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Research

Collaborative Engagement of Local and Traditional Knowledge and Science in Marine Environments: A Review

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ABSTRACT. Local and traditional ecological knowledge (LTK) is increasingly recognized as an important component of scientific research, conservation, and resource management. Especially where there are gaps in the scientific literature, LTK can be a critical source of basic environmental data; this situation is particularly apparent in the case of marine ecosystems, about which comparatively less is known than terrestrial ones. We surveyed the global literature relating to the LTK of marine environments and analyzed what knowledge has been collected and with what aims and results. A large proportion of LTK which has been documented by researchers consists of species-specific information that is important for traditional resource use. However, knowledge relating to marine ecology, environmental change, and contemporary resource management practices is increasingly emphasized in the literature. Today, marine LTK is being used to provide historical and contemporary baseline information, suggest stewardship techniques, improve conservation planning and practice, and to resolve management disputes. Still, comparatively few studies are geared toward the practicalities of developing a truly collaborative, adaptive, and resilient management infrastructure that is embracive of modern science and LTK and practices in marine environments. Based on the literature, we thus suggest how such an infrastructure might be advanced through collaborative projects and "bridging" institutions that highlight the importance of trust-building and the involvement of communities in all stages of research, and the importance of shared interest in project objectives, settings (seascapes), and outcomes.

Key Words: *adaptive comanagement; collaborative research; collaborative resource management; ecological monitoring; environmental change; historical ecology; local and traditional knowledge (LTK); marine conservation; marine ecology; marine ecosystems*

INTRODUCTION

Over the past several decades, as concerns about declines in local habitats, species, and livelihoods have increased, the potential contributions of local and traditional knowledge (LTK) to ecosystem research and management have been increasingly recognized. To date, LTK studies have been diverse and often interdisciplinary. However, there are few examples of works that bring together the literature across these fields in the marine context (see Johannes and Neis 2007 for one broad review). Given the increasing concern about marine ecosystems in relation to climate change, overfishing, pollution, and other anthropogenic impacts, coupled with humanity’s comparative ignorance of the sea in relation to terrestrial environments, interest in marine LTK can be expected to increase. Furthermore, conceptualizations of marine ecosystems inherent in LTK may have increasing relevance to critical adaptation and conservation tasks, such as identifying historical baselines and environmental change, establishing restoration and sustainability targets for species, increasing the resilience of marine social-ecological systems, and improving coastal zone and marine spatial planning and fisheries management.

As a contribution to this effort, we review both the aims and substantive content of work to date on marine LTK, in order to highlight key themes and critical gaps, and to address the role of marine LTK in marine social-ecological systems. We conclude that while empirical studies of LTK are numerous, few engage local knowledge systems and indigenous epistemologies enough to achieve a respectful synthesis or integration (Agrawal 1995, Hamilton and Walter 1999, Nadasdy 1999, Cruikshank 2001, Agrawal 2002, Simpson 2004, Cruikshank 2005, Nadasdy 2005, Wilson et al. 2006, Berkes 2009b). Genuine collaborative projects are rare and often insufficient in scope and depth to address critical, multiscale conservation, adaptation, and management issues facing coastal seascapes today. We explore how this situation might be remedied through collaborative research and management projects that enhance genuine coproduction of knowledge and collaborative implementation of that knowledge in policy. Finally we suggest how diverse, time-tested, traditional knowledge; stewardship principles; and technologies embedded in LTK systems may be applicable to the human adaptation and resilience needs of a complex, changing environment (Berkes et al. 1995). Before turning to the review of the aims and substantive content of LTK studies, we first briefly set out key definitions and how marine LTK may be best understood.

Marine LTK as a body of knowledge

To understand its cultural context and interrelationships, LTK is best conceptualized as a body or system of knowledge rather than a mere assemblage of facts. Foremost, this involves understanding how LTK, including related skills, is

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communicated and transmitted *in situ* and *in vivo* as part of the exigencies of maritime life (Aporta and Higgs 2005, Berkes and Turner 2006, Crona and Bodin 2006, Foale 2006b, Murray et al. 2006, Akyeampong 2007, Palmer and Wadley 2007, Poepoe et al. 2007, Reyes-Garcia et al. 2007, Alessa et al. 2008, Bonny and Berkes 2008, Pearce et al. 2011). Secondly, it involves examining the structure and distribution of knowledge within communities (Felt 1994, Ruddle 1994, Olsson and Folke 2001, Crona 2006, Knudsen 2008) and how it corresponds to broader differentiations and power relations (Crona and Bodin 2010). For example, Chapman (1987) focuses particularly on the different fishing practices and ecological knowledge held by men and women in Oceania, which are distinct but complementary. At a broader scale, the question of how ecological knowledge systems interact at different decision-making scales has also been examined (Evans 2010), as have the impacts of the broader social and political context on the ability of marine tenure systems to adapt and support well-being (Coulthard 2011). Local tenure systems—such as those in the Fiji Local Marine Management Areas network, which are based on traditional i qoliqoli (fishing territories) (Fiji Locally Managed Marine Areas Network 2011)—have also been successfully aggregated, in order to appropriately scale LTK and participation to marine ecosystem governance needs.

Valdés-Pizzini and García-Quijano (2009:163) collected LTK, at the level of the individual fisher, on habitats, species, and the relationships between these two variables, while also exploring fishers' mental schemata of habitats and the habitat–species coupling using the specific example of mutton snapper as a prototype. The relationship between fishers' ecological knowledge and their fishing success has been probed, finding that human factors such as knowledge and skill may play as much of a role in fishing success as material or technological factors (Bjarnason and Thorlindsson 1993), and that LTK may correlate positively with success, where success is understood as a fisher's ability to manage unpredictability in a complex, changing environment (García-Quijano 2009).

A second, growing body of literature discusses the role of LTK in national and international policy (Agrawal 1995, Mauro and Hardison 2000, Berkes et al. 2001b, Agrawal 2002, Memon et al. 2003, Ellis 2005). For example, Satria (2007) analyses why traditional fishing practices ceased and then were re-instated in Indonesia. Power and Mercer (2003) describe the role of fishers' knowledge in the implementation of the *Oceans Act* in Canada, while Shepert (2008) describes the relationship between LTK and the legal framework for finfish aquaculture in British Columbia. More broadly, Zurba (2009) examines how local knowledge may be excluded from governance systems due to existing policies, drawing on data from Great Barrier Reef Marine Park. Finally, Jones et al. (2010) note the important role of LTK in marine spatial planning, which from the Haida First Nation's perspective, is foundational to successful comanagement with Canada's Department of Fisheries and Oceans.

