The unknown known – A review of local ecological knowledge in relation to forest biodiversity conservation

Abstract

Local ecological knowledge and the land use practices of forest resource users who rely on this form of knowledge play a crucial role for biodiversity conservation in managed forests. The understandings of, and approaches taken to analyze, such knowledge are diverse. To systematize the available knowledge, we conduct a review of 51 studies addressing local ecological knowledge (LEK) and forest biodiversity conservation practice. We analyze what specific kind of knowledge is considered, who holds the knowledge, how this knowledge is actively applied in practice and how it relates to biodiversity conservation.

The review shows that local ecological knowledge and forest biodiversity conservation are linked through various socially shared aspects, such as values and norms, spiritual beliefs and perceptions of ecosystem functions and benefits as well as operational conditions, including livelihood strategies and economic constraints. While many of the reviewed studies evaluate local knowledge as holding great promise for biodiversity conservation, the conclusions regarding practical implications of including this knowledge into forest and conservation management are mixed. In particular, the interaction of "traditional" conservation paradigms rooted in local ecological knowledge and science-based "modern" paradigms is not thoroughly addressed. This applies especially to European countries, where research on local ecological knowledge is scattered. Drawing on these observations, we conclude that a greater focus on the ways in which societies in these countries can (re)generate, transform and apply local ecological knowledge can play a crucial role in integrating conservation objectives into forest management under changing environmental conditions.

Keywords:

Local ecological knowledge; Forest management; Forest land use; Biodiversity conservation; Local resource users; Literature review

1 Introduction

Forests harbor the majority of global terrestrial biodiversity (Thompson et al., 2014). Less than 8% of the world's forests are formally designated as protected areas, including areas that allow for some management (IUCN I-IV) (Schmitt et al., 2009). The remaining 92% are subject to various management strategies and practices. Therefore, integrating conservation into managed forests is a major political goal, which is e.g. addressed by the Convention on Biological Diversity (CBD) through its expanded programme of work on forest biological diversity. Besides protecting, recovering and restoring forest biodiversity, the programme explicitly includes the goal to "promote sustainable use of forest resources to enhance the conservation of forest biological diversity" (UNEP/CBD, 2002: 238).

Thereby, the practices and site-specific ecological knowledge of people working in, and making their livelihoods from, natural environments play a crucial role. The importance of local knowledge for conservation is increasingly highlighted in literature (e.g. Gadgil et al., 1993; Berkes and Turner, 2006; Brook and McLachlan, 2008; Gomez-Baggethun et al., 2010; Davis and Ruddle, 2010; Díaz et al., 2015a). This understanding is also reflected in international conventions, i.a. in Article 8(j) of the CBD, which requires all contracting parties to respect, preserve, maintain and apply the knowledge, innovations and practices of indigenous and local communities that are relevant for the conservation and sustainable use of biodiversity (UN, 1992).

In the literature locally held and mobilized knowledge is variously referred to as traditional ecological knowledge (TEK), indigenous ecological knowledge (IEK), local ecological knowledge (LEK) or experience-based, practical or experiential knowledge; forest-specific analyses also apply the term traditional forest-related knowledge (TFRK) (see Table 2 for an overview on terminology). In this review we employ the term local ecological knowledge (LEK) as our interest lies in people's site-specific ecological knowledge that can be practically applied. This includes knowledge held and used by traditionally living indigenous people with a historical continuity of resource use as well as by non-indigenous natural resource users.

LEK is frequently acknowledged as a valuable source of information (Charnley et al., 2007; Hernández-Morcillo et al., 2013) and yet conservation policy and planning is dominantly justified with scientific knowledge. The practical implementation of forest and conservation management relies on the engagement of locally operating practitioners and requires the mobilization of their experiences and site-specific knowledge (Paloniemi et al., 2018; Primmer and Karppinen, 2010). Hence, LEK may greatly determine such management on the ground and should be systematically considered in official conservation management and planning.

Forest managers, for example, perceive themselves as both autonomous and knowledgeable (Primmer and Karppinen, 2010; Maier and Winkel, 2017) and thus may decide rather independently which measures they implement and how. Thereby, their LEK that is not only factual knowledge, but deeply connected to practices and their local and situated contexts, plays an important role. The frequent neglect of this knowledge may explain why the implementation of conservation guidelines by practitioners is not necessarily in accordance with the intentions of those who developed them (Arts et al., 2014). To understand why the implementation may fail or not lead to the desired outcomes, it is first of all necessary to consider LEK not only as additional ecological data, but as an independent knowledge system with its own values, practices, institutions and management systems. Only on this premise can the relevance of LEK for conservation practice be fully grasped.

While the role of indigenous knowledge for development and empowering marginalized, indigenous people in these processes has been widely discussed in development research (Agrawal, 1995; Briggs, 2013; Ferguson et al., 2010; Sillitoe, 2010), a similarly critical analysis has not been conducted with re-

gard to biodiversity conservation. Indeed, it is possible that the ignorance of the potential of LEK in changing conservation practice is a major constraint for effective conservation.

To address these gaps, we conduct a review of the scholarly literature on LEK and biodiversity conservation in forest ecosystems, seeking to answer the following questions for forest-related LEK studies: (1) What knowledge is considered as LEK? (2) How are LEK holders identified? (3) How is LEK applied in practice? (4) How is the application and relevance of LEK for biodiversity conservation evaluated?

The next section introduces the review's applied methodology. The third section presents the results structured according to different analysis categories (see Section 2) with a focus on the application and evolution of LEK and its relevance for forest biodiversity conservation. Section four discusses our findings addressing the aforementioned research questions and reflects the present review's approach. The final section concludes with an outlook on further research needs, including not only questions of content, but also new methodological and conceptual approaches to meet the inter- and transdisciplinary challenges in this field of research.

2 Method

This paper reviews scientific literature published between 1945[1] and April 2017. Relevant papers addressing LEK in forest biodiversity conservation were identified through a TOPIC search (including Title, Abstract, Author Keywords, Keywords Plus) in the ISI Web of Science (WoS) in May 2017 using all combinations of search terms shown in Table 1. This acknowledgement of various knowledge terms describing the site-specific ecological knowledge of local resource users allows to capture the great variety of expressions used in scientific publications. The WoS database was chosen since it covers most of the international and regional journals from natural, social and interdisciplinary sciences and facilitates a transparent and replicable literature search.

Main topics	Forest	Knowledge	Conservation
Search terms	Forest*	Ecological knowledge	Biodiversity conservation
	Woods	Environmental knowledge	Nature conservation
	Woodland	Practical knowledge	Biodiversity preservation
		Experience-based knowledge	Nature preservation
		Experiential knowledge	Biodiversity protection
		Traditional forest-related knowledge	Nature protection
			Environmental conservation

Table 1
Combinations of search terms (columns combined with "AND", rows combined with "OR").

As a result, 95 publications were identified. After reviewing the abstracts of all articles, 33 of them were selected for in-depth analysis as they explicitly examined the interrelation of LEK and biodiversity conservation in forest ecosystems.

The 62 discarded papers were excluded for the following reasons: 37 of them do not address LEK-related forest biodiversity issues since search terms were only found in the Keywords Plus field (consisting of words and phrases harvested from the titles of the cited articles); 21 deal with types of knowledge that fall outside this review's definition of LEK (e.g. urban ecological knowledge, expert ecological knowledge,

[1] Earliest year covered by the WoS database

ecological knowledge of tourists), 2 analyze LEK in a context other than conservation and 2 are editorial notes or prefaces and thus do not include any empirical research results.

The WoS search was supplemented by a snowball approach to identify scientific literature not directly found in the database, but referenced in the 33 reviewed articles. Through a manual search in their bibliographies another 18 articles meeting the aforementioned search criteria were identified. Altogether, 51 publications are reviewed here, including 2 book chapters published in edited volumes.

These papers were then systematically analyzed using the following categories: authors, journals and temporal trend of publications; regional focus; methodology; knowledge definitions and concepts; knowledge categories; findings and conclusions. The findings were described with a focus on the application and evolution of LEK, while the conclusions were analyzed focusing on LEK's relevance for forest biodiversity conservation. The following results are presented using these categories.

3 Results

3.1 Authors, journals and temporal trend of publications

The disciplinary background of lead authors, their affiliation and the journals in which the articles are published may indicate trends in LEK research and, hence, is included in this review. The first authors of LEK papers represent various academic disciplines. While several authors have a multidisciplinary background, in a rough categorization, the largest groups are ecologists and biologists (n=16) or social scientists and anthropologists (n=8). Further lead authors represent forestry, environmental sciences, agriculture and geography. Most of the scholars are affiliated with either Asian or North American universities, which is also reflected in the regional focus of many of the analyzed studies (see 0). However, while Asian research papers focus on cases in and around their home countries, papers from North American institutions deal with cases from all over the world.

