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Insight

Local knowledge in ecological modeling

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ABSTRACT. Local people and scientists both hold ecological knowledge, respectively stemming from prolonged day-to-day contact with the environment and from systematic inquiry based on the scientific method. As the complementarity between scientific ecological knowledge (SEK) and local ecological knowledge (LEK) is increasingly acknowledged, LEK is starting to be involved in all branches of ecology, including ecological modeling. However, the integration of both knowledge types into ecological models raises methodological challenges, among which (1) consistency between the degree of LEK involvement and modeling objectives, (2) combination of concepts and methods from natural and social sciences, (3) reliability of the data collection process, and (4) model accuracy. We analyzed how 23 published studies dealt with those issues. We observed LEK reaches its full potential when involved at all steps of the research process. The validity of a modeling exercise is enhanced by an interdisciplinary approach and is jeopardized when LEK elicitation lacks rigor. Bayesian networks and fuzzy rule-based models are well suited to include LEK.

Key Words: *ecological modeling; elicitation; interdisciplinarity; local ecological knowledge; participatory research*

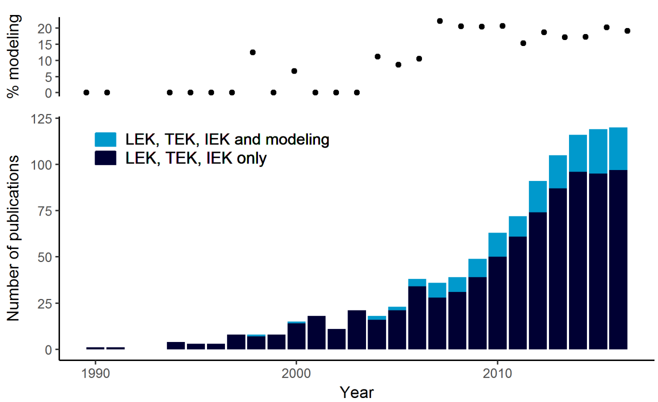
INTRODUCTION

Modeling plays a substantial role in ecology. Models allow researchers to better understand ecosystem functioning, forecast the future according to various scenarios, and provide resource managers with relevant information for decision making (Jørgensen and Bendoricchio 2001). Models address a range of questions, from very simple with few variables to "big" and complex ones involving nonlinear and multiscale processes (Sutherland et al. 2013). Because models are simplified representations of a complex reality (Box 1976), modelers rely on their judgement to decide what component of reality is to be represented, what parameters are most relevant and what level of complexity is necessary (Krueger et al. 2012). Inherent subjectivity makes modeling especially appropriate to combine different forms of expertise arising from scientific and local knowledge (Barber and Jackson 2015).

Research involving local ecological knowledge (LEK) has surged over the last decades (Fig. 1), with the increased recognition among ecologists of the many ways LEK can complement scientific knowledge (Asselin 2015). Scientific ecological knowledge (SEK) generally arises from hypothetico-deductive approaches, while LEK stems from direct contact of people with the environment (Box 1). The trend for increased involvement of LEK into ecological research is fueled by international conventions and declarations where SEK and LEK, including indigenous and traditional ecological knowledge, are found side by side, as United Nations' *Convention on Biological Diversity*, UNESCO's *Declaration on Science and the Use of Scientific Knowledge*, and more recently the *Paris Agreement* on climate change.

LEK not only finds a place in theoretical and applied ecology, but also in ecological modeling (Fig. 1). Indeed, LEK can provide ecological models with information hardly accessible using classical research designs. Reliability, scope, and predictive power of a model depend on data quality and quantity (Rykiel 1996) but data collection can be time- and resource-consuming from a researcher's viewpoint. Alternatively, local people interact with the environment on a daily basis, yearlong, and over the long term. Their knowledge of ecological processes can reach a precision level that is virtually impossible to match with fieldwork conducted over a few weeks and based on a limited sample size. In addition to data provision, LEK may be used to build the conceptual framework behind a model, set the scope, limits, and assumptions, estimate model parameters, and validate model outputs (Krueger et al. 2012).

Fig. 1. Annual number of scientific publications (articles and reviews) retrieved by searching the Scopus database for "local ecological knowledge" or "traditional ecological knowledge" or "indigenous ecological knowledge" and "model(l)ing" in the title, summary, or keywords (1990–2016). Dots in the top panel indicate the annual percentage of publications including a model.



The expected benefits of involving LEK in ecological modeling extend beyond concerns of model performance. The legitimacy of an ecological model increases if it takes into account the knowledge, needs, concerns, and perceptions of those primarily concerned (Ericksen and Woodley 2005), especially when tackling sensitive issues. Moreover, involving local communities in the research process contributes to local development (Sillitoe 1998, Blaikie 2006), providing local experts with opportunities to be