A third body of literature critically reflects on methods (Neis et al. 1999, Neis and Felt 2000, Berkes et al. 2001a, Vayda et al. 2006, Watson and Huntington 2008) and ethics in LTK research (Wenzel 1999, Maurstad 2002, Silver and Campbell 2005). These studies caution against simple, extractive approaches and show how deeper-level ethnographic, participatory, and iterative methods can lead to more ethical, respectful, and constructive engagements with LTK bearers and indigenous communities. The benefits of a deep ethnographic approach, often involving years of research, are evident in a handful of classic marine LTK monographs (e.g., Malinowski 1922, Nelson 1969, Johannes 1981).

Fourth, some work has sought to compare LTK and data gathered by Western scientific methods. For example, Silvano and Valbo-Jorgensen (2008) compare Brazilian fishermen's knowledge with published studies, finding cases of both agreement and disagreement, as do Batista and Lima (2010) in a similar examination of knowledge of jaraquis. Silvano and Valbo-Jorgensen argue that divergent results should prompt new studies rather than lead to the assumption that one knowledge system has the right answer. Daw et al. (2011) compares fishers' reports of catch rates with official landings data and underwater visual census (UVC) in the Seychelles, finding that each data source gave different perceptions of trends in the biomass of fish and catches over the study period. Other such studies have compared seasonal abundance patterns (Manajarréz-Martínez et al. 2010) and seabird chick emergence and size (Moller at al. 2009a). Aporta and Macdonald (2011) contrast scientific and Inuit approaches to sea ice, focusing on the difficulty of documenting the complex interplay of Inuit knowledge and practices outside the context of sea ice travel.

In other cases, rather than comparing knowledge from both LTK and science, work on climate change in the Arctic in particular has sought to improve our understanding of climate change by examining both scientific and Inuit perspectives (for example, Laidler 2006). Finally, a few studies have probed the relationship between scientific and indigenous epistemologies in the context of collaborative management projects (Fienup-Riordan 1999, Zavaleta 1999, Norton 2002, Gearheard et al. 2006, Leduc 2007, Murray et al. 2008). Dale and Armitage (2011) posit a set of five interrelated dimensions —knowledge gathering, sharing, integration, interpretation, and application—requisite for successful knowledge coproduction and adaptive capacity building in Arctic marine mammal comanagement (see also Armitage 2005, Armitage et al. 2007). On a similar theme, Pulsifer et al. (2011) discuss how a sea ice data management system could be structured so as to create a process that includes data based on indigenous knowledge systems linked to data collected in the Western scientific tradition.

This summary of work examining marine LTK as a knowledge system illustrates how the literature focuses not only on knowledge and on the practices themselves, but may also consider processes by which LTK is transmitted within a community or into broader society, and in light of changes, such as technological innovation, that communities face. One potential gap in this literature is an exploration of what conditions are necessary for the continued creation and maintenance of LTK. If LTK is a living, dynamic body of knowledge then, like science, it requires application and refinement in practice in order to persist. Dale and Armitage (2011:446) emphasize that "application is not an end-point in a knowledge co-production process, but rather involves the translation of evolving knowledge into specific management decisions and the development, modification and evaluation of the plans and programs it shapes." Evolving knowledge is also a theme for Aporta and Higgs (2005:738), who analyze how GPS technology affects traditional way-finding, and note that 'despite the well-known Inuit ability to adapt to new technologies and new circumstances, GPS technology has the potential to deeply modify and cause disengagement from a well-established approach to the geographic surroundings and to the environment in general." Other work, such as that of Reyes-Garcia et al. (2007), which considers how market integration of Amazonian societies affects botanical LTK, may be useful in revealing what critical constraints shape the contemporary development and maintenance of marine LTK. These studies suggest that while LTK does not simply erode or ossify in the wake of social, technical, and environmental change, its content, resilience, and adaptive development are not guaranteed and depend on a range of interrelated factors.

MARINE LTK RESEARCH TO DATE: AIMS, SUBJECT MATTER, AND POTENTIAL

This part reviews the aims and focus of marine LTK research to date, highlighting the roles that LTK plays, and could potentially play, in the governance of marine social-ecological systems. We proceed first by defining key terms and the review's scope.

Definitions and scope of review

A broad range of concepts, topics, and terms can be related to LTK, including indigenous knowledge (IK), indigenous skill, folk knowledge, informal knowledge, ethnobiology, ethnoscience, and ethnoichthyology. As noted above, LTK is best understood as integrated and situated knowledge rather than as merely an assemblage of facts; an oft-cited definition of traditional ecological knowledge (TEK) is that it 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 another and with their environment" (Berkes et al. 2000:1252). LTK and TEK are used synonymously here, though LTK is perhaps a broader term because it may include knowledge that is, strictly speaking, not ecological (Berkes 2008). Marine LTK may thus embrace subjects ranging from indigenous knowledge of salmon spawning grounds to the multiple Inuit terms for sea ice, commercial fishermen's knowledge of bait-to-catch ratios, and navigators' knowledge of currents and tides. The term "marine" is similarly broad, and for our purposes includes LTK relating to the zone between the deep sea and coastal habitats.

Our study was carried out by surveying the scholarly literature via electronic databases and library catalogue searches for relevant sources. The review effort attempted to be as comprehensive as possible, but some subject areas were excluded. Inland waters are generally excluded except where they relate to animals that travel inland from the ocean to spawn or to seabirds that inhabit delta regions. Wetlands are also excluded. Moreover, while there is also a burgeoning field of literature dedicated to indigenous knowledge and climate change, this review is limited to studies that are directly concerned with the components of the marine environment, such as sea ice. In addition, the review excludes most work related to prehistory, as well as the medicinal uses of marine resources (cf. Demunshi and Chugh 2010). The review includes studies that describe LTK and those that analyze specific practices, as long as the latter draw links between the practices and ecological knowledge.

