well-being of the ecosystem (SERI, online). Ecological restoration is often a fundamental element of ecosystem management, conservation, and sustainable development programs.

GOALS AND METHODS OF ECOLOGICAL RESTORATION

Ecological restoration improves biological diversity in degraded landscapes, increases the population levels and widens the distribution of rare and threatened species, enhances landscape connectivity, increases the availability of environmental goods and services, and contributes to the improvement of human well-being (SERI & IUCN, 2004). As the goal of ecological restoration is to return an ecosystem to its predisturbance state, knowledge of historic conditions is the starting point of restoration design (Kimmerer, 2000; Egan & Howell, 2001; Lamb, Erskine & Parrotta, 2005). Reconstructed historic reference conditions are used as general restoration guides (Allen *et al.*, 2002). This information helps to determine what needs to be restored, why and how it was lost, and how its functioning could be reset (Egan & Howell, 2001). A reference ecosystem also serves as a model for planning and later to evaluate the restoration outcomes. The following are the sources of information that can be used in describing a reference ecosystem (SERI, online):

1. Ecological descriptions, species lists, and maps of the project site prior to damage;
2. Historical and recent aerial and ground-level photographs;
3. Remnants of the site to be restored, indicating previous physical conditions and biota;
4. Ecological descriptions and species lists of similar, intact ecosystems;
5. Herbarium and museum specimens;
6. Historical accounts and oral histories by persons familiar with the project site prior to damage;
7. Paleoecological evidence, *e.g.*, fossil pollen, charcoal, tree ring history, rodent middens.

A restoration plan should be based on past dynamics of the ecosystem under consideration, its present state, cultural conditions that have shaped the landscape, and other possible constraints and opportunities (Parks Canada, 2009). In the simplest circumstances, restoration consists of removing or modifying a specific disturbance, thereby allowing ecological processes to trigger an independent recovery. In more complex circumstances, restoration may also require the deliberate reintroduction of native species that have been lost and the elimination or control of harmful, invasive exotic species (Lamb, Erskine & Parrotta, 2005). The restoration procedure can be described in terms of a series of linear steps (Table I) concordant with the guidelines for ecological restoration provided by ITTO (2002) and SERI (online). The forthcoming guidelines of the IUCN World Commission on Protected Areas will provide updated procedures for effective ecological restoration (IUCN WCPA, 2012).

In order for ecological restoration to realize its potential as a key tool in managing the challenge of climate change, conventional approaches that rely exclusively on historical references may not be sufficient (Harris *et al.*, 2006). In particular, the usefulness of historical ecosystem conditions as targets and references must be set against the likelihood that restoring these historic ecosystems is unlikely to be easy, or even possible, in the changed biophysical conditions of the future (Harris *et al.*, 2006). Higgs (2003) has tried to address this issue by defending a broader restoration goal of "fidelity" to historical conditions, which may not involve the exact reproduction of those conditions. In addition, Harris *et al.* (2006) recommend building more resilient ecosystems for the future and suggest that greater consideration and debate needs to be directed at the implications of climate change for restoration practices.

The emergence of the "novel ecosystems" concept is reshaping the field of ecological restoration. In the context of past and ongoing local and global changes, many ecosystems are being transformed into new, non-historical configurations (Hobbs, Higgs & Harris, 2009). Because of these changes, historical restoration targets will often be unsustainable in coming decades (Seastedt, Hobbs & Suding, 2008; Jackson & Hobbs, 2009). Therefore, ecological restoration efforts should aim to conserve and restore historical ecosystems where viable, while simultaneously preparing to design or steer emerging novel ecosystems to ensure maintenance of ecological goods and services (Jackson & Hobbs, 2009).

TRADITIONAL KNOWLEDGE AND ECOLOGICAL RESTORATION

Since UNCED (online), many organizations and restorationists have put emphasis on integrating traditional knowledge into ecological restoration planning and projects, and planners that fail to do so are increasingly criticized (Anderson, 1996; Kimmerer, 2000). Incorporating TEK into restoration science and practice takes account of cultural diversity and long-standing approaches to sustainable human participation in ecosystems (Turner, 2005). Recognition of TEK also helps create social, economic, and political space for recognizing traditional ways of life, which can be important for land rights, poverty alleviation, and the political sovereignty of traditional people. The SERI, among others, recognized that local people and their

TABLE I. Outline of the ecological restoration procedure (Egan & Howell, 2001).