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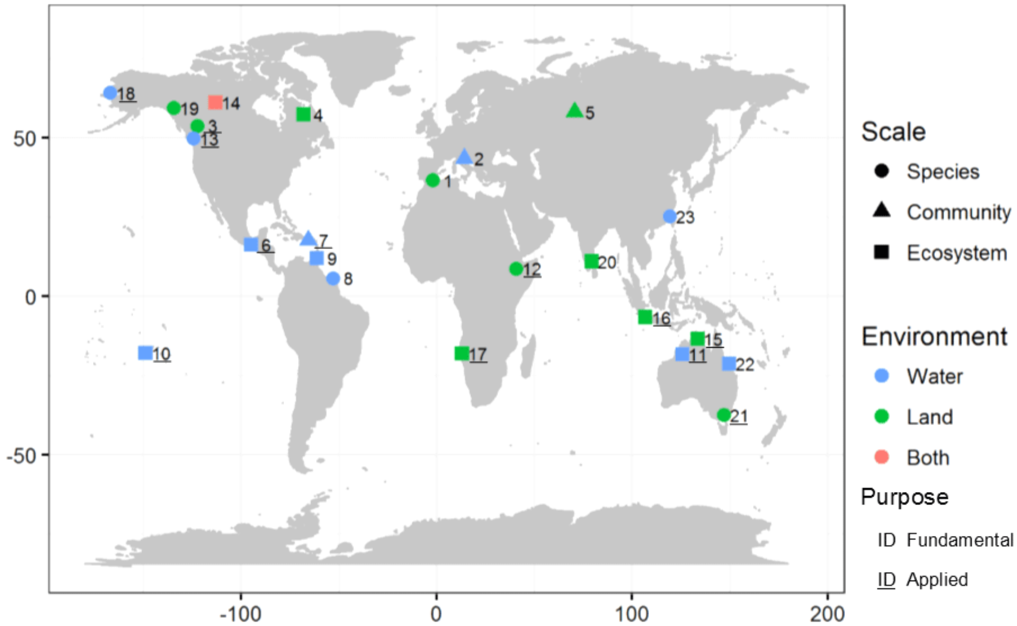
Fig. 2. Spatial distribution, organization scale, type of environment, and purpose of the 23 published studies (identification numbers refer to the studies listed in Appendix 1).



active players in both research and natural resource management. Modeling may thus promote community empowerment by providing a platform for communication, knowledge sharing, appropriation of scientific tools, and joint knowledge creation and learning (Voinov and Bousquet 2010).

Box 1: What are LEK and SEK?

LEK takes a variety of denominations and definitions according to academic cultures and research objects (Davis and Ruddle 2010). LEK, sometimes traditional (TEK) or indigenous (IEK), is here defined as a place-based empirical knowledge, held by a specific group of people, and related to living organisms and their relationship with the environment. LEK can take various forms such as factual knowledge of the environment, knowledge of how the environment is used (practices), or considered (values; Usher 2000).

Although the combination of LEK and SEK is increasingly encouraged, it is not free of critics. At one end of the spectrum, research involving LEK can be politically charged (Davis and Ruddle 2010) and seen as another instance of appropriation of marginalized cultures to the benefit of the dominant western one (Oguamanam 2008). At the other end, because LEK have their own epistemologies and meanings (Agrawal 1995), some might question their reliability as part of a systematic and rigorous research process (Gilchrist and Mallory 2007). Moreover, accessing and understanding LEK calls upon concepts and methods from both ecological and social sciences. Interdisciplinarity is thus an important and challenging component of research projects involving LEK, and researchers need to adapt modeling methodologies to live up to both ethical and scientific standards (Davis and Ruddle 2010).

We reviewed the scientific literature to summarize general issues regarding LEK inclusion in ecological modeling. We considered the following four issues as the most important: (1) consistency between the degree of LEK involvement and modeling objectives, (2) combination of concepts and methods from natural and social sciences, (3) reliability of the data collection process, and (4) model accuracy. We designed an analysis grid to evaluate ecological modeling exercises. We used this tool to assess how 23 published studies dealt with each of the four issues.

LEK is a heterogeneous bloc stemming from culturally specific epistemologies, assumed unknown to the researcher unless specifically investigated (Agrawal 1995, Sillitoe 1998). We refer to "scientific knowledge" as the one generated by methods and epistemologies accepted in ecology as a field of biological sciences (Begon 1996).

PUBLISHED STUDIES

We compiled published studies including both local knowledge and an ecological (or environmental) model. We searched Google Scholar and Scopus for different combinations of the following keywords: "local," "traditional," "indigenous," "ecological knowledge" (Box 1), and "model(l)ing." We then selected all scientific papers that presented an ecological model involving LEK. We extended the search to articles cited in synthesis papers. We ended up with 23 studies published between 2000 and 2017 in peer-reviewed journals. Models span all continents, cover a range of organizational (from species to ecosystems) and spatial (from local to nationwide) scales, environments (land, water, or both), and purposes (fundamental or applied research; Fig. 2). The analysis grid and references for all published studies are available in online material (Appendices 1 and 2).

ISSUE 1: CONSISTENCY BETWEEN THE DEGREE OF LEK INVOLVEMENT AND MODELING OBJECTIVES

There are many reasons for involving LEK in modeling, from wider and easier access to data (e.g., Anadón et al. 2010) to a will to foster social learning and development (e.g., Mendoza and Prabhu 2006, Rajaram and Das 2008). The level of LEK involvement is also quite variable, from basic empirical data collection to full involvement of local people and organizations as coresearchers. In this section, we address the problem of consistency between modeling objectives and degree of LEK involvement. We propose a framework to analyze the rationale behind LEK involvement in ecological modeling and review the methods used to do so, with a focus on participatory research.