More than half of the analyzed papers were published in ecology, forestry or conservation journals. While the scope of the ecology journals cover nearly all sub-disciplines of ecological science (e.g. Ecological Engineering, Ecological Research, Ecological Applications, Ecosphere), most of the forestry and conservation journals focus on natural resource management and conservation issues (e.g. Forest Ecology and Management, Biological Conservation). Some explicitly address biodiversity conservation (e.g. Conservation Biology, Biodiversity and Conservation). Relating to the multidisciplinary background of many authors, multi- and interdisciplinary journals (e.g. Ecology & Society, Human Ecology, Society & Natural Resources) are common publication forums as well. Although there are many social scientists among the authors, none of the articles were published in a dedicated social sciences journal.

While the review search delivered only a maximum of three publications per year up until 2006, the number of articles clearly grew in the late 2000s (see Fig. 1). A great majority of papers (n=42) were published in the last decade (between 2007 and 2016).

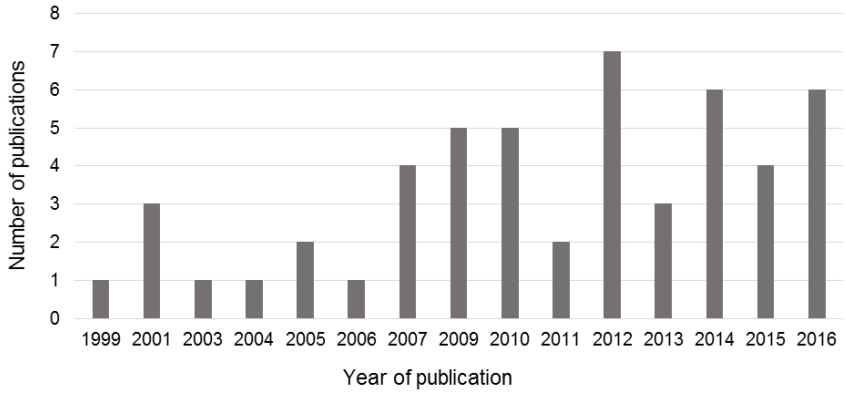

Fig. 1. Number of relevant articles by year of publication (only years with publications are shown).

3.2 Regional focus

To understand the geographical spread and the socio-cultural contexts that LEK studies address, we analyze the regional coverage of study areas. The review shows that LEK research has focused mostly on indigenous communities in Asia (n=24), North and South America (n=7 each) and Africa (n=7), whereas European (n=3) and Oceanic (n=2) cases were rarely investigated. Regarding specific countries, the largest number of analyses focused on India (n=8), China (n=7) and Mexico (n=6).

A great majority of research was conducted at local or regional levels rather than at the national scale. Analyses rarely include comparisons, with the only exceptions found of Young et al. (2016) contrasting three case studies from Scotland, and Rist et al. (2016) comparing cases from India, South America and Alaska. The only two intra-continental studies analyze the role of indigenous knowledge (or, rather, TFRK) in sustainable forest management in Southeast Asia (Rerkasem et al., 2009) and Africa (Oteng-Yeboah et al., 2012).

Owing to the defined search criteria, all articles deal with forest ecosystems, covering a broad range of forest types (from boreal forests to rainforests) and management intensities (from intensively managed agroforestry systems to strictly protected forest reserves).

3.3 Methodology used in LEK papers

3.3.1 Data collection and analysis

As a result of the great variety of lead authors' academic disciplines, a wide range of methods are used. Of the 51 reviewed studies, 29 report the use of exclusively empirical social science methods (such as interviews, surveys, group discussions, participatory observations etc.), while 22 combine methods of empirical social research with biophysical science or economics methods (such as tree inventories, satellite imagery analysis, cost-benefit analysis etc.), which clearly reflects the interdisciplinarity of the research field. A majority of studies rely on qualitative data (n=23), gathered either through empirical data collection or by synthesizing published literature, while 18 articles are based on a mixture of qualitative and quantitative data, and 10 use only quantitative data.

Notably, some of the articles (n=10) lack a description and documentation of research methods (i.e. sample size, period of data, methods of data collection and literature synthesis) and very few studies include a critical reflection of methods applied. This is surprising as most authors agree that LEK represents a particular methodological challenge for empirical research.

One of the few authors who address difficulties in data collection are Donovan and Puri (2004: 5), who find that this "type of knowledge was seldom elicited outside the context of actual collecting expeditions; only through participation and learning by doing could a deeper understanding be gained". Babai and Molnar (2013: 1) go further, describing in detail what questions proved expedient in their interviews: "The questions asked ('what kind of place does species X like?') helped the often implicit knowledge of habitats to be verbalized". Yet, overall, specific difficulties in data collection are hardly mentioned, nor do authors reflect in detail on the quality of their collected data. Amongst the exceptions for the latter are Rist et al. (2010) and Stave et al. (2007), who discuss potential respondent bias, as well as Furusawa et al. (2014) and Silvano et al. (2005), who address small sample sizes as limitations of their studies.

A similar challenge can be identified in regards to the critical reflection of data analysis and interpretation, which is often missing in the reviewed papers. Exceptions include Kai et al. (2014: 6), who use peoples' ability to identify species as an index of LEK but later critically conclude that "the exact relationship between an ability to name species and other components of LEK is not known". Furthermore, Donovan and Puri (2004: 2) criticize approaches that "concentrate on the collection and analysis of verbal knowledge concerning biological taxa" as they were "often neglecting close examination of ecological knowledge and the procedural or skill knowledge underlying a group's interaction with and manipulation of their environment."

3.3.2 Identifying knowledge holders

Typically, LEK comprises a variety of individual and collective experiences and observations so that "no one person or social group holds the entire body of the knowledge" (Cetinkaya, 2009: 34). This indicates another methodological challenge in LEK research, which is the identification of "knowledgeable" persons.

While 15 of the reviewed studies lack information on how LEK holders have been selected, 36 studies indicate their selection process. A majority of these (n=21) use purposive sampling. Typical criteria for choosing knowledge holders are age, place of birth and residence, length of living in the area, experiences in management practice, knowledge about local ecosystems and/or their hierarchal position in the community.

Some of the studies (n=11) used peer recommendations to identify interviewees. Peers can be representatives of official institutions, such as local government authorities, teachers, nature reserve and NGO staff or traditional authorities, such as village committees, village heads and community leaders.

Random (n=8) or stratified random sampling (n=2) was mainly applied in quantitative studies including all potential resource users living adjacent to the ecosystem under investigation. Four studies used snowball or chain-referral sampling, where initial interviewees suggest other knowledgeable persons, thus increasing the sample. Two studies applied knowledge testing in order to identify LEK holders, and two studies, which included a vegetation survey, used the plot selection developed for their survey as sample criterion and interviewed respective plot owners.

The selection strategies varied according to the different target groups that were analyzed in the reviewed papers. Some studies, as said above, gathered data from all residents of the study area. Most studies, however, focus on specific groups, such as resource users (herbalists, harvesters, (agro)foresters, farmers, peasants, pastoralists, herders, traditional healers, family forest owners and native beekeepers), traditional or spiritual leaders (community leaders, village heads, heads of traditional institutions, village priests, shamans, spiritual specialists and religion masters), government staff (state forest officials, government officers and managers), NGO members or specific ethnic groups (e.g. Lacandon

Maya, Baima Tibetans). As it is frequently presumed that LEK has been developed through long-term experience within specific settings, it is often associated with elders "able to offer rich explanations of natural and historic events, sacred and productive forests, village regulations, and changing forest management styles" (Jinlong et al., 2012: 10–11). Nine studies explicitly focus on this type of informant.

An overview of all types of informants and sampling approaches can be found in Appendix A

3.4 Knowledge definitions and concepts

To understand how LEK is conceptualized, we analyze how the reviewed papers define the knowledge they address. Appendix B gives an overview of all knowledge definitions applied, while Table 2 shows the knowledge terms most frequently found in the analyzed articles.

More than one-third of the papers neither give a precise definition of the knowledge term they use, nor do they apply a specific theoretical approach or concept. The majority of papers that clearly specified the knowledge under investigation focused on TEK (n=17), citing the definition of Berkes (1993: 3): "a cumulative body of knowledge and beliefs, handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment." Typically, this body of knowledge is applied in local management systems governed by social institutions embedded within specific worldviews or belief systems.

A few studies (n=8) developed their own knowledge definitions. Though not referencing Berkes (1993), these definitions have a similar coverage, focusing on knowledge that evolves through long-term observations, experiences and interactions between humans and local ecosystems, and the skills and techniques derived from this knowledge. Some put more emphasis on religious or spiritual traditions, values, ethics and cultural beliefs; others focus more on practices, technologies and innovations.