The study reviewed over 240 scholarly articles and books. Geographically, of the articles and books that focus on a particular location, 42% of the research is centered in North America (with studies in Arctic Canada and Alaska accounting for 54% of those North American articles), 22% in Oceania, and 12% in Asia, with each of Africa, Europe, South America, and Central America and the Caribbean) accounting for 2 to 8% of the articles. The predominance of articles from North America reflects a similar finding by Brook and McLachlan (2008) in a broad review of the use of LEK in scholarly research. This dominance can be attributed to the rapid development of these studies among northern indigenous peoples in conjunction with management, conservation, and development initiatives in North America (cf. Cruikshank 2001, Hunn et al. 2003, Turner and Berkes 2006).

Aims of marine LTK research

Given the calls for greater collaboration between scientists and local knowledge holders, we first examine the aims of academic research relating to marine LTK. Broadly put, marine LTK studies can be divided into "documentation" type studies that add to existing knowledge for various uses, and more instrumental studies that explicitly seek to improve marine resource management.

Documentation and research design

Documentation studies are those that describe and interpret LTK within a cultural or cross-cultural context (see, Table 1). For example, within anthropology there is a long history of

Table 1. Species-specific studies.

LTK collected	Species	Source
Current abundance and spatial distribution of species	Beluga whales	Carter and Nielsen 2011
	Bumphead parrotfish	Aswani and Hamilton 2004, Dulvy and Polunin 2004
	Bowhead whales	Noongwook et al. 2007
	Goliath grouper	Cavaleri Gerhardinger et al. 2009b
	Ivory gull	Mallory et al. 2003
	Oysters	Hill et al. 2010
	Polar bears	Dowsley and Wenzel 2008
	Spatial variation in emergence of sooty shearwater chick	Moller et al. 2009a
Migratory or seasonal movements	Beluga whale	Huntingdon et al. 1999, Mymrin et al. 1999
	Bowhead whale	Noongwook et al. 2007
	Brazilian coastal fish	Silvano et al. 2006
	Cod	Murray et al. 2008
	Jaraquis	Batista and Lima 2010
	Pomatomus saltatrix	Silvano and Begossi 2005
Sightings of species	Dugongs	Rajamani and Marsh 2010
	Sharks	Rasalato et al. 2010
Stranding incidents	Dugongs	Rajamani and Marsh 2010
Health of species	Condition of polar bears	Dowsley and Wenzel 2008
Size of species	Patterns in size of *Puffinus griseus* chicks	Moller et al. 2009a
Life history	Goliath grouper	Cavaleri Gerhardinger et al. 2006
	Jaraquis (size of sexual maturity, growth, mortality)	Batista and Lima 2010
Stock structure	Cod	Gosse et al. 2003, Murray et al. 2008
Key habitats	Gadoid fishes	Bergmann et al. 2004
Spawning and nursery areas	Cod	Ames 2007
	Goliath grouper	Aguilar-Perera et al. 2009
	Multiple fish species	Knutsen et al. 2010
Past abundance	Beluga whales	Carter and Nielsen 2011
	Chinese bahaba	Sadovy and Cheung 2003
	Cod stocks	Rosenberg et al. 2005
	Frigate tuna	Venkatachalam et al. 2010
	Goliath grouper	Aguilar-Perera et al. 2009
	Herring	Jones 2007, Thornton et al. 2010
	Lobster (*Jasus frontalis*)	Eddy et al. 2010
	Multiple finfish species (local extinction)	Lavides et al. 2009
Behavior	*Carangidae* fish aggregation	Hamilton and Walter 1999
	Polar bears	Keith et al. 2005, Lemelin et al. 2010
	Dugongs	Johannes and MacFarlane 1991
Reproduction-related behavior	Breeding of geese in relation to storm surges	Fienup-Riordan 1999
	Calving in beluga whales	Huntingdon et al. 1999, Mymrin et al. 1999
	Nesting-site fidelity in sea turtles	Johannes and Neis 2007
	Parental care in jaraquis	Batista and Lima 2010
	Reproduction in various coastal fish	Silvano et al. 2006
	Reproduction in *Pomatomus saltatrix*	Silvano and Begossi 2005
	Spawning of longfin emperor	Hamilton 2005
	Spawning behavior of various reef fishes	Boomhower et al. 2007
	Lunar cycles and fish reproduction	Johannes et al. 1981
Feeding behavior	Beluga whales	Huntingdon et al. 1999, Mymrin et al. 1999
	Jaraquis	Batista and Lima 2010
	Polar bears	Lemelin et al. 2010
	Pomatomus saltatrix	Silvano and Begossi 2005
Effect of physical environment	Effects of lunar periodicity on fish	Aswani and Hamilton 2004
	Reactions of eider to shifting ice pack	Gilchrist and Robertson 2000
	Effects of climate variability on Arctic char	Knopp 2010
Human-animal interactions and effects	Polar bears	Keith et al. 2005, Lemelin et al. 2010
	Reactions of seals to fishing nets	Moore 2003
	Reactions of tuna to fishing devices	Moreno et al. 2007b

documenting indigenous environmental knowledge and its uses within ethnoscience, ethnobiology, and ethnoecology studies. Alternatively, LTK has contributed to structuring and refining the focus of scientific research projects (Hamilton and Walter 1999, Bart 2006, Moreno et al. 2007b). For example, Bart (2006) used information from salt hay farmers about an invasive reed in order to design manipulative experiments that were able to shed light on the causal mechanisms underlying the observations of locals. He argues that "local accounts may provide rich narrative histories that can both refine research questions and suggest multiple plausible scenarios" (Bart 2006:546). Marine LTK can also provide the groundwork for research projects in data-spare situations. For example, LTK has provided initial assessments of both Mayan (Arce-Ibarra and Charles 2008) and Guinean fisheries (Poizat and Baran 1997). In addition, LTK may yield information about the historical structure of and changes in marine flora and fauna, ecosystems, and seascapes (Sadovy and Cheung 2003, Saenz-Arroyo et al. 2005a, Roberts 2007, Thornton et al. 2010, Shackeroff et al. 2011).

Improving resource management

The bulk of recent LTK research has been conducted with resource management in mind. Table 2 highlights three broad categories of studies. These categories include improving management through increased knowledge, improving or assessing management techniques, and informing conservation strategies.