Blackstock et al. (2007), inspired by the principles of deliberative democracy (see Dryzek 2002), summarized reasons to involve stakeholders in sustainability research into three functions. We adapted their framework to the specificities of LEK involvement into ecological modeling:

1. The substantive function relies on complementarity between LEK and SEK. LEK is especially useful when experimental data is incomplete, for example, when studying rare species, long time-series, or remote areas (Anadón et al. 2010, Ehrich et al. 2016, Bastari et al. 2017).
2. The normative function is about the legitimacy of scientific assessments for local populations (Ericksen and Woodley 2005). Ecological research is sometimes criticized for providing only partial knowledge with little external validity, i.e., becoming meaningless when taken out of its local context (Menzies and Butler 2006). Legitimacy of SEK is especially challenged when used to justify resource management policies with consequences for local populations (Booth and Skelton 2011).
3. The instrumental function refers to LEK as a social development tool empowering local communities and institutions for resource management (Fraser et al. 2006). It relies on colearning and coproduction of knowledge between researchers and local people and organizations (Mendoza and Prabhu 2006, Lane et al. 2011).

The degree of involvement of local experts and stakeholders in modeling should be in line with the objectives. To fulfill the substantive function, local understanding of an ecosystem can help build the conceptual framework and observations can be included as first-hand data. However, normative and instrumental functions require deeper involvement (Briggs 2013). Although the importance of opening science to community is generally acknowledged, mere sprinkling of LEK onto an otherwise classical experimental research design may lead to adverse outcomes such as knowledge instrumentalization or cultural appropriation (Oguamanam 2008).

Enforcing one or the other of the substantive, normative, and instrumental functions can be fostered by a participatory modeling process (Lynam et al. 2007, Voinov and Gaddis 2008) where local experts and organizations can contribute to the following:

- Define the objectives;
- Design the conceptual model;
- Collect or communicate data;
- Analyze, validate, and revise the results.

Most published studies (20) claimed substantive function for including LEK, with statements such as "TEK can potentially inform scientific approaches to management, [...] as a source of baseline data to fill information gaps that cannot otherwise be addressed" (Espinoza-Tenorio et al. 2013). Eight published studies sought to increase legitimacy, arguing LEK and SEK are valuable and need to be considered side by side: "local experts were frustrated when Western scientific studies conducted in the region neglected TEK and produced conclusions that were easily invalidated by local observations" (Olsen et al. 2015:11866). Eight published studies endeavored to foster local development. Mantyka-Pringle et al. (2017:126) claimed that "Co-production of TK [traditional knowledge] and SK [scientific knowledge] can also enhance capacity in rural or vulnerable communities observing resource declines, allow new ideas and tools to improve both local and scientific practices, and provide checks and balances to ensure new ideas are acceptable in terms of customary institutions and values."

In the 23 published studies, the most common pattern (18) was to involve LEK in data collection thus fulfilling the substantive function (Table 1). LEK was also involved to formulate hypotheses and to design the underlying conceptual model (15). A few studies involved LEK in setting the research objectives (5), and analyzing and validating research results (6). We observed contradictions in two published studies claiming normative functions but without consequent LEK involvement beyond data provision. One published study (Mantyka-Pringle et al. 2017) should be commended for having involved LEK at all steps of the modeling process.

Table 1. Number of published studies claiming substantive, normative, and instrumental functions of local ecological knowledge (LEK; as per Blackstock et al. 2007), and LEK involvement at four different steps of the modeling process. Studies can meet the criteria for multiple functions and steps, so the sums of lines and columns do not match the total number of studies.

	Modeling steps				
LEK functions	Definition of objectives	Conceptual model design	Data collection	Analysis, validation	Number of studies
Substantive	5	12	18	4	20
Normative	3	6	7	4	8
Instrumental	3	8	4	5	8
Number of studies	5	15	18	6	23

In the light of our analysis of published studies, we argue that there is a potential to involve LEK from the beginning to the end of a research process. We recommend that scientists and local people design and perform research together in order to reach the full potential of the LEK-SEK combination.

ISSUE 2: COMBINATION OF CONCEPTS AND METHODS FROM NATURAL AND SOCIAL SCIENCES

In ecology, LEK does not constitute a research object in itself but is rather used to extend the understanding of ecological phenomena. Thus, ecologists interested in integrating LEK and SEK have to build upon concepts developed within the social sciences (Davis and Ruddle 2010). For example, knowledge systems are studied in ethnology, cultural geography is interested in the relation to the land, whereas knowledge acquisition and expert judgement are concepts relevant to cognitive psychology. Consequently, most of the published studies were in interdisciplinary journals (8) such as *Ecology and Society* or *Human Ecology*, or in thematic journals (6) with no disciplinary specificity such as *Arctic* or *Frontiers in Marine Science*.

Bridging disciplines goes along with challenges. First, concepts often bear different meanings according to disciplines so that their integration requires communication and adaptation efforts (Miller et al. 2008). For example, the concept of "landscape" refers to a spatial scale in ecology and to a combination of physical features, perceptions, and mental constructions in cultural geography (Tress et al. 2001). Moreover, natural and social science epistemologies are different and refer to different standards to evaluate research quality and validity (Moon and Blackman 2014). Published studies entrenched in a single discipline had difficulty reaching the standards from another discipline. For example, McGregor et al. (2010) addressed traditional fire management in wetlands of Australia with an anthropological lens, but omitted to describe natural disturbance regimes and ecological processes occurring in the study area, which are basic information from an ecologist's perspective. Conversely, Luizza et al. (2016) studied an invasive plant in Ethiopian agrosystems using farmers' and villagers' knowledge. However, neither culture (ethnology), nor social organization (sociology) or relationship with the land (human geography) were discussed in an elaborated fashion.