Some authors combine different definitions, but only a few clearly delimit the concepts, e.g. through different temporal and spatial references. In these papers TEK is taken to highlight the historical legacy: "Handed down through generations" (Berkes, 1999: 8), implying the "development of knowledge over a longer timescale" (Rist et al., 2010: 1). This also applies to IEK that was said to accumulate over generations, but puts more emphasis on a "holistic worldview […] embedded in cultural values, spiritual beliefs, and customary legal systems" (Ianni et al., 2015: 145). In contrast, LEK, per se, "is used to emphasize its very localness" (ibid.) and can also be held by "peoples that may not have a long-term relationship with the local environment, but nevertheless have local wisdom, experience, and practices adapted to local ecosystems" (Ballard and Huntsinger, 2006: 530–531).

Despite the great variety of terms, many definitions overlap and differ only slightly, e.g. regarding which knowledge components are particularly stressed. Moreover, some authors even use various terms synonymously (Kai et al., 2014: 1).

Term	Knowledge concept/definition	Reference
Local ecological knowledge (LEK)	"**(LEK)** is defined here as knowledge, practices, and beliefs regarding ecological relationships that are gained through extensive personal observation of and interaction with local ecosystems, and shared among local resource users. Local ecological knowledge may eventually become **TEK**."	Charnley et al. (2007: 15)
Traditional knowledge (TK)	**"Traditional knowledge** is acquired by local people through the accumulation of experiences and informal experiments, and through an intimate understanding of the environment in a given cultural context"	Becker and Ghimire (2003: 1)

Traditional ecological knowledge (TEK)	"[…] a cumulative body of knowledge and beliefs, handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment."	Berkes, (1999: 8)
	"Traditional ecological knowledge (TEK) refers to all types of knowledge about the environment derived from the experience and traditions of a particular group of people transmitted from one generation to the next."	Ianni et al. (2015: 145)
Traditional forest knowledge (TFK)	"[…] **TFK** "a cumulative body of knowledge, practice and belief, handed down through generations by cultural transmission and evolving by adaptive processes, about the relationships of living beings (including humans) with one another and with their forest environment""	Park and Youn (2012: 37)
Indigenous knowledge (IK)	**"Indigenous knowledge** can be broadly defined as the knowledge that an indigenous (local) community accumulates over generations of living in a particular environment (Rÿser 2011)."	Camacho et al. (2016: 5)
	"Indigenous knowledge is used to refer to a holistic worldview inseparable from the indigenous ways of life embedded in cultural values, spiritual beliefs, and customary legal systems (e.g., Maweu 2011)."	Ianni et al. (2015: 145)
Indigenous forestry knowledge (IFK)	**"Indigenous forestry knowledge** systems largely encompass local technologies, innovations, know-how, skills, practices and beliefs uniting local people to conserve forest resources and their cultural values. […] (Armstrong et al. 2006)."	Camacho et al. (2016: 5)

Table 2
Different knowledge terms and their definitions within the analyzed articles.

A majority of the reviewed literature focus on the empirical analysis of site-specific cases. Only some of the papers link their analysis to conceptual frameworks. Examples of this include the six ''faces'' of TEK distinguished by Houde (2007) (Rist et al., 2016) and the knowledge–attitudes–behaviors framework (Shen et al., 2012). Furthermore, the Millennium Ecosystem Assessment drivers of change and constituents of human well-being were applied to analyze TEK change (Cetinkaya, 2009), the ecosystem services framework was used to differentiate services and characterize LEK (Harisha et al., 2016; Higuera et al., 2013) and the comparative ecosystem management framework was used to compare forest fire management practices of different actors (Hill et al., 1999).

3.5 Knowledge categories

To gain a deeper understanding of what knowledge is considered as LEK in the reviewed papers, and to identify dominant ways in which LEK is framed in current research, we distinguish the following four knowledge categories:

1) Factual observations and experiences (locally developed classifications, naming and ecology of species and landscapes, ecosystem components, understanding of interconnections and dynamics)
2) Management systems and practices (methods for land and resource use, conservation and adaptation)
3) Social institutions (governing through customary rules, social norms, prohibitions and sanctions)
4) Worldviews (beliefs, spirituality, sacred objects, rituals and ceremonies)

These categories are based upon a knowledge-practice-belief framework introduced by Berkes (1999: 13), which consists of four levels of analysis: local knowledge of animals, plants, soils and landscape; land and resource management systems; social institutions; and worldview.

Not all analyzed studies deal with all categories. Factual observations and experiences are addressed most dominantly, while management practices, social institutions and worldviews received less attention. Table 3 shows the number of studies per knowledge category and breaks down these numbers according to the regional focus. Below we describe the ways in which these categories emerge in the reviewed analyses.

	Knowledge category			
Regional focus	**Observations and experiences**	**Management practices**	**Social institutions**	**Worldviews**
Asia (n=24)	18	20	19	20
South America (n=7)	7	3	2	1
North America (n=7)	7	6	2	2
Africa (n=7)	7	5	5	4
Europe (n=3)	2	2	2	0
Australia & Oceania (n=2)	2	2	2	2
Intercontinental (n=1)	1	1	1	1
Total (n=51)	**44 (86%)**	**39 (76%)**	**33 (65%)**	**30 (59%)**

Table 3
Number of studies per knowledge category (total and aggregated at continental level).

(1) Factual observations and experiences

The most frequently (n=44) addressed component of LEK is knowledge that LEK holders gain by spending time in forests "observing, experiencing, experimenting, working, and tinkering" (Charnley et al., 2007: 15). This knowledge is reported as consisting of the identification, naming and classification of species, including details about their useful attributes, habitats, abundance, spatial distributions and adaptations. Yet, many papers show that this is not only about knowing the individual ecosystem components, but rather about understanding their interactions and the systems' dynamics, allowing to monitor ecological changes (Donovan and Puri, 2004; Kai et al., 2014; Rerkasem et al., 2009; Stave et al., 2007; Vallejo-Ramos et al., 2016).

The underlying "experimental, anecdotal, and/or observational data" (Charnley et al., 2007: 15), is said to be "developed on a trial-and-error basis" (Donovan and Puri, 2004: 15) through long-term experiences. Since both observations and experiences are seen as site-specific, this knowledge is considered to "differ[s] according to locale" (Park and Youn, 2012: 41) and relates to the "embedded 'signs of nature'" (Siahaya et al., 2016: 14) as visual aspects play an important role in acquiring and applying LEK. Table 4 shows examples of the various knowledge components summarized in this category and described in the analyzed studies.

Knowledge component	**Example**	**Reference**
Observa-	"I frequently go to the mountains to observe native bees. I observe	Park and Youn

tions	when and on the flowers of which trees the native bees hang."	(2012: 40)
Experiments	"Family forest owners […] experiment with planting patterns to foster favored wildlife species and view qualities, and to explore new species arrangements."	Charnley et al. (2007: 19)
Classifications	"many indigenous peoples […] employ a hierarchical system of naming […], which implicitly identifies relationships among species."	Kai et al. (2014: 2)
Species knowledge	"trees left are selected based on several characteristics, including their habit and canopy architecture, compatibility with agricultural crops, and traditional subsistence and commercial uses and values"	Oteng-Yeboah et al. (2012: 49)
Habitat knowledge	"respondents identified local stands of black olive (*Bucida buceras*), sapodilla (*Manilkara zapota*), and Caribbean black cherry (*Lonchocarpus castilloi*) as the bird's preferred roosting sites. Once an area had been logged of these species, sightings of King Vultures dwindled and then fell off altogether."	Haenn et al. (2014: 955)
Ecosystem services	"The most cited of these forest services were cooling of the environment (microclimate), enhancement of water quality and availability (through water conservation and provision), protection against the wind (avoiding damage to houses and buildings) and enrichment of soil organic matter."	Silvano et al. (2005: 376-678)
Ecosystem components	"According to the 79 respondents, the most important prerequisite for forest growth was groundwater […] or high moisture content in the soil […], followed by occasional floods […], heavy rainfall events […], nutrient-rich soils […], and seed-dispersal by livestock"	Stave et al. (2007: 1476-1479)
Interactions	"several harvesters explained that salal responds positively to the silvicultural thinning of trees because thinning opens up the canopy and allows light to penetrate to the forest understory, stimulating growth of the salal and other floral green species."	Ballard and Huntsinger (2006: 539)

Table 4

Examples for different knowledge components of category 1.