The studies set out in Table 2 give some sense of the breadth of ways in which LTK can contribute to marine resource management. Moreover, specific studies within each of these categories illustrate the unique role that LTK can play in management and conservation. First, in relation to improving management simply through increasing the knowledge base about a given species or habitat, such an observation is most apparent in relation to studies that examine LTK of environmental change. In many cases, scientific measures are either too narrow, shallow, or broad to be meaningful in the context of community adaptation at the landscape scale. LTK anchored in particular locales over generations, in contrast, systematically records and contextualizes observations, which can help ground truth environmental events, impacts, and projections that may be captured only by scientific instruments or models at a very broad scale, if at all. Ames (2007:154) argues that the preoccupation of contemporary fisheries science with simplified models "has left it without the historical parameters needed to interpret fine-scale changes in stock distribution, behavior, or migration patterns over time. Consequently, management has lacked the ability to detect or interpret these changes . . ." Using LTK can thus be especially meaningful in recognizing and interpreting changes in habitat, species abundance and distribution, sea-ice qualities, and the like (Knopp 2010, Krupnik et al. 2010, Lauer and Aswani 2010).

Second, LTK has brought to light potentially useful traditional practices or institutions that could be incorporated into "contemporary" resource management. For example, it has been argued that the values, knowledge, and stewardship practices of First Nations peoples could be fruitfully integrated into the management and restoration of watersheds and coastal habitats (e.g., Berkes 1977, Jones and Williams-Davidson 2000, Thornton et al. 2009, Thornton and Kitka 2010, Thornton et al. 2010, Thornton 2012). At the same time, some works caution against a hasty borrowing of traditional practices for management (e.g., Palmer 1994:238), especially where population, habitat, or use conditions have changed appreciably. LTK's very inclusion in management processes may change the broader social context to foster community empowerment in participatory management, such as in sea-urchin harvesting in St. Lucia (Warner 1997). This valorization, reflecting LTK's continuing legitimacy and development, may in turn improve the resilience of the local knowledge and practices by encouraging young people to retain it "as a matter of personal experience" (Johannes 1981:149).

Studies highlighting LTK's role in management conflicts shows that collaboration between LTK holders and scientists holds potential for improving stewardship. For example, Dowsley and Wenzel (2008:184) explore varying perceptions of polar bear abundance in Nunavut in the context of a comanagement arrangement, finding that disagreements over polar bear population numbers may be the result of either or both "incomplete data collection and synthesis among Inuit observers, or of scientific data collection that is too narrowly confined in geographic area." They also note the possibility that LTK bearers have not yet perceived declines in bear conditions or population size, and suggest that improved collaboration between locals and scientists in interpreting large-scale scientific studies in relation to local observations might lead to broader consensus about the status and management of polar bears (Dowsley and Wenzel 2008:186). Huntington et al. (2004) emphasize similar spatial complementarity in studying the migration of beluga whales.

Third, in relation to conservation and marine spatial planning, numerous studies underscore the useful role of LTK. Drew (2005) argues that TEK can strengthen conservation programs through improved knowledge of the specific location and relevant environmental linkages, and through the improved local capacity and power sharing that comes with including knowledge holders as equal partners in research programs. LTK can be especially valuable in planning and assessing Marine Protected Areas (MPAs). For example, Ban et al. (2009) developed a framework for integrating the preferences and concerns of First Nations peoples into the site selection of potential MPAs. A recent review of MPAs suggests there is a long way to go, however, because "potentially existing

Table 2. Management-focused marine LTK studies: examples from the literature.

Broad aim	LTK–management focus	Examples
Increase knowledge base to improve management	Species or habitat	Silvano et al. 2006, Hill et al. 2010, Lemelin et al. 2010, Rasalato et al. 2010
	Stock numbers	Neis 1992, Foale 1998, Saenz-Arroyo 2005a, Jones 2007
	Sightings	Rajamani and Marsh 2010
	Seasonal patterns	Manajarréz-Martínez et al. 2010
	Stock structure	Gosse et al. 2003, Nielsen 2009
	Hunting incidence/incidental catch	Rajamani and Marsh 2010
	Environmental change	Lauer and Aswani 2010, Knopp 2010
	"Shifting baselines"	Saenz-Arroyo et al. 2005b, Eddy et al. 2010, Thornton et al. 2010, Venkatachalam et al. 2010
	Identify commonalities between LTK and commercial fishers knowledge	Batista and Lima 2010
Assess, improve, and or/develop management techniques	Examine seabird egg harvesting strategies in relation to population ecology	Hunn et al. 2003
	Bring to light potentially useful traditional practices	Berkes 1977, Baines and Hviding 1993, McClanahan et al. 1997, Johannes 1998, Jones and Williams-Davidson 2000, Johannes 2002, Mathooko 2005, Linkous Brown 2006, Menzies and Butler 2007, Ashaletha and Immanuel 2008, Heaslip 2008, Thornton 2008, Rathakrishnan et al. 2009, Satria and Adhuri 2010, Thornton and Kitka 2010
	Improve management practices in commercial fisheries	Moore 2003, Price and Rulifson 2004, Harnish and Willlison 2009, Moreno et al. 2007a, Szuster and Albasri 2010
	Resolve management disputes	Davis et al. 2004, Dowsley and Wenzel 2008
	Assess parametric fisheries management	Acheson and Wilson 1996
	Protocols for incorporating GIS and LTK	Calamia 1999, Close and Hall 2006, St. Martin and Hall-Arber 2008
	GIS mapping of mapping local fishing areas	Anuchiracheeva et al. 2003
	GIS mapping of spawning and nursery areas	Knutsen et al. 2010, Thornton et al. 2010
	Classification of remote sensing imagery	Lauer and Aswani 2008
	Develop expert system models	Mackinson 2001, Grant and Berkes 2007
	Develop parametric indicators	Wilson et al. 2006
	Inform marine spatial planning	Cinner et al. 2010
Develop and inform conservation strategies	Identify essential habitats	Bergmann et al. 2004
	Bringing together fisher and scientist knowledge	Akimichi 2001
	Construction of artificial reefs	Kurien 2001
	Assess effectiveness of conservation zone	Baird and Flaherty 2005
	Assess conservation status of species	Dulvy and Polunin 2004
	Determine local extinction vulnerability of species in IUCN hotspots	Castellanos-Galindo et al. 2011
	Identify potential environmental and human-related factors impacting beluga whales	Carter and Nielsen 2011
	Inventory the disappearance of certain fish	Lavides et al. 2010
	Improve conservation through targeted data collection	Cavaleri Gerhardinger et al. 2006, Richmond et al. 2007, Cavaleri Gerhardinger et al. 2009b
	Study fisher perception of conservation efforts	Rosa et al. 2005
	Inform mangrove restoration	Biswas et al. 2009
	Creation and evaluation of marine protected areas	Aswani and Hamilton 2004, Scholz et al. 2004, Aguilar-Perera et al. 2006, Aswani and Lauer 2006, Mallory et al. 2006, Aswani et al. 2007, Mow et al. 2007, Aswani and Vaccaro 2008, Ban et al. 2008, Ban et al. 2009, Cavaleri Gerhardinger et al. 2009a, Espinoza-Tenorio et al. 2010