Social sciences also play an important role in the assessment and validation of ecological models. The information provided by an ecological model should always be considered in the light of the model's assumptions, parameters, scope, limits, and uncertainties (Jørgensen and Bendoricchio 2001). Yet, ecological methods are rarely accurate for this kind of examination. For example, they are not suited to appraise limits and uncertainty of LEK that may take the form of myths, legends, or rituals (e.g., Colding and Folke 2001). Moreover, validation of LEK according to experimental ecology standards raises ethical questions, especially in intercultural and indigenous contexts (Brook and McLachlan 2005). Although indigenous people still struggle with the aftermath of a colonial history, attempts to validate a knowledge system through the lens of another will contribute to maintain power inequity (Asselin 2015). Alternatively, model assessment can be facilitated by methods of the social sciences suited to analyze the meaning and scope of LEK as part of a knowledge system. According to Davis and Ruddle (2010) and Usher (2000), such an assessment could allow for the following:

- Discern observations from inferences;
- Analyze how knowledge is created from observations;
- Determine whether information is widely shared within a community or held by a happy few;
- Describe knowledge transmission processes from one generation to the next;
- Describe how individual experiences and interactions with other cultures change a knowledge system.

Two published studies directly addressed the question of discipline integration. Liedloff et al. (2013) provide an interesting example of interdisciplinarity, where methods and espitemologies of anthropology, ecology, and hydro-geosciences were brought together in a single model (Miller et al. 2008). Authors built an integrative framework based on two independent studies of the Fitzroy River (Western Australia), respectively about hydrogeology and socioeconomy of the local indigenous population. The resulting model is consistent with local conceptions of the environment, e.g., indigenous seasonal calendar, and validated with both LEK and SEK.

Espinoza-Tenorio et al. (2013) address fisheries' sustainability in Mexico using a transdisciplinary design. Compared with interdisciplinarity, transdisciplinarity relies on a common epistemology developed ad hoc (Miller et al. 2008). Authors thus built their own conceptual framework by combining the theoretical bases and methods of impact assessment, landscape ecology, and TEK.

Although few published studies directly addressed discipline integration, efforts dedicated to interdisciplinarity or transdisciplinarity contribute to reach quality, validity, and reliability standards from both natural and social sciences.

ISSUE 3: RELIABILITY OF THE DATA COLLECTION PROCESS

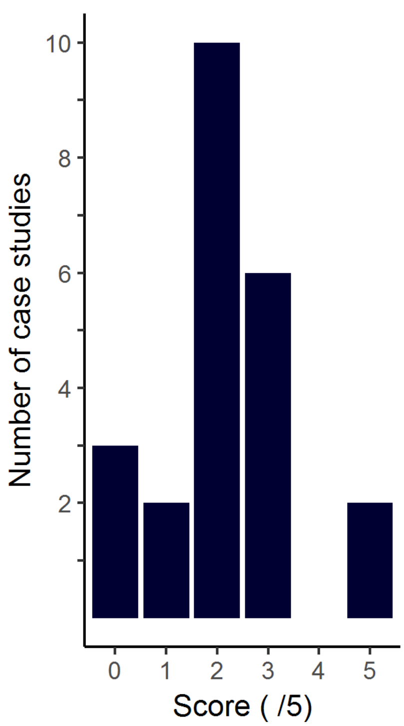
Elicitation is the process used to access expert knowledge and measure its uncertainty (O'Hagan et al. 2006). LEK holders can be considered as experts: their knowledge is based on empirical observations, is grounded in local context, and it can be used to make inferences and judgements (Usher 2000, O'Hagan et al. 2006). Importance of rigor in elicitation designs was underlined in research involving LEK (Davis and Wagner 2003) or more generally expert ecological knowledge (Martin et al. 2012). Expert knowledge elicitation is a research area in and of itself. It addresses issues relative to the selection of local experts, balance between representativeness and knowledgeability, dosage of sampling effort, bias control, and quantification of uncertainty (Ayyub 2001). It can be performed by semistructured interviews, workshops, questionnaires, or collaborative fieldwork (Huntingdon 2000).

A good LEK elicitation design for modeling purposes should provide details on at least five basic elements (adapted from Martin et al. 2012): (1) methods used to select participants; (2) number of participants; (3) methods used to pool information; (4) discussion on uncertainty; and (5) discussion on bias.

Most published studies selected respondents according to explicit criteria, e.g., occupation, age, or experience. However, only 11 clearly explained their selection procedure, such as random or snow-ball sampling. Sixteen published studies mentioned the number of respondents, 14 explained how they pooled data from many experts, five discussed uncertainties, and four discussed bias. We calculated an elicitation score from zero (when none of the five elements were presented) to five (when information was provided for all elements) for each of the 23 published studies (Fig. 3). Most published studies (15) scored below three, meaning critical information is generally lacking. Only two published studies obtained a perfect score (Bridger et al. 2016, Mantyka-Pringle et al. 2017).

We noted a nearly systematic lack of critical information in elicitation designs throughout the published studies. Elicitation designs should be systematic, rigorous, and reproducible, just as any other form of data/knowledge collection (Davis and Wagner 2003). We recommend peer-reviewers and editorial board members to be more critical of research designs before accepting manuscripts for publication.

Fig. 3. Number of published studies per elicitation design score (0–5). One point was attributed for each of the following when clearly mentioned: (1) systematic selection of participants, (2) number of participants, (3) methods used to pool various information sources, and acknowledgement of (4) uncertainty and (5) bias.