(2) Management systems and practices

Category 2 comprises management systems that are said to use the LEK elements of category 1 in order "to sustain livelihoods and to enhance adaptive capacity of […] socio-ecological systems" (Oteng-Yeboah et al., 2012: 47). The reviewed papers reveal a wide variety of natural resource management practices that require a comprehensive understanding of ecological interrelations and local environmental conditions (Yaofeng et al., 2009). These include, among others, "rotational use and division of forests into compartments, selective felling of trees and promotion of natural regeneration of forests" (Tiwari et al., 2010: 335), "multiple cropping, enrichment planting and protection" (Camacho et al., 2016: 9), "conserving primary forest to provide seeds and animal refuge" (Diemont and Martin, 2009: 264) as well as "planting among a mosaic of successional stages that mimics the natural vegetation" (Bohn et al., 2014: 271).

Further examples described in the papers range from traditional land use systems, such as Muyong, a forest watershed management system in the Philippines (Camacho et al. 2016), Mayan swidden systems in Mexico (Bohn et al., 2014), Hani terraces management in China (Jiao et al., 2012) and Satoyama Eco-

systems in Japan (Indrawan et al., 2014) to agroforestry systems adopting modern agricultural techniques (Rerkasem et al., 2009; Vallejo-Ramos et al., 2016).

Management systems and practices are a commonly analyzed component of LEK across all regional studies. This illustrates the importance of the knowledge-practice interlinkage, and shows that it applies in various regional and cultural contexts.

(3) Social institutions

Two-thirds of the papers address the importance of (local) social institutions, which govern resource access and use "according to local customs and traditions" (Tiwari et al., 2010: 334). These customary institutions are seen as evolving against the background of locally grown experience in managing ecosystems, and influencing the implementation of management practices based on LEK.

In Meghalaya (India), for instance, community forests are controlled and managed by village councils: "Subject to the conditions laid down by these institutions […] people can collect fuelwood, fell trees for construction of houses, collect wild fruits, vegetables, orchids and medicinal herbs" (ibid.: 335). These types of collective agreements and customary laws are usually taken to reflect a common sense of correct attitudes to adopt towards the environment, based on "ethical responsibility and social norms of reciprocity and respect for ecosystem integrity" (Torri and Herrmann, 2011: 185). In the sense of rules-in-use, institutions provide the means by which resource users can act and are thereby considered to serve "the same function as externally defined, formal natural resource management regimes" (Sardjono and Samsoedin, 2001: 122). Violators of customary rules face "social, economic or material sanctions" (Moreno-Calles et al., 2012: 218) or, at least, will be "looked down by others within the community" (Shen et al., 2012: 167). Singh et al. (2015: 196), for instance, report that a "community member who deliberately or accidentally cut or damaged a paisang tree would not only be socially criticized, but also fined either in cash […] or kind" by the head of the village council. Some authors assume that this form of social control may "be more effective at regulating and constraining people's behavior towards conservation than government laws and regulations" (Shen et al., 2012: 167).

Our review shows that social institutions were recognized more in some geographical regions than others: While a majority of the studies conducted in Asia and Africa address the institutional context of the knowledge systems they analyze, only some of the South and North-American studies pay attention to social institutions and/or customary rules governing local knowledge systems.

(4) Worldviews

Many of the reviewed papers referring to Berkes' (1999: 13) "knowledge-practice-belief complex" base their analysis on the assumption that LEK is "embedded in conceptual/spiritual belief systems" (Torri and Herrmann, 2011: 184) that shape environmental perceptions. Peoples' traditional and spiritual beliefs, superstitions, legends and fairy tales, rituals, religious ceremonies and sacred objects (Anthwal et al., 2010; Donovan and Puri, 2004; Irakiza et al., 2016; Moreno-Calles et al., 2012; Torri and Herrmann, 2011; Yaofeng et al., 2009) are thereby understood to constitute important elements of how people know about forest ecosystems. In many African societies, TEK of indigenous people is even "synonymous with spirituality, which contributed to sustain the sacred forests" (Irakiza et al., 2016: 2).

Results show that it is mostly studies on traditional or indigenous people that apply the knowledge holders' worldviews as "a framework for interpreting and understanding their relationship with their physical and biological environments" (Jiao et al., 2012: 251). While the majority of studies dealing with cases in Asia, Africa and Oceania addressed the worldviews of LEK holders in their analyses, studies conducted in other regions hardly took this aspect of LEK into account.

3.6 The application and evolution of LEK

The range of topics addressed in the reviewed papers can be roughly divided into three groups. The first major topic that many of the articles analyze is the practical application of LEK in natural resource management, advancing the understanding of its potential contributions and its relevance for biodiversity conservation. The second major topic is the different types of ecological knowledge and their interrelations: some articles attempt to validate the accuracy of LEK against scientific ecological knowledge (SEK) or explore their differences and similarities; others assume that different knowledge systems are complementary and argue for a greater integration of LEK into management and conservation programs and policy. The third topic, also touched upon by many of the articles that deal with the previous two, is the substantial socio-economic–ecological changes that resource users face, leading to adaptation and increasing dynamics of knowledge systems.

As it is not possible to summarize each article, an overview of the main findings of the three topic groups will be given, focusing on the application and evolution of LEK.

3.6.1 Application of LEK in natural resource management

The practical application of LEK as described in the case studies is usually guided by differing management goals and strategies, which may be based on various values or determined by social norms and institutions. Utilitarian strategies include measures for income generation, e.g. if LEK provides "the basis for creating value added products" (Youn, 2009: 2033), or practices that indirectly affect productivity, such as water and soil preservation (Jiao et al., 2012) or maintaining "trees and shrubs to ensure the specific habitat of some other useful species" (Vallejo-Ramos et al., 2016: 5). In contrast, other studies, especially those that consider the worldviews of LEK holders, emphasize the important role of "[e]thic values […], the social prestige associated to nature conservation, and traditional customs" (Moreno-Calles et al., 2012: 220), a set of practices that can be labeled as moral strategies. However, against the background of changing socio-ecological systems (see 3.6.3), those values and strategies may be replaced by utilitarian ones. Oteng-Yeboah et al. (2012: 59–60) give an example from Ethiopia where the "traditional conservation of larger trees […] formerly hinged on religious beliefs and cultural attachments that are presently nonexistent." Nevertheless, these trees are still "conserved because of the benefits the community derives from the resources rather than the non-binding […] social sanctions". Thus, changes in motivation to conduct traditional practices do not necessarily alter the practices themselves.

3.6.2 Knowledge integration

The second major research focus was on comparing and integrating the knowledge of local resource users with that of actors involved in conservation politics or research. While some authors stress the necessity of a "scientific verification" (Rerkasem et al., 2009: 2042) of LEK, others highlight "the need to focus less on issues of "correctness" […] and to place more emphasis on what it can add to resource management when used in combination with standard scientific approaches" (Rist et al., 2010: 12).

The vast majority of reviewed studies – including those according to which LEK does not withstand scientific scrutiny (Silvano et al., 2005) or has undesirable outcomes on biodiversity (Becker and Ghimire, 2003) – emphasize the complementarity of both knowledge systems and the potential benefits of combining them: "ecosystem management measures may be improved if they integrate locally based information […] with global and empirical perspectives provided by scientific data" (Silvano et al., 2005: 378). Along with the authors, interviewees also stress the importance "of collaborating in conservation activities" (Higuera et al., 2013: 870).

A criticism of knowledge integration is that LEK may lose its authenticity when being merged with SEK, such that their distinct features and contributions cannot be identified. Agrawal (2002) cautions against

this process of "scientisation", which he argues can strip away the unique contextual and applied characteristics of LEK. At the worst, scientisation increases existing inequalities, if LEK is misappropriated and the benefits arising from its utilization are not equitably shared with the holders of that knowledge.

Thus, before effective integration of knowledge systems can take place, an alignment across differing interpretations of reality is needed, acknowledging the "differences in how people perceive and understand history, landscapes, resources and ecological dynamics" (Rist et al., 2016: 809), which may result in conflicting values and goals in resource management. The reviewed literature describes several preconditions for successful knowledge integration, such as "understanding the communication and operating styles of the people that hold TEK and LEK, and establishing a foundation of trust to work from" (Charnley et al., 2007: 24), "identifying incentives for, and mutual benefits from, knowledge sharing" (ibid.: 25) and "a genuine willingness to share power" (Young et al., 2016: 201). Furthermore, Shen et al. (2012: 168) emphasize that "policy makers and conservation managers should respect local autonomy for practicing their own conservation beliefs and practices" as resource users were considered to be "knowledgeable regarding their local environment and do not appreciate being "taught" environmental concepts by outside experts" (Silvano et al., 2005: 382).