ecological knowledge of local communities is seldom acknowledged when designing MPAs" (Ferse et al. 2010:26). Indeed, in the context of a national park in southern Brazil, Almudi and Coswig Kalikoski (2010:225) found that a top-down MPA model "disregarded the fisherfolk's cultural practices and particular knowledge, thereby violating their rights as traditional people." Such violations tend to further undermine the integrity and resilience of LTK and livelihood systems.

Substantive focus of LTK research

A broad review of the literature reveals that LTK has been collected about many facets of marine environments, though species-specific studies are particularly prominent. Table 1 details these findings.

Table 3. How the substantive focus of marine LTK studies has broadened: examples from the literature.

Category	Study focus	Examples
Ecology	Marine habitats, spawning and nursery areas	Knutsen et al. 2010, Thornton et al. 2010
	Historical ecology of coral reef guilds	Shackeroff et al. 2011
	Mangroves and lagoons	Johannes 1978, Johannes 1981, Kovacs 2000, Hernandez Cornejo et al. 2005, Aswani and Lauer 2006, Walters et al. 2008
	Seagrass environments	Lauer and Aswani 2010, Turner and Clifton 2006, Wyllie-Echeverria et al. 2002
	Marine/coastal habitats and tsunami impacts	Venkatachalam et al. 2010
Physical environment and cultural adaptation	Tidal cycles and wind patterns	Tobisson et al. 1998, Nirmale et al. 2004a
	Lunar cycles	Cordell 1974, Nirmale et al. 2004a
	Effect of water color on catch	Nirmale et al. 2004a
	Weather and climate	Lefale 2010
	Indicators of cyclone intensity	Nirmale et al. 2004b, 2007
	Seabed morphology	Tobisson et al. 1998
	Finding fishing spots based on physical environment	Forman 1967, Schafer and Reis 2008
	Response to potentially tsunami-forming earthquakes	McAdoo et al. 2009
	Interpreting satellite images and aerial photos using LTK	Aswani and Lauer 2006
	Tropical coastal habitat connectivity	Garcia-Quijano 2007
	Currents and island wakes	Johannes 1981
	Sea ice (freeze/thaw processes, influence of winds and currents)	Nelson 1969, Dowsley and Wenzel 2008, Laidler and Elee 2008, Laidler and Ikummaq 2008, Aporta and Macdonald 2011, Inuksuk 2011
	Adaptation to sea ice environment	Riewe 1991, George et al. 2004
	Incorporation of sea ice LTK and satellite imagery	Laidler et al. 2011
	Glaciers	Cruikshank 2001, 2005
	Navigation (general)	Paine 1957, Gladwin 1970, Finney 1976, and Feinberg 1988
	Navigation (landmarks)	Forman 1967, 1970, Igarashi 1984, Ammarell 1995
	Navigation (stars, swells)	Ammarell 1995, Feinberg 1995
	Navigation in the Arctic	Aporta 2002, 2004, 2009
	Using GPS to map trails	Aporta 2003
	Collaborative mapping	Gearheard et al. 2011
	Weather/ocean/climate conditions	Alvarez and Vodden 2009
Assessing environmental change	Mangrove forests (e.g., disturbance, extent)	Kovacs 2000, Hernandez Cornejo et al. 2005
	Geographic distribution, seasonality and severity of algal blooms	Schlacher et al. 2010
	Long-term ecological change in seagrass meadows and causal factors	Lauer and Aswani 2010
	Nearshore macrobenthos affected by local sewage disposal	Jewett et al. 2009
	Climate variability and Arctic	Knopp 2010, Barber et al. 2010
	Changes in sea ice	Gearheard et al. 2006
	Relationship between sea ice and climate change	Laidler 2006
	Climate–walrus–human relationships	Krupnik and Carleton Ray 2007, Metcalf and Robards 2008
Language and marine cognition	Names for fish	Akimichi 1978, Akimichi 1986, Ankei 1989, Ambali et al. 2001, Anderson 2007
	Marine invertebrates	Sloan and Barthier 2009
	Names for hydrological features	Burenhult 2008
	Landscape and seascape terms	Cablitz 2008, Levinson 2008, O'Conner and Kroefges 2008, Senft 2008, Thornton 2011
	Coastal proverbs	Kurien 1998
	Terms for sea ice conditions	Norton 2002, Laidler and Elee 2008, Laidler and Ikummaq 2008, Heyes 2011, Krupnik 2011
	Ancestral sayings and a coastal wetland plant	Wehi 2009
	Terms for tidal current patterns	Johannes et al. 1981
Resource management	Management practices in small-scale subsistence or commercial fisheries (artisanal fisheries)	Morrill 1967, Johannes 1978, Johannes 1981, Klee 1980, Swezey and Heizer 1984, Amos 1993, Johannes and Yeeting 2000, Blount 2005, Hickey 2007, Thornton 2008, Mangahas 2010, Nguyen and Ruddle 2010, Satria and Adhuri 2010, Coulthard 2011