Step A: Carry out preliminary research.
- 1. Perform site inventory and analysis.
  - a. Match the most appropriate species for the considered environment, without relying too extensively on broadly tolerant species.
  - b. Document initial conditions, which greatly influence the direction of vegetation change (colonization, inhibition, facilitation).
- 2. Study remnants to develop ecosystem models for the restoration to emulate.
- 3. Review reports of previous restoration experiments and projects.
- 4. Locate sources of materials to be used for restoration.

Step B: Determine project purpose, site use policy, and research needs.

Step C: Describe the desired "end point" and what is to be planted where and when to achieve the end point.
- 1. Determine ecosystem restoration goals and objectives based on ecosystem model.
  - a. Specify species composition, abundance, and distribution patterns.
  - b. Describe desired community structure.
  - c. Highlight desired ecological processes.
- 2. List numbers and proportions of species to be planted (if any).
- 3. Choose materials: seeds, seedlings, cuttings.
- 4. Determine planting techniques.
  - a. Specify method.
  - b. Specify timing:
    - *i*. Which season?
    - *ii*. All at once or in phases?
- 5. Specify (or not) locations of individual plants or seed mixes.

Step D: Prepare the site.
1. Remove undesirable biota. 2. Create a good planting medium. 3. Enhance site conditions.

Step E. Implement project and research plan.

Step F: Monitor the site to see if objectives are being met.
1. If so, continue as planned. 2. If not, make mid-course correction.

Step G: Prepare restoration plan for animals, insects, etc.

Step H: Manage the site.
1. Discourage pests. 2. Maintain natural processes.

land management practices should be part of any effort to restore and preserve ecosystems (SERI, online):

> Many cultural ecosystems have suffered from demographic growth and external pressures of various kinds, and are in need of restoration. The restoration of such ecosystems normally includes the concomitant recovery of indigenous ecological management practices, including support for the cultural survival of indigenous peoples and their languages as living libraries of traditional ecological knowledge. Ecological restoration encourages and may indeed be dependent upon long-term participation of local people.

The localized and site-specific nature of traditional knowledge makes it particularly applicable to restoration design, which is also site-specific (Kimmerer, 2000). In landscapes of which traditional societies are integral components, restoration efforts must be tailored on the basis of people's perceptions, resource dependence, and reliance on ecosystem goods and services (Cook *et al.*, 2004). Thus, careful evaluation of the connection between people and nature is needed to develop effective strategies for ecological restoration. A study conducted in Ecuador explored traditional knowledge related to plants and animals and showed that the people's motivations for restoring their forest land were related to species utility and desired environmental goods and services, such as water, soil conservation, wind protection, and landscape preservation (Baez, Ambrose & Hofstede, 2010). Long, Tecle, and Burnette (2003) explored the traditional understanding of restoration by the Apache tribe of Arizona, for whom ecological restoration signifies giving a healing treatment to the ecosystem based on its state of mind and willingness to be healed as well as environmental factors that could influence the outcome. These approaches are similar to the modern approaches to restoration that require understanding of ecosystem dynamics before implementing restoration plans (Perrow & Davy, 2002). Exploring traditional practices used in ecological restoration (Table II), we found that TEK can contribute to all major steps of the ecological restoration procedure (Table I). The following sections explore specific areas where traditional knowledge can contribute to ecological restoration.

CONSTRUCTION OF REFERENCE ECOSYSTEMS

Determining reference conditions is a central component of ecological restoration (Higgs, 1997). One of the most important contributions traditional knowledge can make to ecological restoration is knowledge of historical reference systems, including original species composition and distribution, successional trajectories, and appropriate management techniques (Anderson, 1995; Kimmerer, 2000; Anderson, 2001; Robertson & McGee, 2003; Anderson, 2005; Wehi, 2009). The reference ecosystem provides a model to follow and is also used as a standard for evaluation and monitoring (Meffee & Carroll, 1994). Although there are several sources of information available to reconstruct reference ecosystems, TEK is of particular importance in contexts where aerial photographs and ecoforestry maps are not available, or where paleoecological or archaeological records are scarce or incomplete (Wehi, 2009). Oral tradition and long-term ecosystem

TABLE II. Examples of use of traditional ecological knowledge (TEK) in ecological restoration and planning.