While knowledge integration is one of the main topics of LEK research, only a few examples are reported from forest practice. In their literature synthesis, Charnley et al. (2007) find collaborative species-specific management, co-management, integrated scientific panels, formal institutional liaisons, ecological modelling as well as participatory research and monitoring as models of knowledge integration. Yet, studies about those examples often miss an assessment on how well LEK is actually incorporated in forest management and what are successful factors for knowledge integration (ibid.). All in all, the power dominance of SEK seems to persist, and central agencies continue to rely on SEK, often neglecting other ways of knowing (Ellis, 2010) or solely exploiting LEK to strengthen their own position of power. Consequently, there remains a substantial "lack of understanding on how the traditional and official conservation paradigms interact" (Shen et al., 2012: 161), that needs to be addressed for LEK to complement scientific knowledge in official conservation programs.

3.6.3 Dynamics of knowledge systems

The third major topic is the dynamics of knowledge systems. Many of the articles addressing this start with identifying drivers of change. These encompass an increased dependence on globalized markets, urbanization and migration, industrialization and occupation change, neglect of LEK in policies and regulations, imbalanced power relations between forest authorities and local users, external exploitation of resources or restricted resource access, declining interest in traditional knowledge among younger generations and a general erosion of traditional culture (Cetinkaya, 2009; Harisha et al., 2016; Ianni et al., 2015; Jinlong et al., 2012; Oteng-Yeboah et al., 2012; Rerkasem et al., 2009).

The papers addressing these dynamics focus either on analyzing the evolution and adaptation of LEK systems or on the loss of LEK. The first set of papers emphasizes the resilience and adaptability of LEK. For instance, as an "on-going construction" (Vallejo-Ramos et al., 2016: 11), traditional forest knowledge "is dynamic, and has evolved in response to changing environmental, social, economic, and political conditions" (Jinlong et al., 2012: 9). According to Oteng-Yeboah et al. (2012: 68) this characteristic is crucial "to ensure that forest resources continue to provide […] benefits […] for present and future generations." Despite these adaptive capacities, LEK and inherent practices of sustainable resource use remain vulnerable to outside forces. This vulnerability motivates the latter set of papers' warning that LEK and, with it, biodiversity may be lost (Jiao et al., 2012).

Reversely, some authors argue that "[b]iodiversity loss is also a driver of the loss of LEK" (Kai et al., 2014: 1) as "young people today cannot experience […] the forest their parents grew up with and consequently

knowledge of many local species is being lost" (ibid.: 7). This illustrates how tightly LEK is linked to the specific natural surroundings of resource users.

Yet, the abandonment of knowledge that has become obsolete may result in the adoption of new knowledge and skills. In some of the analyzed cases, local resource users integrated external knowledge to adapt to changing socio-economic conditions: "cultivators incorporate new technologies […] and become more familiar with cash cropping and dealing with the market" (Rerkasem et al., 2009: 2039). In other cases, external knowledge increased the resilience in response to natural threats: "By incorporating some modern timber technology, small farmers […] have been able to control an epidemic of banana disease as well as to increase their income from timber production" (ibid.: 2042). In others still, external agencies actively engaged in knowledge transfer, following specific purposes, such as influencing "people's attitudes and behaviors towards conservation […] through formal education […] conducted by local government agencies" (Shen et al., 2012: 161).

Only one fourth of all reviewed papers explicitly describe the evolution of LEK through the integration of new knowledge from external sources (e.g. media, science, NGOs or government agents) into local knowledge systems (Kai et al., 2014; Becker and Ghimire, 2003; Osemeobo, 2001; Shen et al., 2012; Yaofeng et al., 2009). Focusing mainly on LEK loss, little attention is devoted to processes of knowledge hybridization and adaptation. The majority of analyzed papers that deal with dynamics of LEK describe (potentially) negative outcomes of changes within knowledge systems and warn that LEK may lose its vitality and pragmatism when being integrated with SEK (Agrawal, 2002).

3.7 The relevance of LEK for forest biodiversity conservation

3.7.1 LEK as spiritual and utilitarian driver for biodiversity conservation

The analyzed articles proclaim LEK's relevance for biodiversity conservation in two ways: Through its importance in sacred natural sites that are protected for their spiritual meaning, and/or through its application in managed forests and landscapes.

Sacred sites (e.g. sacred forests, mountains, trees) are portrayed as being protected through cultural and religious norms and values of traditional societies (Anthwal et al., 2010), including supernatural beliefs such as: "high dense forests safeguard the souls of their ancestors" (Jinlong et al., 2012: 15), "God trees […] provide safety, fortune, and good harvests" (ibid.), "the village god dwells in the holy forests" (Jiao et al., 2012: 257) and "trees shelter the spirits of the forest" (Camacho et al., 2016: 9). Customary rules, use regulations and prohibitions are usually established to preserve these sacred objects. Salick et al. (2007: 701), for example, find that "[l]ocal customs prohibit timber extraction from sacred areas, protecting their old growth trees and forests", while in the Tibetan villages investigated by Shen et al. (2012: 167), "taboos often exist for core areas of sacred mountains, such as prohibition of livestock grazing and non-timber forest product collecting". The protection of sacred sites was evaluated as "analogous to the present day's concept of biodiversity conservation through protection of sanctuaries, national parks, and biosphere reserves" (Anthwal et al., 2010: 967) and thus may constitute "a functional conservation policy with rules obeyed by everyone" (Oteng-Yeboah et al., 2012: 43). Compliance is thereby ensured both through social convention, since "[o]beying these rules gives prestige, moral value and proud" (Moreno-Calles et al., 2012: 218), as well as through sanctions: "Violators are punished according to the village rules" (Jiao et al., 2012: 257).

Several studies dealing with sacred sites stress their importance for biodiversity conservation. Tiwari et al. (2010: 337), for example, find that "[s]acred forests […] are well preserved, often in their pristine state and are rich in biodiversity". Anthwal et al. (2010: 969) perceive sacred sites as both ecologically and genetically important, since they "provide a comprehensive and rich ecological niche as repositories of

genetic diversity". Beyond sacred sites, LEK in general includes an "ecological ethic of respecting all living beings" (Yaofeng et al., 2009: 2000) and a "high value attributed to ongoing ecological processes, biological evolution, and the protection of threatened species" (Hill et al., 1999: 216), which forms the ethical basis of maintaining biodiversity. However, some authors warn against over-emphasizing spiritual motivations for indigenous resource management. Becker and Ghimire (2003: 8) conclude that "whatever wildlife protection norms exist in indigenous communities […], they are predominately based on utilitarian relationships". Similarly, Torri and Herrmann (2011: 185) stress that "beliefs may have little to do with actual behavior towards the natural environment, since often economic needs are more decisive". Yet, utilitarian and spiritual motivations might not contradict in traditional resource management systems where conservation motivation relates to knowledge about benefits of ecosystem services. Higuera et al. (2013: 870) find that LEK, measured as "the number of services identified, increased both the probability and the amount that users are willing to pay or collaborate […] with conservation activities". Vallejo-Ramos et al. (2016) conclude that the main driver for conserving biodiversity is how resource users perceive and value ecosystem functions, which might include spiritual and utilitarian factors.

3.7.2 The relevance of LEK for integrating biodiversity conservation into forest management

One major challenge for forest resource users are trade-offs in forest management, which may lead to conflicts regarding biodiversity conservation. Several scholars point out that LEK can play an important role in balancing various management goals and maintaining biodiversity as it comprises the "multiple constituents, functions and interactions" (Vallejo-Ramos et al., 2016: 2) of ecosystems, necessary to assess trade-offs between different functions. Furthermore, LEK entails sustainable land use practices valuable "both for increasing productivity, thus improving local livelihood, and helping to maintain many services of forested land" (Rerkasem et al., 2009: 2042). This "rich understanding of the […] complex environment is a valuable asset" (Jiao et al., 2012: 261) enabling resource users to develop locally adapted practices that support biodiversity conservation in managed forests.

In contrast to preservationist approaches aiming to prohibit resource use, many traditional and indigenous societies proclaim that "human modifications can positively affect biodiversity" (Furusawa et al., 2014: 2). The study conducted by Bohn et al. (2014: 277), for example, "supports the idea of ''biodiversity is diversity in use'' wherein a diversity of land use practices is used as an approach towards maintaining ecosystem biodiversity". Some authors draw the even more pronounced conclusion that "the reality of conservation will have to be "use it or lose it"" (Gichuki and Terer, 2001: 157) and that its focus "must shift toward human-modified forests where the people use the natural resources in a sustainable way" (Furusawa et al., 2014: 18).

Thus, LEK is seen as crucially important for integrating various goals in forest management offering another option, in contrast to a "hands-off, preservationist approach" (Charnley et al., 2007: 25), for forest biodiversity conservation through locally adapted multiple land use practices.

