BioScience Advance Access published March 30, 2016

The Importance of Indigenous Knowledge in Curbing the Loss of Language and Biodiversity

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Biodiversity inventory, monitoring, and species-recovery efforts can be advanced by a dynamic collaboration of Western, citizen, and ethnoscience. Indigenous and local traditional knowledge of place-based biodiversity is perhaps the oldest scientific tradition on earth. We illustrate how an all taxa biodiversity inventory network of projects in collaboration with the Comcaac (Seri people) in northwestern Mexico is advancing not only biosystematics but also species recovery, habitat restoration, language conservation and maintenance, and the maintenance of traditional livelihoods. We encourage scientists to establish collaborations with indigenous and other place-based communities to better understand the wealth of knowledge held in local categorization systems. It is essential to not merely seek out one-to-one correspondences between Western and indigenous knowledge but also to recognize and respect the creative tensions among these different knowledge systems, because this is where the most profound insights and fruitful collaborations emerge.

Keywords: traditional ecological knowledge, biodiversity, citizen science, conservation, transdisciplinary collaboration

With the accelerating losses of biodiversity, habitats, and native languages, indigenous knowledge—including the study of traditional ecological knowledge of species and landscapes maintained by native nations—has become ever more significant. Globally, 20% of described species are likely to face extinction over the next two to three decades (Maffi 2001, Cardinale et al. 2012). Current extinction rates exceed background rates among vertebrate taxa by 114 times under the most conservative of calculations (Ceballos et al. 2015). Simultaneously, Rogers and Campbell (2015) estimated that one language goes extinct every 3.5 months and that 3134 of the 6901 known living languages are endangered. Linguistic and biological diversity are tightly coupled and face similarly grim futures (Gorenflo et al. 2011).

Collaborative efforts to document local biological classifications and associated traditional knowledge of species distributions and habitats are time sensitive. Many ancient place-based knowledge systems pre-date the formal articulation of Western and Eastern scientific tenets by thousands of years. However, adaptive ecological knowledge is rapidly shifting if not dramatically eroding (Loh and Harmon 2014). This is especially true among communities suffering from the declining use of their languages. As such, there is an urgent need to support communities attempting to revitalize their native tongues and maintain their traditional livelihoods based on local natural resources. Fortunately, there are growing efforts to incorporate indigenous cultures into projects that restore habitats of declining species and resuscitate lost practices and knowledge. Examples range from large-scale indigenous-led monitoring efforts of wildlife populations (Luzar et al. 2011) and carbon stocks (Butt et al. 2015) in Amazonia to the mapping of traditional lands in the little-known Darién province of Panama (Herlihy 2003).

The long-term success of conservation initiatives hinges on a pluralistic and interdisciplinary course of action. Recently, citizen scientists' monitoring efforts have been the focus of research aimed at better understanding global biodiversity (Theobald et al. 2015). Laudable endeavors are underway to reengage a broader segment of the population in making natural-history observations of biodiversity imperiled by climate change and discussing the moral implications of such changes (Nisbet et al. 2010, Miller-Rushing et al. 2012). These efforts are complemented by drawing attention to the wisdom embedded in *traditional ecological knowledge* (TEK). Defined as "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 2012), TEK has guided efforts that protect habitats of endangered or

doi:10.1093/biosci/biw026
Advance Access publication XXXX XX, XXXX

culturally important species (e.g., Nabhan 2000, Johannes and Yeeting 2001). In some cases, TEK has also assisted conservation planning (e.g., Fraser et al. 2006).

Here, we wish to continue this trend and direct attention to the value of indigenous knowledge embedded in local taxonomies. A realm of collaboration—a new era of citizen science with indigenous foragers, fishers, hunters, farmers, and artisans who have a sophisticated grasp of place-based changes in biodiversity through time and space—awaits. Accommodating their knowledge should be of interest to those scholars working to bridge the environmental sciences with social sciences, arts, and religion. Doing so will better engage diverse constituencies in addressing the biological and cultural consequences of global change (Nisbet et al. 2010). It may also avoid a truncated approach to knowledge that limits the horizon of discovery.