Example	TEK involved	Restoration implication	Reference(s)
New Zealand flax used in restoration planting in New Zealand.	TEK preserved in early ethnographies of Aboriginal people provided information about species biology, soil and nutrient requirements, ecological niches, and ecological communities.	TEK provided information about historical ecology and reference systems when other information sources were not available or reliable.	Wehi, 2009
Native forest restored and exotic species minimized by using indigenous tree species in the Philippines.	Local people selected several dozen indigenous tree species and provided information on specific uses, location of seed trees, characteristics of the species' ecological niches, and flowering and fruiting periods. Traditional knowledge used in nursery establishment, propagation, domestication, and tree management.	Use of seeds and wildlings as sources of germplasm demonstrated the ability of indigenous people to cope with the issues of limited planting materials of indigenous origin to replace exotic species.	Tolentino, 2008
Restoration of large areas of acacia and miombo woodlands that were transformed into semi-desert in Tanzania.	Species selection, identification of livelihood needs and individual preferences, and participation in project implementation via traditional institutions. Traditional practices of pasture management, fodder production, and grazing suppression strategies used together with improvement of local livelihood through development of non-timber forest products.	Ecological restoration was made possible by ensuring that the incentives provided for the local people were right and the legal frameworks – both traditional and institutional – were supportive.	Monela *et al.,* 2004
Restoration of fallow land after swidden cultivation, and eradication of the impact of an invasive fern in southern Mexico using native balsa species by the Lacandon people.	Observed impact of invasive fern in restoration process and developed strategies to control invasive species. Selection of fast growing, locally abundant evergreen native species (balsa) that copes well in the shallow and infertile soils that commonly occur in degraded land, to accelerate succession towards mature forest and eliminate invasive ferns. Traditional technique involving site preparation by fire, broadcasting large numbers of small balsa seeds, and applying traditional weeding techniques that promote rapid balsa growth.	Traditional techniques of understanding of successional processes and regeneration used in designing restoration projects. Effective control of invasive species. Ecological characteristics of the tree species selected by native people also promote the establishment of other woody species under its canopy, as it has a very high rate of leaf growth and leaf turnover that leads to the formation of a dense litter layer within a year, which in turn reduces soil erosion and increases the availability of soil nutrients.	Levy-Tacher & Golicher 2004; Douterlungne *et al.,* 2010
Scientific approach suggested cultural keystone species for restoration purposes in Canada.	Indigenous people identified species of interest for restoration.	Use of such approaches connects people with landscapes and helps build partnerships between indigenous people and scientists that ensure the success and effectiveness of restoration goals.	Garibaldi & Turner, 2004
Restoration of viable population of medicinal plants in Nepal.	Rotation harvesting method applied by local people.	Rotation harvesting provides enough time to restore populations in old harvested sites.	Ghimire, McKey & Aumeeruddy-Thomas, 2005
Restoration of viable population of food plants in Canada.	Rotation harvesting method applied by local people.	Rotation harvesting provides enough time to restore populations in old harvested sites.	Turner, Ignace & Ignace, 2000
Restoration of grazing land in African Sahel.	Rotation grazing and herds relocation. Seasonal migration of traditional herders.	Such practices provide enough time for restoration to proceed.	Niamir-Fuller, 1998
Restoration of fish and game species in northern Canada and New Zealand.	Periodical hunting, fishing, or trapping restrictions by indigenous people.	Such practices provide enough time to re-colonize and restore populations.	Moller *et al.,* 2004; Berkes, 2008
Participatory forest restoration using plants of local interests in China.	Species identified for restoration plantation. Knowledge of species that are suitable in local conditions.	Participatory projects yield high success in short time and at low cost. Increased social acceptability of projects.	He *et al.,* 2009
Restoration of food plant (camas) in Canada involving a multidisciplinary scientific team.	Traditional harvesting practices that depended on elaborate management techniques, including selective harvesting of camas bulbs, seed harvesting and replanting, weeding, and annual prescribed burning.	Use of insights from a multidisciplinary team provided important clues for restoration that helped identify issues and develop strategies.	Higgs, 2005

TABLE II. Concluded.