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	Basic fisheries assessments	Arce-Ibarra and Charles 2008
	Fish harvesting techniques and technologies (artisanal)	Akimichi 1986, Hviding 1996, Anuchiracheeva et al. 2003, Linkous Brown 2006, Nirmale et al. 2004a, Nirmale et al. 2004b, Langdon 2006, Nirmale 2007, Nsiku 2007, McClanahan and Cinner 2008, Manna et al. 2009, Rathakrishnan et al. 2009
	Assessing bait to catch ratios (commercial)	Harnish and Willison 2009
	Bycatch assemblages	Hill et al. 2010
	Changing uses of bycatch	Lobo et al. 2010
	Comparative study of fishing tuna	Moreno et al. 2007a
	Spatial distribution of scallops (commercial)	Wroblewski et al. 2009
	Spatial distribution of lobster	Acheson 1988
	Harvesting methods for seaweeds	Turner and Clifton 2006
	Assessing effectiveness of conservation measures	McClanahan et al. 1997
	Village-managed fish conservation zones	Baird and Flaherty 2005

Not surprisingly, LTK collected in these studies is focused at the human scale of experience. For example, animal-related LTK focuses especially on species that are hunted, while that which deals with physical geography generally relates to navigation and safety. This emphasis supports the view that fishers' ecological knowledge is primarily, though not exclusively, utilitarian (McGoodwin 2001). Indeed, Foale (1998:200) remarks that most LTK "possessed by subsistence, artisanal and commercial fishers is focused on how to locate individuals of a target species in space and time, and, once located, how to capture them." Baines (1992:100) adds that on a Pacific island, fishers' knowledge is instrumental, or "primarily behavior oriented, focusing on the information required to find and capture." Correlatively, "empirical gaps" (Foale 2006a) in LTK concern parts of the life cycle that are comparatively unknown to fishers because they are beyond the scope of their experience or perception. Thus local observations and traditional knowledge are generally not very useful at chemical, biochemical, or cellular levels (Berkes et al. 2007). On the other hand, the phenotypic manifestations of chemical changes within an animal may be readily perceived by LTK holders.

Table 3 summarizes marine LTK studies relating to ecology, the physical environment, assessments of environmental change, language, and resource management. The table illustrates how the substantive focus of modern LTK studies has broadened beyond knowledge of species to include marine ecological and physical processes. Knowledge of marine ecology is often built up and maintained in the context of specific subsistence practices, such as hunting and fishing, which are conditioned by broader ecosystem dynamics (Johannes and MacFarlane 1991). For example, following a 2007 tsunami in the Solomon Islands, McAdoo et al. (2009:81) found that indigenous knowledge can be "an effective tsunami mitigation tool when the right combination of education and physiography come together". Many authors (Wohlforth 2005, Laidler and Elee 2008, Riewe and Oakes 2006, Henshaw 2009, Gearheard et al. 2011, Pearce et al. 2011,) suggest that LTK can be used not only to understand the physical and socio-cultural risks, vulnerabilities, and other impacts of climate change in the Arctic but also as a source of resilience and adaptive capacity in response to these changes.

Moreover, classical ethnoscience studies carried out by linguists and ecological anthropologists (cf. Conklin 1957) have recognized the importance of language and nomenclature in reflecting the LTK of environments. Indeed, names for marine species, habitats, and the like can be an important first step in integrating LTK with scientific knowledge (Sloan and Barthier 2009). The potential link between the richness of terminology and knowledge of geological features and processes has also been highlighted in recent studies (Terry and Etienne 2011). There is scope to further explore such relationships between language, culture, and marine ecology and biocultural diversity.

In parallel with the studies described above, which aim to improve management techniques, another body of research embraces the diversity of community resource management practices. For example, Klee (1980; see also Johannes 1981) describes taboos and bans in lagoon tenure systems in the South Pacific Islands, as well as the figure of the "Master Fishermen" who acted as an island's authority on fishing lore and practice. Thornton (2008, 2012) describes a similar "Master of the Stream" figure for important Tlingit salmon watersheds in southeast Alaska, and Swezey and Heizer (1984) link the "first salmon" ritual of multiple aboriginal communities in California to conservation practice. Knowledge of this diversity can improve regulatory regimes when these rules do not conflict with sustainable local practices; McClanahan and Cinner 2008), for example, examined the fishing gear used by a community in Papua New Guinea, and suggest that LTK in tandem with scientific monitoring could be used to establish an adaptive management framework for gear restrictions.

AN EMERGING FOCUS ON COLLABORATIVE RESEARCH AND MANAGEMENT

As noted above, collaboration and the coproduction of knowledge between LTK communities, scientists, and

Table 4. Collaborative projects that bridge LTK and science: examples from the literature.

Examples	Focus	Methods
Baines 1992	Various subjects, focusing on fish and fishing	Researchers resident in community, reciprocal training
Carmack and Macdonald 2008	Water and ice-related phenomena (Arctic Canada)	Dialogue with elder
Fernandez-Giminez et al. 2006	Beluga whales (Alaska)	Comanagement committee
Fienup-Riordan 1999	Geese (Alaska)	Interviews
Gearheard et al. 2006	Sea ice (Alaska/Canada)	Knowledge exchange with field trips
Hall et al. 2009	Oyster fishery (New Zealand)	Participatory monitoring
Krupnik 2002	Ice and weather (Alaska)	Workshop and locally led documentation project
Moller et al. 2009b	Seabird harvest (New Zealand)	Long-term research partnership
Norton 2002	Sea ice (Alaska)	Symposium
Obura et al. 2002	Local fish monitoring (Tanzania)	Community engagement in research
Tremblay et al. 2008	Local climate (Arctic Canada)	Community-based monitoring

resource managers on research and management projects is a potentially constructive pathway to bridge science and LTK. The growing literature on collaborative projects is instructive in providing guidelines for how to approach this bridging in ways that maintain the integrity of knowledge systems and enhance exchange between them, while at the same time improving adaptive management. This section examines eleven examples of collaborative projects. Table 4 lists the main studies examined, and their focus and methods. The table makes it clear that the majority of these examples come from the North American Arctic, where it would appear there is the most collaborative research activity. The following analysis therefore bears in mind this context, although it is arguable that a number of the considerations discussed will be applicable elsewhere.