ISSUE 4: MODEL ACCURACY

Statistical and empirical models that are commonly used in ecology are designed to deal with data from experimental designs and are poorly adapted to deal with LEK and their specificities (Krueger et al. 2012). LEK may take a quantitative or qualitative form (Berkes 2012). It can be explicit (enunciated), implicit (could be enunciated but is not), or tacit (cannot be enunciated; Fazey et al. 2006). Scientists can only access LEK through their holders, involving inherent uncertainties and biases that need to be quantified, which might prove easier said than done. Modelers could turn to alternative model families better suited to welcome LEK as expert judgement rather than experimental data. Those so-called "expert models" rely on artificial intelligence to introduce judgement by emulating human reasoning with mathematical language (Krueger et al. 2012). They are increasingly used to combine data from experimental design and expert knowledge. Eleven published studies used such models with a platform specifically adapted to work with LEK, while 12 used classical ecological models (e.g., multivariate analyses, linear regressions, habitat suitability indices) or other model families.

Two families of expert models are recurrent in the published studies and bear a great potential for LEK-SEK integration: fuzzy rule-based models (FRBM; 4 published studies) and Bayesian networks (5 published studies; Fig. 4). They can deal with qualitative and quantitative data and they consider uncertainty intrinsically (Adriaenssens et al. 2004, Kuhnert et al. 2010). Moreover, both can be represented with a simple graphic structure, easy to understand and to modify, making them well suited for participatory modeling (MacKinson 2000, Aguilera et al. 2011).

FRBM address complex systems dealing with the interrelations between qualitative, uncertain, and imprecise variables (Yager and Filev 1994). They rely on the mathematical theory of fuzzy sets, an extension of the set theory (Zadeh 1965). An object, instead of being described by its belonging to one set or another, is described by its "degree of belonging" to these sets. For instance, MacKinson (2000), studying herring shoals through fishers' knowledge, described the shore size with "degrees of belonging" to the small, medium, and large sets (for example, small: 0%, medium: 20%, large: 80%). Links between variables are formulated as "IF/THEN" rules and variables are described by belonging functions (Yager and Filev 1994). LEK provide observational data to feed the model and to calibrate belonging functions. Local experts may also share their understanding of the links between parameters to formulate the rules (MacKinson 2000).

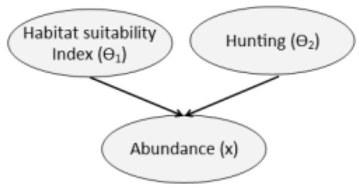
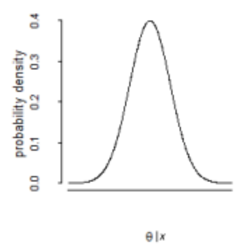
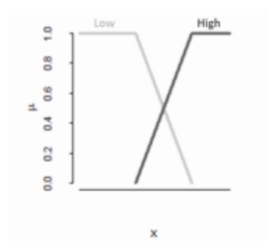
Bayesian networks combine probabilistic and graph theories (Aguilera et al. 2011). They are represented as multivariate, acyclic, and directional causality networks. Probabilistic statistics differ from frequentist statistics, of general use in ecology, by their probabilistic and inferential approach (Ellison 1996). In probabilistic statistics, parameters are not considered to have a fix value with a confidence interval. Instead, parameters are considered random and are described by a probability distribution. Bayes' theorem infers a posterior probability distribution for a parameter using prior knowledge and likelihood. For example, Girondot and Rizzo (2015) used LEK of turtle nesting phenology as prior probability distributions in combination with experimental data as likelihood distributions. As in FRBM, LEK can also contribute to build the conceptual model (e.g., Mantyka-Pringle et al. 2017).

The review of published studies indicates that model families adapted to include expert judgement are also well suited for LEK inclusion. However, efforts should be made to better consider the uncertainties and biases in both elicitation and modeling.

CONCLUSION

Modeling has great potential for LEK-SEK integration and its popularity will likely keep growing in the near future. Despite methodological issues, modeling offers a great opportunity to involve local populations at all steps of a research project, thus

Fig. 4. Fictive example of a moose (*Alces americanus*) population ecology study as seen through the lens of Bayesian networks and fuzzy rule-based models (FRBM).

Problem	To predict moose abundance (x) in a given territory, habitat quality (Θ_1) and hunting pressure (Θ_2) are the main parameters considered.	
Model family	**Bayesian networks**	**Fuzzy rule-based models**
Conceptual model	Directed acyclic graph 	Set of IF/THEN rules IF Habitat suitability is good AND Hunting pressure is low THEN Abundance is high IF Habitat suitability is good AND Hunting pressure is high THEN Abundance is low IF Habitat suitability is bad THEN Abundance is low
Mathematics	Bayes theorem $$P(\theta\|x) = \frac{P(x\|\theta)P(\theta)}{P(x)}$$ $P(\Theta\|x)$: *Posterior probability* (of obtaining Θ given the data) $P(x\|\Theta)$: *Likelihood* (probability of x given θ) $P(\theta)$: *Prior probability* (of θ) $P(x)$: *Prior probability* (of x)	Fuzzy sets Abundance : {high, low} Habitat suitability : {good, bad} Hunting pressure : {high, low} (X,μ): Fuzzy set of Abundance (x) μ:$X \rightarrow [0,1]$ Membership function $\mu(X)$: Degree of membership of x in (X,μ)
Parameter estimation	Conditional probabilities 	Membership functions 
LEK contribution	- Build conceptual network - Provide prior distributions P(Θ) Provide likelihood functions (P(x|Θ))	- Set IF/THEN rules - Build and calibrate the fuzzy sets

fostering knowledge sharing and empowerment. From the analysis of 23 published studies, we conclude that methodological guidelines are not completely settled yet, especially regarding participatory methods and elicitation designs. The most pressing challenge relies in the integration of methods and concepts from social and natural sciences.