Example	TEK involved	Restoration implication	Reference(s)
Restoration of fallow forest land after swidden cultivation in Mexico, Thailand, and India.	Selection of pioneer tree species that have economic and ecological value in restoration. TEK of regeneration processes in degraded lands.	Knowledge of natural regeneration processes in rotational shifting cultivation is applicable to forest restoration as well.	Ramakrishnan, 2007 a,b; Wangpaka-pattanawong *et al.,* 2010; Diemont *et al.,* 2006; Diemont & Martin, 2009
Restoration of amla trees in India that were infected by a parasitic plant.	Local people identified areas of high infection and provided knowledge about management of the parasitic plant. Site identification for restoration.	Local participation ensured a better management plan and helped also in monitoring and evaluation.	Rist *et al.,* 2010
Restoration of basketry plants of cultural importance in the USA.	Declining resource availability and growing disturbance factors reported by indigenous people (and verified by ecological sampling, confirming the need for restoration). Past management activities explored by interviewing indigenous people (and by reviewing the ecological literature). Identification of old growth areas and associated site characteristics. Sites selected for restoration. TEK incorporated into research to gain an understanding of the ecology and management of the plants of interest.	TEK can be used in different stages of restoration such as recognizing disturbance factors, understanding population trends and ecological processes, identifying suitable restoration sites and species, and designing restoration methodology.	Shebitz, 2005; Anderson, 1996
Restoration of soil fertility using traditional practices in Belize and India.	Traditional people leave cut, non-seeding weed biomass in the field as a source of organic matter for soil fertility restoration and to conserve nutrients, which would otherwise be lost through erosion or leaching.	Traditional soil fertility restoration practices also offer effective weed control methods.	Diemont & Martin, 2005; Ramakrishnan, 2007b
Practice of sparing remnant trees in the field to restore the forest by facilitating regeneration and by increasing soil fertility in Cameroon.	Selection of diverse range of species that have multiple benefits, *e.g.*, some species provide food and medicine, some provide shade for crops, and some have leaves that also act as a fertilizer.	Selection of species that are useful to the local people can result in restoration success by motivating people.	Carrière, 2000
Restoration of riparian forests in Mexico.	TEK used to identify reference sites and target species and sites for restoration (along with ecological studies).	Combined use of TEK and ecological studies helps to cross-reference the information.	Allen *et al.,* 2010

observation by native people may hold clues to missing species (Kimmerer, 2000).

Sacred groves are another contribution of indigenous cultures to the identification of reference ecosystems. Dedicated to ancestral spirits or deities, such sites may be kept intact by local people for centuries (Bhagwat & Rutte, 2006). Found in many parts of the world, such areas cover a wide variety of habitats; they are often located in biodiversity-rich regions and serve as refugia for many species (Mgumia & Oba, 2003; Bhagwat & Rutte, 2006). The lands around such sites are often degraded forests or agricultural landscapes that may require restoration attempts. In such circumstances, sacred groves can play a valuable role as reference sites.

KNOWLEDGE ABOUT TRADITIONAL LAND MANAGEMENT PRACTICES

TEK can be used to help reconstruct indigenous peoples' interactions with their environment in specific areas, making a significant and lasting contribution to the understanding of indigenous land use while possibly also yielding a set of management techniques that can be used in restoration ecology (Anderson, 2005). Important information about former management goals and practices can be obtained from native people living near the area to be restored (Anderson, 2005).