How have collaborative projects managed the relationship between LTK and modern science? The differences between LTK and modern science are often significant (Cruikshank 2005) and underpinned by foundational differences in cosmology and worldview, but at the same time can be overdrawn (Agrawal 1995). As Krupnik (2002:185) suggests, “it is not a different nature but rather a different focus of scientific and ‘local’ knowledge, that commonly keeps these two types of expertise looking in different directions.” An appreciation of where LTK and science have their relative expertise is thus important, as is the relative status of that expertise (Laidler 2006) and mutual respect (Moller et al. 2009b). In cases where the focus or scale of inquiry may be the same, collaborative research may take science and LTK as equals. Carmack and Macdonald (2008:25) term this approach “coscience” where “natural phenomena are examined through both indigenous and Western methods; each approach is assumed valid within its own set of rules and neither replaces the other.” They argue further that “the practical and emergent outcome of this approach is that joint enquiry will focus on phenomena that are important to native peoples for their way of life and will bring Western scientists closer to a ‘system science’ level of understanding.” Similarly, in a participatory mapping exercise, Hall et al. (2009:2059) aimed to create a “virtual space” in which LTK and science “can play equal roles relative to rekindling the broader goal of collaborative participation in management and planning.” However, appreciative inquiry and participatory methods in themselves may not lead to the development of co-equal knowledge and management systems (Nadasdy 2003).

Fernandez-Giminez et al. (2006) delineate signs of successful integration of LTK and science. In examining the Alaska Beluga Whale Committee, they found that hunters began to communicate scientific knowledge, and even quite specific scientific studies, amongst each other, while scientists began to understand the broader cultural context and implications of their work. Moller et al. (2009b:234) report that Maori interest in research led to the formation of Maori research methodologies “where Maori remain in charge of research initiation, benefits, representation, legitimation and accountability.” The process of getting to such an understanding may be a necessary first step toward developing co-equal knowledge and management systems, and can be fostered by setting collaboration milestones to achieve successful integration. Yet cases of native-led research and equitable partnerships between science and LTK, despite the promise of coscience, are still quite rare.

In terms of practical engagement, the importance of relationships and trust is emphasized in successful collaborative projects. Many scientists have noted the important role that ongoing relationships in a given community play in their work (Norton 2002, Fernandez-Giminez et al. 2006, Gearheard et al. 2006, Tremblay et al. 2008). Indeed, Moller et al. (2009b:219) note that of the attributes identified for successful comanagement by scientists and local resource managers, “trust and respect for each other were the most fundamental and time consuming to establish and demonstrate.” Where such relationships did not initially exist, it was important for scientists to build trust and respect for themselves (Fienup-Riordan 1999). Norton

(2002:131) describes how these relationships grew by "scientists learning to live and conduct fieldwork safely on the ice alongside whalers for two months each spring." In building these relationships, the creation of different opportunities in which communication can be fostered is important, through both formal and informal interactions (Baines 1992, Fernandez-Giminez et al. 2006, Gearheard et al. 2006). In particular, Gearheard et al. (2006:203) note that "opportunities for cultural exchange were an important aspect of the project that helped create trust and comfort in the research team." Obura et al. (2002) also argue that, particularly in the case of long-term monitoring, relationships are crucial, and that commitment from all actors involved is necessary. Even before any knowledge sharing can begin, and questions of how to bring together science and LTK can be raised, relationships based on trust and shared experience must be developed. Moller et al. (2004) note that studies which aim to combine scientific and traditional methods may be a fruitful context in which to build such relationships. Indeed, Turnbull (1997:551) affirms that there is a need to "enable disparate knowledge traditions to work together through the creation of a third space in which the social organization of trust can be negotiated."

In project design, this "third space" often springs from a shared interest in a vital subject. For example, both Norton (2002) and Tremblay et al. (2008) note that their focus on nearshore sea ice and its link to safety meant that their research was useful to the community, which is a compelling environmental change and management problem for study. Moller et al. (2009b) explain that concern for seabirds and their well-being meant that many birders saw long-term value in the research. In other cases, the desire to collaborate on formal documentation of LTK was motivated by the community's aim to safeguard the knowledge for future generations (Baines 1992, Krupnik 2002, Fernandez-Giminez et al. 2006, Hall et al. 2009).

The collaboration of LTK bearers in codirecting all phases of the research is consistently highlighted as an important element of successful projects. Research questions and protocol are best developed in collaboration with village elders (Fienup-Riordan 1999). In cases in which collaboration focuses on a group setting, it is crucial that the group be made up of locals and scientists (Fernandez-Giminez et al. 2006, Gearheard et al. 2006) and that the organizational structure be conducive to power sharing (Fernandez-Giminez et al. 2006). In cases in which collaboration emphasizes monitoring, an appropriate level of training is requisite (Obura et al. 2002). Ultimately, these factors contribute enormously to a constructive sense of cooperative ownership of the project (Fernandez-Giminez et al. 2006). These considerations are reflected in Pearce et al.'s (2009) review of collaborative climate change research in Arctic Canada, which also emphasizes the importance of having early and ongoing communication, involving communities in research design and development, and facilitating opportunities for employment and disseminating results. Correlatively, Gearheard and Shirley (2007) make a number of recommendations stemming from their analysis of natural sciences research in Nunavut, among them that trust-building can be fostered through early community consultation, regular research reports, and the use of local experience and resources.

However, as Obura et al. (2002:219) stress, project design must also help local communities build capacity for the collection, analysis, and dissemination of technical information so that their ability to participate in resource management is strengthened. Thus, funding for community participation and "the equitable sharing of resources to facilitate active participation is essential" (Moller et al. 2009b:229). Projects with such community benefits are more likely to garner community involvement and support that will enhance long-term relationships necessary for trust and capacity-building and adaptive learning about the benefits of LTK in relation to science.

Yet, collaborative research poses a number of challenges. The cases examined emphasize that perceptions of the role of science and the aims of the scientists may have an influence on how projects proceed, particularly at their inception. For example, Fienup-Riordan (1999) found that elders expressed deep resentment toward the nonlocal control that researchers and wildlife managers represented, while Fernandez-Giminez et al. (2006) note that hunters often perceived knowledge to be a tool of state control. Moller et al. (2009b) maintain that in order to succeed, research partnership projects require both a strong mandate from the community at large and active leadership from within the participating community. Project design therefore not only has to be cognizant of these attitudes but has to take positive steps to engage them by creating a new space for knowledge coproduction, colearning, and comanagement.