We make four recommendations to favor best practices of LEK-SEK integration in ecological modeling:

1. Participatory research is a helpful tool to reach the full potential of the LEK-SEK combination. Researchers and local managers should work together to design research projects able to share, enhance, and legitimate knowledge of ecosystems.
2. Research teams aiming at LEK-SEK integration in ecological modeling should include scientists from different disciplines to make sure the process meets the quality, validity, and reliability standards of both natural and social sciences.
3. Efforts should be made to design rigorous, appropriate, and reproducible methodologies for LEK elicitation.
4. Great potential lies in expert models designed to bring together expert knowledge and experimental data. Bayesian networks and FRBM are well suited for this task and widely accepted in ecology (Krueger et al. 2012).

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/9949

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		General information			Issue 1 (LEK functions)				Issue 1 (Modeling steps)				Issue 2 (Interdisciplinaity)	Issue 3 (Elicitation)					Issue 4 (Models)
ID	**Reference**	**Location**	**Object**	**Purpose**	**Substantive**	**Normative**	**Instrumental**	**Quotes**	**Objectives**	**Conceptual model**	**Data provision**	**Analysis & validation**	**Journal purpose**	**Systematic expert selection**	**n**	**Pooling**	**Uncertainty**	**Bias**	**Type of model**
1	Anadón JD, Giménez A, and Ballestar R. 2010. Linking local ecological knowledge and habitat modelling to predict absolute species abundance on large scales. *Biodivers Conserv* **19**: 1443–54.	Almeria, Spain	terrestrial species distribution	fundamental	x			"The results obtained show that LEK provides high-quality and low-cost information about the distribution and relative abundance of T. graeca."			x		Disciplinary	x	172	x			GLM + multivariate
2	Bastari A, Beccacece J, Ferretti F, *et al.* 2017. Local Ecological Knowledge Indicates Temporal Trends of Benthic Invertebrates Species of the Adriatic Sea. *Front Mar Sci* **4**: 157.	Adriatic Sea, Itlay	aquatic communities	fundamental	x			"Over the last decades, "Local Ecological Knowledge" (LEK) has emerged as an alternative approach to collecting information on species presence or abundances when historical data are lacking"			x		Thematic		44	x			Logistic, model selection
3	Bridger MC, Johnson CJ, and Gillingham MP. 2016. Assessing cumulative impacts of forest development on the distribution of furbearers using expert- - based habitat modeling. *Ecol Appl* **26**: 499–514.	British Columbia, Canada	terrestrial species distribution	applied	x			"When empirical data are unavailable, expert knowledge can be used to parameterize such models. "	x		x		Disciplinary	x	21	x	x	x	Analytical Hierarchy Process (AHP)
4	Currier A, Brunet ND, Gérin-Lajoie J, *et al.* 2015. The Study of Inuit Knowledge of Climate Change in Nunavik, Quebec: A Mixed Methods Approach. *Hum Ecol* **43**: 379–94.	Nunavik, Canada	terrestrial vegetal and animal communities	fundamental	x	x		"TEK has been an important resource in understanding how systems have changed over time by providing otherwise inaccessible early records of variation over very long timeframes" "Still, this recognition of the value of TEK does not often translate into its use in science and decision making where scientific knowledge, measurements and projections are privileged"			x		Interdisciplinary	x	46	x			Multivariate
5	Ehrich D, Strømeng MA, and Killengreen ST. 2016. Interference in the tundra predator guild studied using local ecological knowledge. *Oecologia* **180**: 1195–203.	Low arctic and subarctic, Norway and Russia	terrestrial animal communities	fundamental	x			"The arctic tundra and adjacent forest tundra is characterized by vast remote territories and very low densities of predators, making it difficult to obtain reliable data about species abundances (Reid et al. 2013). In such situations, the knowledge of local people living and working in the focal ecosystem (Local Ecological Knowledge—LEK) may yield relevant biological information"			x		Disciplinary		113	x			Multivariate
6	Espinoza-Tenorio A, Wolff M, Espejel I, and Montaño-Moctezuma G. 2013. Using traditional ecological knowledge to improve holistic fisheries management: Transdisciplinary modeling of a lagoon ecosystem of Southern Mexico. *Ecol Soc* **18**.	Southern Mexico	aquatic systems	applied	x		x	"Such TEK can potentially inform scientific approaches to management, either as a source of baseline data to fill information gaps that cannot otherwise be addressed, or to provide alternative management approaches from which scientists and managers might learn " "With most capital investment coming from foreign loans, these countries' massive fisheries have largely followed the management policies of developed nations such as command control measures and single-species management "	x	x	x		Interdisciplinary	x	33+39	x			Loop Analysis
7	García-Quijano CG. 2007. Fishers' knowledge of marine species assemblages: Bridging between scientific and LEK in southeastern Puerto Rico. *Am Anthropol* **109**: 529–36.	Puerto Rico	aquatic animal communities	applied	x	x		"LEK can be the source of insights and information about ecosystem function and change that otherwise are unavailable to Western science, especially to resource management and governance agencies." "Much inquiry has focused on studying local ecological knowledge (LEK) held by small-scale natural resource users (e.g., fishers, farmers, hunters-gatherers), considering how to include this knowledge in natural resource management"		x	x		Disciplinary	x	18+37	x			Multivariate
8	Girondot M and Rizzo A. 2015. Bayesian Framework to Integrate Traditional Ecological Knowledge into Ecological Modeling: A Case Study. *J Ethnobiol* **35**: 337–53.	French Guyana	aquatic species	fundamental	x			"The main advantage of TEK is that it is based on a longer and much richer experience with the ecological system"			x		Interdisciplinary		3	x			Bayesian Network
9	Grant S and Berkes F. 2007. Fisher knowledge as expert system: A case from the longline fishery of Grenada, the Eastern Caribbean. *Fish Res* **84**: 162–70.	Gouyave, Granada	aquatic ecosystems	fundamental	x			"Fisher knowledge (also referred to as local or traditional ecological knowledge) can complement scientific knowledge (Johannes, 1998; Johannes et al., 2000), improve decision-making (Berkes and Folke, 1998; Baticados, 2004),and provide practical information"		x	x		Thematic		40				Fuzzy
10	Leenhardt P, Stelzenmüller V, Pascal N, *et al.* 2017. Exploring social-ecological dynamics of a coral reef resource system using participatory modeling and empirical data. *Mar Policy* **78**: 90–7.	Moorea Island, French Polynesia	aquatic system	applied	x		x	" In this study the term expert refers to anyone with relevant and extensive or in-depth experience in relation to a topic of interest"		x		x	Thematic	x	25				Regressions, correlations
11	Liedloff AC, Woodward EL, Harrington GA, and Jackson S. 2013. Integrating indigenous ecological and scientific hydro-geological knowledge using a Bayesian Network in the context of water resource development. *J Hydrol* **499**: 177–87.	North-western Australia	aquatic system	applied	x	x		"Indigenous knowledge, which can be 'geographically and temporally more extensive' (Fraser et al., 2006) than research-based (or scientific) knowledge, may be of value to researchers and water managers for its empirical strength." "Furthermore, indigenous people have distinct and diverse interests in the outcomes of water allocation decisions and therefore need to be involved in deliberating over the consequent costs and benefits of water use scenarios "	x	x	x	x	Disciplinary	x	9			x	Bayesian Network