Various tools—from prescribed burning to direct seeding—are used in traditional land management systems to manipulate the patterns and processes of ecological succession and to produce the desired species composition and structure in the restored community (Kimmerer, 2000). It is important to understand the environmental and cultural processes that shaped the places that are to be restored (Storm & Shebitz, 2006). In order to restore such landscapes it is necessary to restore the processes that shaped them. Traditional knowledge provides important information about historical land-use practices, and elders' explanations of why native plants are disappearing and tribal memories of the abundance of these species are useful in the formulation of management and restoration options (Anderson, 2001). Knowledge of how historic landscapes came to be, how they were maintained by indigenous peoples, and what factors disturbed the landscapes enables development of restoration programs with a better chance of success and a greater level of historical authenticity (Anderson, 1996; 2005). Traditional resource management strategies involve the coherent and integrated manipulation of a broad range of plants and animals and their habitats. The ecological restoration objectives of traditional land management practices include increasing resource availability for the benefit of all plant and animal species. By understanding the intricacies and mechanics of how traditional people manage ecosystems, restorationists will be able to make informed, historically based decisions (Anderson & Barbour, 2003).

FIRE AS A RESTORATION TOOL

Fire has been used by indigenous people since prehistoric times, not only to increase resource availability, but also to restore forest species, habitats, and landscapes (Anderson, 1995; Anderson & Barbour, 2003; Shebitz, 2005; Charnley, Fischer & Jones, 2007; Miller & Davidson-Hunt, 2010). Fire is particularly important for pest control, site preparation, wildlife habitat maintenance, production of basketry materials and other non-timber forest products, and fuel reduction to prevent catastrophic crown fire (Lewis & Ferguson, 1988; Kimmerer, 2000; Berkes, 2008; Pyke, Brooks & D'Antonio, 2010). Indigenous people often set fires to keep areas in earlier successional states that harbour greater plant biodiversity and landscape heterogeneity (Anderson & Barbour, 2003). Excessive fuel accumulation, which creates conditions that inhibit seedling establishment and encourage disease and insects, is prevented by frequent burning. Fire exposes bare mineral soil, increasing seed germination rates of annual herbs and vegetative reproduction of perennial herbs. Such burning practices often create a two-storied forest with a tree canopy and an understory of grasses and forbs, ultimately leading to an increase in plant species diversity (Anderson & Barbour, 2003). Such TEK is consistent with ecological restoration practices and lends support to fire ecologists and advocates of prescribed burning, who emphasize the role of fire in the renewal cycle of ecosystems and challenge the widespread idea that all fires should be suppressed (Berkes, 2008).

TRADITIONAL HARVESTING PRACTICES FOR RESTORATION

Ecological restoration of culturally important species requires restorationists to know how successful a particular harvesting regime can be in maintaining a plant population and how quickly densities can return to equilibrium after harvesting. Traditional knowledge can tell, for example, if rest periods can allow for population recovery, if there were attempts to keep population density above a certain threshold, if the selected technologies are appropriate, or if new technologies or tools could be more suitable. Harvesting strategies that demonstrate compatibility between use and conservation should be favoured by restorationists (Anderson, 2005). Traditional practices of rotational harvesting and grazing and seasonal migration enable populations and habitats to renew themselves (Moller *et al.*, online; Niamir-Fuller, 1998, Turner, Ignace & Ignace, 2000; Ghimire, McKey & Aumeeruddy-Thomas, 2005; Berkes, 2008).

RESTORATION OF FALLOW LANDS

For centuries, traditional people in many tropical areas have practised shifting (swidden or slash-and-burn) cultivation, accumulating a considerable pool of TEK. Indigenous shifting agroforestry has been proven both to be productive and to maintain ecological integrity (Ramakrishnan, 2007a; Vieira, Holl & Peneireiro, 2009; Diemont *et al.*, 2010). TEK of this kind can provide practical guidance for tropical forest restoration. Mayan TEK and ecosystem management practices are now considered a way forward for ecological restoration in Mesoamerica (Diemont & Martin, 2009; Diemont *et al.*, 2006; 2010), and in most of the tropics (Vieira, Holl & Peneireiro, 2009). Some of the best practices include those of the Lacandon Maya people of southern Mexico, who have a deep understanding of the patterns and processes of ecological succession (Levy-Tacher & Golicher, 2004; Diemont *et al.*, 2006; Diemont & Martin, 2009; Diemont *et al.*, 2010; Douterlungne *et al.*, 2010). The Lacandon people have relied on slash-and-burn (*milpa* in Spanish) farming systems for centuries, meeting their subsistence needs while maintaining both secondary and primary forests. The traditional ecological restoration practice of fallow land after slash-and-burn agriculture involves the selection of useful plant species that fill family needs and trigger the early successional stages in the restoration process (Diemont & Martin, 2009). By selecting for certain species and managing the natural succession, the Lacandon people are able to restore soil fertility and regenerate secondary forests in less than 20 y. The Lacandon example demonstrates that restoration of forest ecosystems can be done while maintaining subsistence production, and that traditional knowledge can play an important role in the selection of appropriate species (Diemont & Martin, 2009).