While most authors stress the positive impacts of LEK on conservation, some also provide examples where biodiversity was depleted despite or even because of LEK. This can be the case if rapid or drastic socio-ecological changes occur and the existing body of knowledge is not adapting fast enough and may be rendered unsuitable in the altered conditions (Torri and Herrmann, 2011). For instance, if population or economic growth accelerates the demand towards forest goods, it may transform a traditionally sustainable forest management practice into a destructive one through intensification and uncontrolled exploitation of natural resources. This may be the case, e.g., through "[s]lash and burn practices coupled with fast rotation, hardly controlled wildlife hunting, […], over-collection of non-timber forest resources […] and land use to provide the increasing population shelter" (Hens, 2006: 25).

In summary, LEK may either harm, conserve or enhance forest biodiversity. In any case, it has a notable impact on biodiversity in managed forests that should be considered in conservation planning.

4 Discussion

This review sets out to (1) identify the ways in which LEK about forest ecosystems is conceptualized in the literature in terms of content, knowledge holders and practical application, and (2) to analyze how LEK affects forest biodiversity conservation according to the reviewed studies. As for the first point, our results confirm the findings of Davis and Ruddle (2010) that there is no narrow definition or even general agreement on the content and nature of LEK. Since local knowledge systems are interrelated with different environments and cultures, LEK is "made up of a blend of social, political, technical, scientific, and local elements mixed together" (Valencia et al., 2015: 13). Depending on the geographical and cultural context, and the analytical approaches taken, studies emphasize various LEK components, such as land and resource management practices, social institutions and cultural or spiritual values. It appears that while spiritual and religious beliefs play an important role in indigenous societies with subsistence economies, those aspects are less relevant for communities that manage natural resources primarily for income generation. The focus in these latter cases is more on management systems and practices (e.g. shifting cultivation or fallow and succession management). Yet, all of the knowledge systems described in the reviewed articles are interrelated with dynamic ecological and social processes. Management systems and governing institutions are constantly evolving, which in turn affects the worldviews and belief systems in which they are embedded.

In this dynamic setting, the analysis of LEK remains methodologically challenging. While some scholars – on an ontological level – question how far such tacit knowledge can be made explicit at all, others indicate the methodological challenges related to its analysis. For instance, individuals may struggle to verbalize knowledge they may not even be aware they know (Collins, 2001; Polanyi and Sen, 2009). This may indicate the need to grasp LEK not only through interviews and surveys, but also observations. In any case, clear definitions and transparent methodological approaches seem imperative for a systematic analysis of LEK. Our review indicates that this imperative is not always taken seriously. The lacking methodological rigor may increase general criticism towards the LEK literature as being driven by positive normative assumptions rather than empirical findings, and may make it difficult to re-conceive the different components and the overall importance of LEK in specific contexts and beyond.

Our review further demonstrates that LEK is a heterogeneous body of knowledge, which is not shared equally within a community (Cetinkaya, 2009). The quality and depth of LEK held by individual resource users varies, as do the practices they derive from LEK. In order to cover these differences and what they imply for biodiversity conservation, an elaborated sampling strategy for identifying knowledge holders is crucial. In the end, data quality depends largely on who is identified as "knowledgeable" and for what reasons. Researchers already identify some of the factors affecting the distribution of LEK, such as age, gender, profession, residence time and transmission of knowledge through the family or other community members (Iniesta-Arandia et al., 2014). These are also reflected in the selection criteria of the reviewed studies that use purposive sampling. However, further factors may be case-specific and need to be individually explored for each site. Given the variety of LEK systems, there are no defined procedures or guidelines on how to identify and select "knowledgeable" respondents. Yet, Davis and Wagner (2003) show that asking a wide range of community members for recommendations on whom to consult led to a more appropriate selection of knowledge holders than just assuming that those who have accumulated the most experience (e.g. elders) are best suited to represent the LEK of a community. Regardless of the procedures chosen, both identification and sampling should be documented transparently. Failure to do so is a shortcoming of many of the reviewed studies, irrespective of which sampling approach was used.

When it comes to the practical application of LEK in natural resource management and conservation, and its consequences for ecological systems, this review shows that the implementation of LEK depends on various interrelated factors. Internal factors, such as natural ecosystem conditions, individual management goals, values and social norms, as well as external factors, such as economic pressure, governmental regulations and state forest management, influence the ways in which knowledge is applied and is related to biodiversity conservation in each specific case.

The majority of studies emphasize the value of LEK as an information source for conservation science, policy and management, thereby arguing to conserve LEK itself as a "vital conservation resource" (Tang and Gavin, 2010: 194). Its relevance is considered particularly high if science-based data is missing, which is often the case in remote areas (Tang and Gavin, 2010), during rare events such as the occurrence of pest species, or for larger temporal scales (Rist et al., 2010). Furthermore, LEK is appreciated for its great site-specificity (Ballard and Huntsinger, 2006; Becker and Ghimire, 2003; Stave et al., 2007) and its "multiple scales, from species-specific information to details of ecosystem dynamics" (Tang and Gavin, 2010: 194). Due to its often narrow spatial focus and long-term evolution in a specific context, LEK may provide insights unattainable for conventional ecological research, which mostly addresses larger geographical scales for shorter periods of time. This may be particularly relevant for forest ecosystems characterized by long-term ecological cycles.

LEK may, however, stand in contrast to scientific biodiversity conservation approaches. For instance, Becker and Ghimire (2003: 7) conclude for their case that "local institutions and indigenous ecological knowledge were not sustaining biodiversity and ecosystem function [...] to an extent desired by scientifically trained western conservation biologists". Diverging views exist on what should be preserved, and how. Arising from independently viable systems of knowledge, all of these views should be considered as valid for debate (Ellis, 2010). In fact, however, these different perceptions are rather identified as one reason why forest policy and administrations may draw the conclusion that local resource users mismanage their environment or even represent a serious threat to biodiversity (Oteng-Yeboah et al., 2012: 63; Yaofeng et al., 2009: 1998). Accordingly, there are concerns that LEK is only acknowledged if it is in line with established scientific doctrines (Ellis, 2010), undermining the potential of its complementary character that may foster exchanges of perspectives and innovative approaches to sustainability challenges in resource management.

This corresponds with our observation that the reviewed papers tend to either focus on negative aspects of traditional management practices or positively promote them, with hardly any paper taking up an approach in between these two poles. Exceptions include Rist et al. (2010: 13), who point out that LEK should "be used in full recognition of its limitations" as it "may compromise on accuracy for specific variables" and miss "context beyond the local level" (Becker and Ghimire, 2003: 10).

Such concerns and limitations may explain why only a few of the reviewed studies analyze examples where LEK has been integrated into official conservation programs. In fact, forest biodiversity related examples can mainly be found in grey literature (Davis and Wagner, 2003). Additionally, these analyses often focus on specific indigenous communities of the Global South and of North America, whereas LEK in countries of the Global North, with no indigenous people left, is hardly investigated. This results in a lack of knowledge regarding the importance of LEK in areas where modernization and professionalization of forest management have arrived earlier. It remains an open question how far LEK in those contexts has been displaced, or if the lack of study simply mirrors a "selection bias" of the research community. One of the few studies from Europe emphasizes that LEK "also belongs to 'normal' contemporary rural people managing 'ordinary' landscapes, for example, social groups in Europe who have played a central role in shaping local biodiversity" (Ianni et al. 2015: 154). As local and practical knowledge is crucial in integrated conservation planning (Paloniemi et al., 2018), this issue deserves further empirical work.

Before concluding what we learned about current research on LEK and what remains to be investigated, we reflect on the present review's approach. Concerning the selection of papers, there is certainly a bias in terms of language (English) and literature database (WoS). Within these limitations, however, our use of the snowball approach to complement the database search (see Section 2) was very helpful for identifying relevant literature. Furthermore, one must be aware that this review focuses on LEK's role for biodiversity conservation solely in forest ecosystems, and its findings are hence confined to these ecosystems.

5 Conclusion

Local ecological knowledge remains a challenging and sometimes polarizing concept in conservation research. While hardly anyone would deny that the local knowledge context matters greatly in natural resource management and conservation practice on the ground, open questions relate to the presence, type and impact of LEK in this context. Somewhat simplified, the perceptions of LEK holders currently range from a transfigured, eco-romantic image of the 'noble savage' whose knowledge and practices are idealized to a much more pessimistic view of LEK as backward and outdated. Advocates of the latter promote a scientific-rational perspective, dismissing practical knowledge as static and anecdotal, and denying that LEK holders can innovate, adapt and transfer knowledge.