Indigenous science as compared with academic and citizen science

As never before, direct comparisons of classifications of species, habitats, and landscapes from Western and indigenous perspectives are now possible. The different ways of perceiving and cataloguing biodiversity is a bountiful realm for collaboration and respectful cross-cultural learning. The nexus of diverse worldviews can be the departure point for future efforts to both document and conserve. Interestingly, disparate cultures have not necessarily arrived at parallel typologies and classification structures for discerning the lives and habitats around them (Atran 1998). Why are there widely heralded cases of one-to-one correspondence of Western and local classifications but intriguing divergences as well? Can the indigenous names and mythology of the geographic origins of species serve as the basis for testable hypotheses just as scientists' observations have been used?

The knowledge base of most indigenous science is rooted in place-based natural-history observations gathered over centuries or millennia, distilled in the lexicon, calendars, place names, maps, and other practices of indigenous resource managers. Indigenous scientific knowledge is in many ways complementary to—not contradictory or redundant with—academic science or citizen science (table 1). In fact, local taxonomies already bridge detailed place-based natural-history observations with moral dimensions and artistic, effective communication strategies that some biodiversity and climate scientists are now striving to encompass in their own work (Nisbet et al. 2010).

As linguistic loss accelerates and traditional natural resource-based livelihoods decline, there is a concomitant loss of traditional ecological knowledge (Loh and Harmon 2014). This compromised knowledge base—as indicated by the disuse of lexemes that refer to particular organisms or ecological interactions—may hamper indigenous communities and humanity at large in gaining a holistic understanding and management framework for dealing with imperiled species, habitats, and the stresses currently being placed on them (Berkes 2012). In addition, there is an increasingly skewed distribution of speakers and languages globally. Half of the world's population speaks 1 of only 24 of the world's approximately 7000 languages, whereas only about 0.1% of the world's population, or about 8 million people, currently speak about 3500 of the world's languages (Loh and Harmon 2014). Nevertheless, the distributions, habitat needs, and behavior of locally declining or endemic species may remain better known by indigenous or local peoples than by Western-trained scientists (Nabhan 2000). We urgently need such place-based knowledge to help guide both species-recovery and habitat-restoration efforts. These efforts may also be essential in supporting the persistence of resources on which livelihoods for indigenous fishermen, foragers, or hunters are based (Berkes 2012).

Fortunately, for decades, individuals in the biological and social sciences have worked with indigenous leaders to document the biocultural diversity still extant in First Nations' lands and waters (Maffi 2001). Until recently, only a minority of studies were formally guided or directed by traditional tribal elders, with technical support being provided by professional scientists (Gupta et al. 1993). However, more than ever before, indigenous leaders are taking full leadership in documenting the diversity in their territory. Foremost among them are the ethno-ornithological, mammal, and traditional medicinal plant inventories in the Kuna Yala homelands of the Kuna in Panama (Ventocilla 1995).

There remain creative tensions to be dealt with when attempting to integrate information, values, and cosmologies from distinct cultures. Perhaps there has been a prevailing ideological bias among linguists and biologists toward finding "universal principles" of classification embedded in folk biological taxonomies. Such apparent commonalities have been enough to convince some scientists that the prevailing one-to-one correspondences of folk and scientific taxonomies indicate that such taxa are "biologically real" entities and not just arbitrary constructs (Begossi et al. 2008). Such oversimplified use of universal principles risks ignoring the very essence of diversity itself. Instead, we believe that particular attention must be paid to the anomalies, the unique cultural expressions, and the collisions of dissonant taxonomic structures. Historically, although linguists or taxonomists may have favored certitude over incongruence, we no longer wish to risk doing so at the expense of the very diversity we wish to honor.

Profiles of select traditional knowledge and biocultural conservation initiatives

Here, we present a brief panorama of what can be gained by incorporating indigenous knowledge in scientific studies in order to provide different ways of understanding biodiversity and its conservation. Increasing efforts over the past two decades have identified and documented perspectives that broaden Western science-based approaches and engage with local indigenous communities in knowledge transmission, in both directions. Likewise, projects of empowerment aim to support and train indigenous leaders and institutions in efforts to protect their landscapes and seascapes. The

Table 1. A comparison of features of Western science, citizen science, and traditional ecological knowledge (TEK).