SPECIES SELECTION FOR RESTORATION PLANTATION

Most efforts to overcome forest degradation and restore ecological integrity involve tree planting (Lamb, Erskine & Parrotta, 2005). However, the choice of plantation species can influence both the rate and trajectory of restoration processes and determine the success of the projects. The selection of inappropriate species that have no use to the local people can result in restoration failure (Sayer, 2005). Hence, the species to be used should have diverse ecological importance, have traditional economic value, or be suitable for existing or potential markets (ITTO, 2002). Multi-purpose trees may have an especially important role for local communities. This type of information can be obtained by exploring traditional knowledge. Ideally, the species selected for restoration endeavours should tolerate unfavourable conditions and be easy to grow in large numbers in nurseries, fast-growing, and able to shade out grasses or other unwanted plant species in early successional stages. Species capable of coppicing and favouring soil improvement, tolerant of heavy pruning or pollarding, and resistant to fire, pests, and diseases are to be preferred (ITTO, 2002). Traditional people often have extensive knowledge of propagation methods, species suitability for specific light and soil conditions, and management methods for a range of tree species, which can help in designing restoration projects (Tolentino, 2008). Including the social and cultural values attached to forest plant and animal species in the criteria used for species grouping and selection can contribute to the adoption of silvicultural practices that accommodate a range of management objectives.

It is important that restorationists identify culturally and economically important plant and animal species of former ecosystems. Selecting species that were once well adapted to a particular ecosystem requires consultation with local people (Uprety, Asselin & Bergeron, 2011). Understanding species requirements and assessing their former importance must be tied to the actual planning and implemention of a restoration project (Anderson, 2005). Local people usually insist on using species that have both ecological and social values, and people's preferences are found to be consistent with ecological restoration practices (Tolentino, 2008; He *et al.*, 2009; Wangpakapattanawong *et al.*, 2010).

Site selection for restoration plantation

Site selection for restoration plantation is as important as species selection (Shebitz, 2005). The selection of priority areas in which to promote restoration depends on the broad social and ecological context that exists within the landscape. Choosing sites of interest to indigenous people can determine the success of restoration projects. Traditional knowledge can also provide information about the appropriateness of the sites where target species used to be found. This is particularly important in the restoration of culturally important species and traditional landscapes (Anderson, 1996; Shebitz, 2005).

Management of alien invasive species

Since ecological restoration seeks to recover as much ecosystem integrity as possible, the reduction or elimination of exotic species is highly desirable (SERI, online). Much energy is dedicated to the control of alien invasive species in restoration projects all over the world (Anderson, 1995). It is important to understand the ecological and biological conditions required to control alien species, and their interactions with native species have to be documented. Using science to answer these questions could require long-term study, whereas traditional knowledge can provide instant data, as long-term information is readily available through oral tradition. For example, the Lacandon Maya people's knowledge about the use of native species to control invasive fern species could provide clues on how traditional methods have been practised to manage the impacts of invasive species (Douterlungne *et al.*, 2010).