Future research on LEK should critically question all these clichés. LEK can neither be expected to be inflexibly "written in stone" nor its contribution taken a priori to be positive for conservation. Rather, the focus should be on the dynamic nature of LEK in correlation to both changing ecosystems and knowledge environments. Current modernization processes do not only alter traditional knowledge cultures, but knowledge systems more generally. This may be a chance for LEK to overcome its marginalization as its adaptive potential fits well with new knowledge mobilization modes and interfaces, such as co-production of knowledge, crowdsourcing data collection, citizen science and knowledge brokering. These new approaches to knowledge generation may facilitate knowledge integration and even integrate different knowledge systems in the framing of questions and approaches, in a transdisciplinary fashion. The inclusion of indigenous and local knowledge in the assessments of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), is a clear signal in the direction of formal acknowledgement of LEK (Díaz et al., 2015b), and has spurred a debate on the position of such knowledge systems (Peterson et al., 2018). As our analysis shows, it is time to move beyond analyzing and validating what people know in order to address the dynamics of local knowledge systems and the question of how people know and how their knowledge contributes to the design of inquiry. This might require flexibility in combining different qualitative and quantitative methods as well as natural and social science approaches.

We thereby suggest a greater focus on dynamic knowledge systems and more acknowledgment of the ability of non-indigenous Global North societies to (re)generate, transform and apply as well as to integrate LEK with "modern" scientific or professional knowledge. To consider processes of knowledge hybridization and adaptation, research should identify which local knowledge components are abandoned, remain stable or evolve. With such a holistic and dynamic perspective looking into relevant factors that influence knowledge production, application, transmission, adaptation, loss and preservation, the interplay of different types of knowledge in the local setting can be much better accounted for. This includes an understanding of how practices derived from LEK affect biodiversity and how local resource users can adapt to changing environmental conditions and increase the resilience of their socio-ecological systems, now and in the future.

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7 Abbreviations

CBD	Convention on Biological Diversity
IEK	Indigenous ecological knowledge
IK	Indigenous knowledge
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
LEK	Local ecological knowledge
NGO	Non-governmental organization
SEK	Scientific ecological knowledge
TEK	Local ecological knowledge
TFK	Traditional forest knowledge
TFRK	Traditional forest-related knowledge
TK	Traditional knowledge
WoS	Web of Science

Supplementary Material

Appendix A

Reference	Type of informant	peer recom-mendation	random sampling	purposive sampling	snowball sampling	population	not spec-ified	no empiri-cal study	others
Anthwal et al. (2010)	---							x	
Babai and Molnar (2013)	residents						x		
Ballard and Huntsinger (2006)	harvester	x			x				
Becker and Ghimire (2003)	heads of households		x						
Bohn et al. (2014)	agroforester (farmer)			x					x
Camacho et al. (2016)	farmers village leaders NGO members government officials tribal farmer leaders			x					
Cetinkaya (2009)	plant users harvesters	x							
Charnley et al. (2007)	American Indians Family Forest Owners NTFP harvesters							x	
Diemont and Martin (2009)	agroforester (farmer)						x		
Donovan and Puri (2004)	harvester						x		
Furusawa et al. (2014)	villagers elders	x							

Gavin and Anderson (2007)	residents		x	x			
Gichuki and Terer (2001)	residents					x	
Haenn et al. (2014)	farmers villagers	x					
Harisha et al. (2015)	villagers		x (survey)	x (survey)		x (inter- views)	
Higuera et al. (2013)	residents					x	
Hill et al. (1999)	Australian Aborigines government managers			x			
Ianni et al. (2015)	residents elders			x	x		
Indrawan et al. (2014)	---						x
Irakiza et al. (2016)	traditional healers villagers	x					
Jiao et al. (2012)	community's key stakeholders (village priest/shaman, head of the hamlet, spiritual specialist) government staff villagers	x		x			
Jinlong et al. (2012)	villagers religion master village head elders		x	x			
Kai et al. (2014)	villagers		x				
Kala (2013)	villagers (farmers)					x	
Martini et al. (2012)	agroforester (farmer) government officer			x (villages)		x (key per-	

	harvester						sons)		
Mbile et al. (2005)	villagers			x					x
Moreno-Calles et al. (2012)	agroforester (farmer)								x
Osemeobo (2001)	herbalists gatherers traders on biodiversity community leaders		x						
Oteng-Yeboah et al. (2012)	---							x	
Park and Youn (2011)	native bee-keepers						x		
Rerkasem et al. (2009)	farmers agroforester							x	
Rist et al. (2010)	NTFP harvester	x							
Rist et al. (2016)	indigenous residents NTFP harvesters resource managers							x	
Salick et al. (2007)	villagers Tibetan doctors						x		
Sardjono and Samsoedin (2001)	farmers agroforester						x		
Schmidt and Ticktin (2012)	NTFP harvester			x					
Shen et al. (2012)	villagers			x					
Siahaya et al. (2016)	agroforester village head community leader elders	x		x					
Silvano et al. (2005)	farmers	x		x	x				
Singh et al. (2015)	agroforester (farmer)	x	x	x					

	pastoralist							
Stave et al. (2007)	nomadic pastoralists settled pastoralists agro-pastoralists farmers	x	x					x
Tang and Gavin (2010)	herder			x		x		
Tiwari et al. (2010)	state forest officials heads of traditional institutions herbal practitioners villagers		x	x				
Torri and Herrmann (2010)	villagers spiritual heads			x				
Valencia et al. (2015)	agroforester (farmer)				x			
Vallejo-Ramos et al. (2016)	agroforester							x
Wekesa et al. (2010)	residents community elders government officers NGOs personnel		x	x				
Yaofeng et al. (2009)	villagers patriarchs / elders			x				
Youn (2009)	villagers forest resource users			x (survey)			x (inter-views)	
Young et al. (2016)	foresters				x			
Zorondo-Rodriguez et al. (2014)	peasant						x	

Table A.1
Overview of all types of informants and sampling approaches

Appendix B

Reference	Original knowledge definition
Anthwal et al. (2010: 963)	Traditional ecological knowledge includes worldview and religious traditions of a society. Every cultural group shares a range of environmental values and ethics along with their practices. Environmental relations of a group are not uniform, but they are shaped by the day-to-day interactions as well as their worldview and ethics.
Charnley et al. (2007: 15)	[…] new knowledge is created all the time, and indigenous peoples are not the only ones who have ecological knowledge of value. This more recent local ecological knowledge (LEK) is defined here as knowledge, practices, and beliefs regarding ecological relationships that are gained through extensive personal observation of and interaction with local ecosystems, and shared among local resource users. Local ecological knowledge may eventually become TEK.
Jiao et al. (2012: 258–259)	IEK […] is a way of knowing the world based on an accumulation of observations. Thus, it is a dynamic system that has evolved by observing and adapting to changes in the social and physical relationships between a society and its environment
Osemeobo (2001: 205)	Because the rural resource users are part of the ecosystems, they have gained some indigenous knowledge about the dynamics of species and ecosystems through experiences gained from farming, hunting, fishing, gathering and utilization of forest products
Oteng-Yeboah et al. (2012: 38)	Through long experience, these communities have accumulated a significant body of knowledge on the sustainable conservation, harvesting, processing, and utilization of forest resources.
Valencia et al. (2015: 2)	By knowledge we refer to an understanding of the world that is acquired by perceiving, experimenting, and learning. Philosophers distinguish between a posteriori knowledge, or knowledge that is gained by experience, and a priori knowledge, or knowledge that is gained independently of experience. A posteriori knowledge, also known as empirical knowledge, includes learning by observation and experimentation, such as observing the forest and experimenting in crop fields. A priori knowledge includes knowledge gained from myths, family members, agricultural extension agents, and conservation organizations, for example.
Vallejo-Ramos et al. (2016: 2)	TEK based on centuries and even millennia of interactions between humans and nature, as well as knowledge and techniques resulting from such interactions.
Yaofeng et al. (2009: 1995)	[…] through historical processes, local ethnic groups have developed very close interrelationship with local animals, plants and forests, and formed distinctive diversified indigenous knowledge systems and traditional cultural beliefs.