12	Luizza MW, Wakie T, Evangelista PH, and Jarnevich CS. 2016. Integrating local pastoral knowledge, participatory mapping, and species distribution modeling for risk assessment of invasive rubber vine (Cryptostegia grandiflora) in Ethiopia's Afar region. *Ecol Soc* **21**.	Afar region, Ethiopia	plant terrestrial species	applied	x	x	x	"Ecological knowledge of local communities can provide an important tool for early detection and understanding of invasion impacts" "Despite an array of research noting the importance of local ecological knowledge for resource management and conservation planning " "[...] and the growing call for broader inclusion of stakeholder perceptions in invasion research "	x	x	x		Interdisciplinary		46			x	Habitat modeling
13	Lynam T, Drewry J, Higham W, and Mitchell C. 2010. Adaptive modelling for adaptive water quality management in the Great Barrier Reef region, Australia. *Environ Model Softw* **25**: 1291–301.	Great coral reef region, Australia	aquatic ecology	applied			x	"Not only is adaptive management advocated by government policy but it is also advocated by managers and researchers in the GBR (Eberhard et al., 2008; Hughes et al., 2007) with some identifying adaptive management as ''to effective conservation, use and management of Australia's coastal catchments and waterways'' (Bennett et al., 2005). Conceptually at least, learning is the heart of adaptive management"		x		x	Interdisciplinary		NA		x		Bayesian Network
14	Mackinson S. 2001. Integrating local and scientific knowledge: An example in fisheries science. *Environ Manage* **27**: 533–45. MacKinson S. 2000. An adaptive fuzzy expert system for predicting structure, dynamics and distribution of herring shoals. Ecol Modell 126: 155–78.	British Columbia, Canada	aquatic species behaviour	fundamental	x			"Fortunately, since fishers, fishery managers and alike, operate within the same mesoscale realm as the fish (individual shoals being their target), some of their knowledge is appropriate to combine with scientific information"		x	x		Disciplinary (1), interdisciplinary (1)		24	x	x		Fuzzy
15	Mantyka-Pringle CS, Jardine TD, Bradford L, *et al.* 2017. Bridging science and traditional knowledge to assess cumulative impacts of stressors on ecosystem health. *Environ Int* **102**: 125–37.	North-West Territories, Canada	ecosytem	applied	x	x	x	"This paper empirically contributes to the debates by operationalizing the integration and complementarity of TK and SK for environmental and natural resources decision-making" "There have been persistent calls for greater inclusion of local and indigenous or traditional knowledge (TK) alongside conventional scientific knowledge (SK) in making decisions about natural resources" "Co-production of TK and SK can also enhance capacity in rural or vulnerable communities observing resource declines, allownewideas and	x	x	x	x	Interdisciplinary		11 and 16	x	x	x	Bayesian Network
16	McGregor S, Lawson V, Christophersen P, *et al.* 2011. Indigenous Wetland Burning: Conserving Natural and Cultural Resources in Australia's World Heritage-listed Kakadu National Park. *Hum Ecol* **38**: 721–9.	Kakadu National Park, Australia	terrestrial ecology	applied	x	x	x	"Driven by concerns about the failure of western science and management to address ecosystem degradation and species loss, people are looking to the deep ecological understandings and management practices that have guided indigenous use of natural resources for millennia for alternative ways of sustainably managing the earth's .natural resources" "This new recognition of traditional knowledge, coupled with greater control by indigenous peoples over their land and sea estates, holds great		x	x	x	Interdisciplinary		NA				Bayesian Network
17	Mendoza GA and Prabhu R. 2006. Participatory modeling and analysis for sustainable forest management: Overview of soft system dynamics models and applications. *For Policy Econ* **9**: 179–96.	Indonesia	socio ecosystem	applied		x	x	"Resource management often includes many components and stakeholders with their own demands in terms of resources, uses, goods, and services." "the paradigm of participatory or collaborative management has been widely accepted as a more appropriate and effective paradigm for natural re-source management particularly in the developing nations. "		x		x	Disciplinary	x	9999	x			Cognitive mapping (fuzzy)
18	Müller, Birgit, Christian Wissel, Anja Linstädter, Karin Frank MB. 2007. Learning from local knowledge: modeling the pastoral- nomadic range management of the himba, namibia ¨. *Ecol Appl* **17**: 1857–75.	Himba, Namibia	systèmes agricoles	applied	x			"The transfer of local knowledge to global scientific knowledge may help to find basic principles. These principles could be, under certain conditions, applicable to other range management systems with different ecological and economic settings."		x			Disciplinary		NA				Multi-agent
19	Olsen PM, Kolden CA, and Gadamus L. 2015. Developing theoretical marine habitat suitability models from remotely-sensed data and traditional ecological knowledge. *Remote Sens* **7**: 11863–86.	Bering Strait region, USA, Russia, Canada	aquatic species distribution	fundamental	x	x		"An alternative source of information on bearded seals during summer and fall seasons is indigenous hunters and community elders, who have detailed multi-generational knowledge and observations of seals and their hunting areas" "Additionally, local experts were frustrated when Western scientific studies conducted in the region neglected TEK and produced conclusions that were easily invalidated by local observations (Gadamus, personal observation)"			x		Thematic		NA				Classification Tree Analysis
20	Polfus JL, Heinemeyer K, and Hebblewhite M. 2014. Comparing traditional ecological knowledge and western science woodland caribou habitat models. *J Wildl Manage* **78**: 112–21.	British Columbia, Canada	terrestrial species habitat	fundamental	x			"Recent studies demonstrate that whenTEK is brought into play early in a wildlife management process, the combination with scientific data can lead to more efficient and effective wildlife management decisions "			x		Thematic	x	8	x			Rule-Based Habitat Suitability Index
21	Rajaram T and Das A. 2010. Modeling of interactions among sustainability components of an agro-ecosystem using local knowledge through cognitive mapping and fuzzy inference system. *Expert Syst Appl* **37**: 1734–44.	South of India	système agricole	applied			x	"Participatory approaches have been acknowledged as an effective way to take advantage of the rich traditional knowledge available with the local community and to bring a sense of ownership to policies and programs. "		x			Thematic	x	NA		x		Fuzzy
22	Yamada K, Elith J, McCarthy M, and Zerger A. 2003. Eliciting and integrating expert knowledge for wildlife habitat modelling. *Ecol Modell* **165**: 251–64.	Victoria, Australia	population espece terrestre	fundamental	x			"Expert knowledge is an important resource that may improve the reliability of modelling (Džeroski et al., 1997; Venterink and Wassen, 1997; Hackett and Vamnclay, 1998; Horst et al., 1998; Moltgen et al., 1999). It is particularly valuable where no systematic field investigations have been conducted."		x	x		Disciplinary		9	x			Multivariate + Habitat Suitability Index
23	Zhang X and Vincent ACJ. 2017. Integrating multiple datasets with species distribution models to inform conservation of the poorly-recorded Chinese seahorses. *Biol Conserv* **211**: 161–71.	China (shore)	aquatic species	fundamental	x			"Compared with traditional surveys (e.g. transect sampling), interview-based LEK research can generate cost-effective but often coarse-resolution (e.g. 10 × 10 km2) datasets"		x	x		Disciplinary	x	463	x			Habitat suitability (Maxent, presence only)