Partnership for restoration

Successful ecological restoration depends on effective partnerships between conservationists, managers, and indigenous people (Higgs, 2005; Fraser *et al.*, 2006). Restoration projects exist within a social context, and they must therefore produce environmental conditions that are not just ecologically sound, but also economically viable and socially acceptable (Hull & Gobster, 2000). One way of doing this is by incorporating traditional knowledge and building strong partnerships with indigenous people. Ecological restoration can be more efficient and restoration activities can be facilitated when local people are involved (Choi *et al.*, 2008). Where one is seeking community participation, traditional knowledge is a powerful tool because it links ecological and social processes and helps design sustainable land use practices (Ramakrishnan, 2007a). In addition, projects that receive the support of local people have a greater chance of being deemed acceptable and therefore sustainable (Danielsen, Burgess & Balmford, 2005; Rist *et al.*, 2010). Restoration in small areas can often be carried out using existing local organizations where traditional structures are in place and decision-making can be flexible and adaptive (Lamb, Erskine & Parrotta, 2005). Creating partnerships also creates volunteer communities that sustain projects over the long run (Hull & Gobster, 2000) and facilitates early conflict resolution between stakeholders (Robertson & McGee, 2003; Rist *et al.*, 2010).

Monitoring and assessment of restored ecosystems

Traditional knowledge has been found to be effective and efficient for the monitoring and assessment of restoration projects (Monela *et al.*, 2004). Most traditional monitoring methods used by indigenous cultures are rapid, low-cost, and easily comprehensible assessments (Moller *et al.*, 2004). Monitoring resource status is a common practice among many indigenous groups, and it is often accompanied by the monitoring of ecosystem changes (Berkes, Colding & Folke, 2000). Local people observe day-to-day changes and are among the first to notice if resources are no longer readily available (Berkes, Colding & Folke, 2000). Traditional monitoring methods used by indigenous cultures are useful in ecosystem monitoring and timely planning of restoration projects before the resource reaches a critical level. In particular, traditional knowledge can contribute information about the spatial and temporal distribution, composition, health, condition, and behaviour of many species and the factors that affect them (Stevenson, 2005). It can also provide information about the trajectory of the restoration plantation, disturbance factors, and further interventions, if necessary, at low cost and with little delay. Monitoring not only enables restorationists to determine if the objectives of the restoration are being met, it also provides information on the capacity of the restored ecosystem to supply desired goods and services to the local people.

Complementary role of traditional knowledge and science for ecological restoration

Science has powerful tools for testing "whys" and "hows", but it can also waste time and effort on trivial hypotheses (Moller *et al.*, 2004). TEK can provide important information of equivalent or higher accuracy in less time and at a lower cost than conventional ecological research as it is already the result of long-term observations and experimentation (Rist *et al.*, 2010). Traditional people often interact with a landscape at a much larger scale and over longer periods of time than are possible in scientific investigations (Fraser *et al.*, 2006; Wehi, 2009). Local observations can be of significant value as it is difficult to systematically conduct properly planned and replicated experiments in complex systems (Gadgil *et al.*, 2003). Holders of traditional knowledge are exceptionally good at observing extreme events, variations, and unusual patterns and remembering them through oral history and social memory that can be collected more rapidly and efficiently with a lower budget (Moller *et al.*, 2004). Traditional knowledge could also allow restorationists to cross-reference their information, thereby increasing data validity (Anderson, 2005; Shebitz, 2005; Allen *et al.*, 2010). It also provides precious information that science alone cannot provide. For example, Chalmers and Fabricius (2007) studied land cover change on the Nqabara coast of South Africa using both aerial photos and traditional knowledge. Traditional understanding was not only remarkably consistent with science, but it considerably added to understanding of the ultimate causes of land-cover change in the area that would have been impossible to decipher from aerial photographs alone. Hence, traditional knowledge and science should be seen as complementary rather than irreconcilable opposites (Berkes, 2008). TEK can fill information gaps and highlight promising directions for management and further research, but it must be used with full recognition of its limitations.

CHALLENGES OF INTEGRATING TRADITIONAL KNOWLEDGE AND ECOLOGICAL RESTORATION

Many studies have insisted on the necessity of integrating traditional knowledge and scientific information in order to lead to management that is "in tune with ecosystem dynamics" (for example, Olsson & Folke, 2001; ITTO, 2002; Rist *et al.*, 2010). However, there are challenges associated with integrating scientific and traditional knowledge systems. At issue is not only the role of traditional knowledge in decision-making, but also the role of the indigenous people who are the bearers of traditional knowledge (O'Flaherty, Davidson-Hunt & Manseau, 2008).