Logistically, the costs and complexity of creating such spaces can be high. Even setting up a simple knowledge exchange with field visits is expensive (Gearheard et al. 2006). Obura et al. (2002) discovered the difficulty of securing sufficient long-term funding for such things as monitoring. The pace of research is also likely to be slower than that done in the absence of a community of interest (Moller et al. 2009b). Other challenges to successful collaboration include: local employment trends and attitudes, revolving membership and leadership of community organizations, competing or concurrent local activities at the time of research, cultural barriers, poor historical research, community–researcher relations, the economic subtext of many community–research relationships, financial limitations, time constraints, and communicating results to stakeholders (Pearce 2009). These practical challenges can undermine the viability, equality, integrity, and resilience of coscience systems emerging in the third space.

Stable bridging institutions such as the Alaska Eskimo Whaling Commission remain the exception rather than the rule, and they require significant funding, logistical support, and community backing to carry out their mandates. Significantly, this institution was born in the early 1980s out of conflict surrounding a proposed international moratorium on whaling that could have ended Eskimo subsistence on foundational species like the bowhead. Instead, however, the Commission was created to improve the science at the local scale by incorporating LTK (which showed significantly more whales present than scientists had been able to count) and management (distribution of hunting quotas) in meaningful and substantive ways. This has been highly effective, as Huntington (1992:115) relates, because: (1) the whalers administer the allocation and scientific review regime; (2) the quotas reflect the real needs of communities for whales; (3) whaling is a major economic and communal activity with strong traditional protocols and support for sharing and cooperation; and (4) "the goals of the AEWC have always been clear, and the battle with an outside authority has helped the whalers form a cohesive group. By averting the threat to Eskimo culture, the AEWC proved its usefulness, earning the pride and respect of the whalers." In addition to this strong foundation and track record, the Commission is also comparatively well funded and high profile in its activities, reflecting its status and legitimacy across cultures.

CONCLUSION: A COLLABORATIVE AGENDA FOR MARINE SCIENCE AND LTK

Despite comprising more than 70% of the Earth's surface, marine environments remain among the least understood of ecosystems. Yet they are increasingly under threat from development, degradation, climate change, and other forces. A lack of historical–ecological depth in marine studies means that in many cases we do not realize what we have lost (Anderson 2007, Roberts 2007). Despite some classic studies, marine LTK research overall is relatively young and is evolving rapidly, and there is a critical need for more substantive, deep ethnographic *and* multiscale research on marine ecosystems, as our ocean-dominated planet continues to evolve and change.

The successes and challenges discussed provide some guidelines for how successful collaborative work may proceed to improve our understanding of marine systems and foster adaptive management as they change. A diversity of approaches is evident in the literature, including multilocal bridging organizations, such as the Alaska Beluga Whale Committee (Fernandez-Giminez et al. 2006). These comanagement organizations are made up of local and state actors that can "provide an arena for knowledge co-production, trust building, sense making, learning, vertical and horizontal collaboration and conflict resolution" (Berkes 2009a:1695). Such institutions can create a forum in which local and scientific knowledge can be shared, produced, maintained, and used collaboratively. Dowsley (2009) advocates for a "community cluster approach" consisting of neighboring communities that share a spatially defined resource. She suggests that collaborative research would benefit from such a networked approach through increased information and monitoring that can lead to faster recognition of changes in the resource.

To keep the collaborative projects "moving forward" (Neis 2011), novel and hybrid approaches may be necessary to successfully represent LTK in the academy and beyond. Watson and Huntington (2008), for example, show how a traditional academic paper can be restructured to better represent different accounts of reality. Felt (2008) proposes that fisheries scientists in training should take part in a residency of a few months with local fishers, as such immersion through participant observation can help build trust and mutual appreciation and understanding. Workshops cosponsored with LTK holders may also provide "a practical and concrete basis upon which to build a shared understanding, or at least greater insight into the reasons behind divergent views" (Huntington et al. 2002:788). The Sitka Tribe of Alaska (a collaborator in numerous LTK studies) has, in the case of one key cultural species, gone beyond workshops to found the broad-based Sitka Sound Herring Research Planning Group to carry the collaborative agenda forward through regular communications, thereby building towards new research and management priorities that link local fishers' knowledge and practices to appropriate methods and scales of marine ecosystem governance. Like their Haida neighbors, the Sitka Tribe seeks to collaborate with scientists to improve understandings of critical, complex, and changing marine environments with the help of LTK. Unfortunately, the embrace of LTK by state management is still too limited, though recent actions to create subsistence-only zones in key herring-spawning habitats in Sitka Sound (as requested by the Sitka Tribe) are an encouraging sign of respect for LTK and its herring-management principles.

These examples demonstrate that there is considerable room for constructive engagement of LTK as part of marine research, monitoring, spatial planning, and conservation. Further steps to enhance its role in improving adaptation and resilience should include: (1) stronger recognition of the relationship between marine biodiversity and the cultural diversity among maritime peoples; (2) acknowledgement of threats and stresses to marine LTK and sustainable livelihoods by historical and contemporary commercial harvesting, development, and environmental change in coastal zones and seascapes; and (3) the nurturing of traditional and collaborative stewardship systems to protect, restore, and enhance the productivity, diversity, and resilience of critical marine ecosystems that support sustainable maritime cultures.

By reviewing some of the successes and failures in marine LTK–science production, dissemination, policy implementation, and collaborative infrastructure development, we hope that more successful bridging projects and institutions that link local knowledge and science will be conceived, funded, and implemented in order to better inform critical environmental change and adaptive comanagement issues facing marine social-ecological systems today. This is a matter of some urgency, for as Alaskan Yup'ik Eskimo elder John Eric states, drawing on his own people's reservoir of marine LTK: "We cannot live without the ocean. Our ancestors sustained themselves mainly from the ocean . . . . It's no wonder that the ocean has the name *ímarpik* [from *imaq*, "contents,"], because it holds everything" (Fienup-Riordan and Reardon 2012:215).

Responses to this article can be read online at:
http://www.ecologyandsociety.org/vol17/iss3/art8/responses/

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