		Criteria	Description
General Information		Location	Region of the study area
		Object	Type of environement (terrestrial, aquatic or both) and research object
		Purpose	Either fundamental (expand general body of knowledge) or applied (e.g. for management or development purpose)
Issue 1	function	Substantive	Yes/No (see the main text for details)
		Normative	Yes/No (see the main text for details)
		Instrumental	Yes/No (see the main text for details)
		Quotes	Quotes to justify LEK substantive, normative and instrumental functions
	Modeling steps	Objectives	Yes/No (Were LEK involved to set research objectives?)
		Conceptual model	Yes/No (Were LEK involved to design the conceptual model or research hypothesis?)
		Data provision	Yes/No (Were LEK used to provide data / observations?)
		Analysis & validation	Yes/No (Were LEK involved in results analysis and model validation?)
Issue 2	Journal purpose		Either disciplinary, interdisciplinary or thematic according to online journal purpose description.
Issue 3	Systematic expert selection		Yes/No (Is the way experts were sected is explained and systematic?)
	n		Number of participants
	Pooling		Yes/No (Is the way expert knowledge were pooled together explained?)
	Uncertainty		Yes/No (Is there a discussion about uncertainty relative to experts/participants input?)
	Bias		Yes/No (Is there a discussion about bias relative to experts/participants input?)
Issue 4	Type of model		Type/family of model