Table B.1
Overview of original knowledge definitions

Reference	Knowledge definition referring to other publications
Ballard and Huntsinger (2006: 530–531)	The definition used here for traditional ecological knowledge (sometimes used interchangeably with indigenous knowledge) is “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 anoth-

	er and with their environment" (Berkes et al., 2000). Local ecological knowledge is used to refer to local expertise of peoples that may not have a long-term relationship with the local environment, but nevertheless have local wisdom, experience, and practices adapted to local ecosystems (Berkes and Folke, 1998; Olsson and Folke, 2001).
Becker and Ghimire (2003: 1)	Indigenous knowledge (IK) and "traditional" knowledge are terms that describe knowledge specific to a given culture or society (Warren and Rajasekaran 1993). The development of IK is a dynamic process that changes with the availability of resources and the demands of local communities. Traditional knowledge is acquired by local people through the accumulation of experiences and informal experiments, and through an intimate understanding of the environment in a given cultural context […] Most of the time, IK is transferred orally; […] Traditional ecological knowledge (TEK) is a construct within IK that focuses more on a local culture's conceptualization and interactions with their biotic and abiotic environment (Gadgil and Berkes 1991, Nabhan 1997). TEK encompasses everything from cursory awareness of natural histories associated with local wildlife to cultural norms for land management and resource allocation.
Bohn et al. (2014: 271)	(TEK)—knowledge gained from long term relationship with an environment, characterized by adaptive strategies possibly based on millennia of observation and dependence on natural resources […] (Berkes and Folke, 1998; Olsson and Folke, 2001).
Camacho et al. (2012: 5)	Indigenous knowledge can be broadly defined as the knowledge that an indigenous (local) community accumulates over generations of living in a particular environment (Rÿser 2011). Indigenous forestry knowledge systems largely encompass local technologies, innovations, know-how, skills, practices and beliefs uniting local people to conserve forest resources and their cultural values. These have developed over thousands of years of direct human contact with the environment (Armstrong et al. 2006).
Cetinkaya (2009: 27)	Berkes (2001) and Berkes and Folke (2002) state that TK is an attribute of societies with historical continuity in resource use on a particular land, particularly in non-industrial and less technologically oriented societies. […] The legally binding definition of TK is stated in the Convention on Biological Diversity (CBD). According to the CBD, the term TK refers to the "knowledge, innovations and practices of indigenous and local communities around the world" [Article 8(j) and 18.4 of the Convention].
Charnley et al. (2007: 15)	We adopt Berkes (1999) definition of traditional ecological knowledge (TEK) as a cumulative body of knowledge about the relationships living things (including people) have with each other and with their environment, that is handed down across generations through cultural transmission. TEK includes knowledge, practices, and beliefs that are more-or-less integrated with one another. It is dynamic and evolves as people build on their experiences and observations, experiment, learn from others, and adapt to changing environmental conditions over time. TEK is place-based and geographically specific, and is most often found among societies that have engaged in natural resource use in a particular place over a long time period, such as indigenous peoples
Harisha et al. (2016: 311)	(TEK) is well-recognized and defined as an intellectual activity in a wide range of social, cultural, and environmental contexts (Reyes-Garcia et al., 2006). Many researchers also define TEK as a design of people centered approach (MEA, 2005); practice and innovations that are distinctively associated with many indigenous communities by customary laws (Pieroni et al., 2011); a cultural heritage of the society which preserves and transmits between generations (Cocks, 2006).

Ianni et al. (2015: 148)	Following Berkes (1999), general ecological knowledge is understood here as the ability to name the living (i.e., plants and animals) and physical (e.g., soils, water, weather) components of the ecosystem as well as knowledge of the functions and uses of each component.
Irakiza et al. (2016: 1)	Traditional ecological knowledge is defined as a cumulative body of knowledge, practice and belief. It is a mutual relationship between living beings (including humans) and its environment which evolves by adaptive processes and are handed down through generations by cultural transmission (Berkes 1999).
Jinlong et al. (2012: 9)	Traditional knowledge […], tightly interwoven with traditional religious beliefs, customs, folklore, and land-use practices, is dynamic, and has evolved in response to changing environmental, social, economic, and political conditions. […] (Parrotta and Angoletti, 2007; Liu, 2007).
Kai et al. (2014: 1)	Local ecological knowledge (LEK), which is synonymous with traditional ecological knowledge [1] or indigenous knowledge [2], can be defined as a cumulative body of knowledge and beliefs about the relationships of living beings (including humans) with one another and with their environment [3]. It is usually based on frequent observations at a restricted geographical scale and, hence, information about the taxonomy, life histories, behaviour, abundance, and habitat preferences of certain species […] can be very detailed (e.g. [4–7]).
Kala (2013: 201)	The constant interaction with biophysical environment has made the tribal communities and other forest dwellers to learn intricacies of nature and natural resources. Over the period of time, such interactions have led to evolution and accumulation of knowledge on the ecosystem properties that may be termed as traditional ecological knowledge. Traditional ecological knowledge has a historical continuity of resource use practice that is based on an integrated system of knowledge, practices, and beliefs including cosmology (Berkes et al., 2000).
Park and Youn (2012: 37)	[…] deeming TFK "a cumulative body of knowledge, practice and belief, handed down through generations by cultural transmission and evolving by adaptive processes, about the relationships of living beings (including humans) with one another and with their forest environment" (UNFF, 2004).
Rist et al. (2010: 1)	Traditional, indigenous, and local ecological knowledge (TEK, IEK, and LEK, respectively) have all been used to refer to sources of knowledge about species, ecosystems, or practices held by people whose lives are closely linked to their natural environment (Freeman 1992, Gadgil et al. 1993, Berkes 1999). The distinction between traditional/ indigenous and local knowledge is of greatest significance because the first two terms imply the development of knowledge over a longer timescale (Gilchrist et al. 2005). However, some communities with a more recent association with an area or resource still possess a detailed acquired knowledge or understanding of the ecology and management of that area and the resources they use. Communities that are dependent on natural resources can rapidly develop insight into factors influencing resource availability or quality. Such information can be shared among users and can develop into a substantial body of knowledge (e.g., Acheson et al. 1998, Hanna 1998).
Rist et al. (2016: 799)	We use the term 'knowledge' to encompass knowledge and belief systems in recognition of the ''knowledge-practice belief complex'' nature of much local or traditional ecological knowledge (Berkes 1999; Pierotti and Wildcat 2000).

Schmidt and Ticktin (2012: 187)	Local ecological knowledge and the traditional management practices derived from it are developed over time as a result of observation, as well as from trial and error processes. They are passed down by individuals and communities (Berkes, 2008)
Shen et al. (2012: 167)	Traditional ecological knowledge exists as a knowledge-practice-beliefs complex passed down within the community through generations (Berkes et al., 2000).
Siahaya et al. (2016: 15)	Traditional ecological knowledge is defined by Berkes (2008) 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'.
Silvano et al. (2005: 370)	Local human populations that directly depend upon natural resources usually have ecological knowledge about these resources (Gadgil et al., 1993; Williams and Baines, 1993; Berkes, 1999). Such local knowledge, usually acquired through experience and oral transmission, often accounts for the inter-relationships among animals, plants, humans and the environment […] (Berkes et al., 1998).
Singh et al. (2015: 187)	Traditional ecological knowledge (TEK) represents a body of knowledge accumulated over many generations through close interaction between people and their environment (Berkes et al. 2000).
Stave et al. (2007: 1472)	TEK may offer an alternative source of information rooted in long-term ecological observations (Ford and Martinez 2000). An underlying assumption is obviously that indigenous cultures have in-depth knowledge about their immediate environment, and that this knowledge is relevant to science and conservation.
Tang and Gavin (2010: 193)	Traditional ecological knowledge is a knowledge–practice–belief system, comprised of the ability to identify components of an ecosystem and to use and manage them, and a worldview that shapes environmental perspectives (Berkes 1999). The term traditional ecological knowledge recognizes that the knowledge is often long-standing and passed on from generation to generation (''traditional''), and it is fundamentally linked to ecology (''ecological''). While TEK has clear intergenerational links, it is also dynamic, and subsequent generations and individual TEK holders continue the adaptation process (Battiste and Henderson 2000; Berkes et al. 2000).
Tiwari et al. (2010: 329–330)	Close proximity to these resources and their constant utilisation have enabled traditional communities to develop an understanding of the conservation and sustainable utilisation of forests. This knowledge is expressed in the diverse cultural practices of the local people and forms part of their human heritage. Popularly known as traditional ecological knowledge, such knowledge is widely used by local and indigenous communities to develop various resource management techniques, rules and practices in order to ensure uninterrupted supply of forest products and other benefits from the forests (Phuthego & Chanda 2004).
Torri and Herrmann (2011: 171–172)	The preferential term "indigenous environmental knowledge" as used by Ellen and Harris (2000), is understood in accordance with the operational definition provided by Berkes (1999), who describes "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." […] The concept of knowledge developed through traditional relationships with nature can be expanded to TEKW (wisdom), recognizing the holistic aspect of TEK and that it is not

	easily subject to fragmentation (Turner et al. 2000). TEKW acknowledges that there is more than simply quantitative descriptions of these relationships; there is also wisdom acquired through understanding and maintaining these relationships in a complex system.
Young et al. (2016: 201)	[…] local ecological knowledge, defined as "the body of knowledge held by a specific group of people about their local ecosystems" (Scholz et al., 2004: 336)

Table B.2
Overview of knowledge definitions referring to other publications

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