Although the potential contribution of traditional knowledge to environmental sciences is increasingly recognized, some scientists are still reluctant to use TEK (Houde, 2007), and the question of how the 2 knowledge types can be weaved together continues to be debated (Fraser *et al.*, 2006; Berkes, 2008). It is difficult for researchers to access TEK that is relevant to restoration planning (Wehi, 2009). Concerns are also being raised by TEK proponents over the incorporation of TEK into science without it being considered on its own grounds (Stevenson & Webb, 2003; Fraser *et al.*, 2006; Berkes, 2008). Many ecologists are still unfamiliar with the many ways in which TEK could add to the body of knowledge about ecosystem functioning (Huntington, 2011). For example, Adams (2002) reported the lack of scientific knowledge about African ecosystem dynamics but failed to take traditional knowledge into account. While there is an increasing number of international mandates for the inclusion of TEK in ecological restoration and conservation (Ford, 2000), the contribution of traditional knowledge to ecological restoration was absent from a worldwide review of restoration policies (Perrow & Davy, 2002). Therefore, a current challenge is the development of strategies to incorporate traditional knowledge into state-driven restoration programs. Policy formulation is still mostly driven by scientifically trained people, largely unaware of the available relevant traditional knowledge.

The methods adopted for documenting TEK largely determine the quality of the data obtained and their application in ecological restoration. The collection of TEK is challenging due to cultural, communication, and language issues. Although the study of museum artefacts and old ethnographic documents can provide important information (Anderson, 2001; Wehi, 2009), open-ended, close-ended, semi-directive formal and informal interviews and group discussions are the main methods available for documenting traditional knowledge (Huntington, 2000; Anderson, 2001). Challenges related to semi-directive interviewing include the choice of interviewees and the weight to be attributed to each interview during analysis (Huntington, 2000). The question of how traditional knowledge experts are identified and selected is a major methodological issue in TEK research (Davis & Wagner, 2003). It is important to contact community officials to identify key informants for the interviews and fieldwork (Fraser *et al.*, 2006). Key informants should be peer selected (Huntington, 2000), applying chain referral, also called snowball sampling (Biernacki & Waldorf, 1981). Information accuracy can be verified by cross-checking with other groups, conducting ecological field experiments, and using archaeobotanical remains (Anderson, 2001). The concordance of information provided by multiple informants from the same area suggests consensus and validity (Fraser *et al.*, 2006).

One of the potential barriers to integrating TEK into restoration practices is the protection of intellectual property rights (IPRs). Although equitable sharing of the benefits arising from using TEK has been emphasized since Rio (CBD, online), efficient mechanisms to ensure protection of IPRs are still lacking. Traditional people often ignore that their knowledge is being used by scientists. They often lose control over the information they share, and have no power over how that knowledge is interpreted and used (Stevenson, 1996). Concerns about the respect of IPRs thus render most indigenous people reluctant to disclose their knowledge to outsiders (Karjala, Sherry & Dewhurst, 2002; Uprety *et al.*, 2012).

Conclusion

The knowledge developed over generations of interactions between traditional people and ecosystems can make a valuable contribution to ecological restoration. This review showed how traditional knowledge could (and does) contribute to all stages of ecological restoration, from construction of the reference ecosystem to monitoring and assessment of restoration outcomes. Successful restoration depends on the effective coordination of science and TEK (Higgs, 2005), which should be considered to be on an equal footing and treated as complementary to each other (Moller *et al.*, 2004; Shebitz, 2005; Chalmers & Fabricius, 2007; Berkes, 2008). As Higgs (2005) stresses, successful restoration projects cannot be based solely on scientific knowledge, independent of local knowledge, experience, and the insights that come from an intuitive understanding of ecosystems. Over reliance on science can undermine the work of restorationists by pushing other forms of knowledge to the sidelines (Higgs, 2005) and make restoration projects unsuccessful. Therefore, effective mechanisms should be developed to incorporate traditional knowledge into ecological restoration while taking into account cultural, policy, and ethical issues.

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