Characteristics	Western science	Citizen science	TEK
Goals	Seeking universals and testing theories through experiments, the analysis of data, and models	Offering local data to those seeking universals and testing theories	Usually offering data and pattern analysis specific to or bounded by a culturally defined space and time
Participants	Largely done by academically trained professionals and technicians, some of them naturalists	Largely done by enlightened/ committed “amateur” naturalists, often trained in other professions	Largely done by “proto-professional” naturalists: foragers, hunters, fishers, farmers, and shamans
Communication	Primarily transmitted through written works, graphs, and formal oral presentations	Primarily transmitted through field notes, social media, online databases, and informal oral presentations	Primarily transmitted orally in an indigenous language and also through song, story, maps, and art
Framework	Done by individuals, small teams, or cybernetworks for universal benefit	Done for pleasure by individuals or cohorts of volunteer participants in informal networks often guided by professionals	Done in multigenerational communities primarily for the community
Worldview	In most cases, wary of spiritual dimensions and ambivalent on the ethical–moral context	Variable in directly addressing spiritual, moral, and ethical dimensions, depending on the community	Seamlessly linked to spiritual dimensions and ethical–moral considerations
Methodological concerns	Insists on separation of object–subject	Ambivalent on object–subject dichotomy	Less object–subject dichotomy
Location/Scale	Increasingly done irrespective of place or focused on model systems	Preferably affectionately done as place-based inquiry	Embedded in cultural cosmology specific to place

Source: Berkes (2012) and Miller-Rushing and colleagues (2012).

avenues of collaboration are as vast as our disciplines of study can accommodate.

Indigenous worldviews supporting long-term resiliency strategies. For over 3000 years, Maya people have inhabited diverse landscapes in the Yucatan Peninsula, Southern Mexico, and Central America. As could be said of many place-based societies, the way Yucatec Maya people relate with their surrounding landscapes pivots on a system of values, beliefs, and symbolic representations of the natural world. As small-scale cultivators, Mayan soil taxonomy uses over 80 descriptive terms for biodiversity in soils, soil heterogeneity, and the adaptive practices required for successful cultivation in changing landscapes. Maya knowledge of the environment is applied through multiple use strategies such as the milpa or maize production, agroforestry, gardening, beekeeping, hunting, gathering, and fishing (Barrera-Bassols and Toledo 2005). The social and ecological resilience of the Maya is intertwined with the sacred, in which the interweaving of the spiritual and practice realms is encoded in a healing ritual with the land that sustains a biologically diverse landscape (Barrera-Bassols and Toledo 2005, Berkes 2012).

The same characterization of indigenous communities can be extended to local place-based communities that have unique adaptations and cultures, which face the same challenges of modernization as indigenous societies. One such community is that of Los Californios, ranching families in the remote sierras of the Baja California peninsula, decedents of eighteenth-century soldiers, sailors, and servants brought to assist missionary and military endeavors during the settlement of Baja California (Crosby 1981). Hundreds of families still live much as their colonizing ancestors did more than two centuries ago: Ranch life is both self-sufficient and noted for leathermaking and gardening in the oases of the sierras. The close connection between Los Californios and the land mirrors that of other indigenous communities across the world.

Congruent knowledge systems. The integration of traditional ecological knowledge and that of evolutionary biology can be particularly relevant to biodiversity conservation in isolated areas, where intraspecific diversity can go unrecognized in both systems of knowledge. Examples of indigenous knowledge of biologically real entities below the species level contributing to conservation planning include caribou (*Rangifer tarandus*), bowhead whale (*Balaena mysticetus*), Pacific herring (*Clupea pallasi*), green sea turtle (*Chelonia mydas*), and bumphead parrot fish (*Polbometopon muricatum*; Fraser et al. 2006).

The integration of TEK among the *Eeyou Istchee* Cree First Nations people with biology is a clear example of how indigenous knowledge contributes to conservation planning (Fraser et al. 2006). Traditional knowledge of the brook charr (*Salvelinus fontinalis*), known as *màsimekw* by the Cree, was contrasted with previously obtained Western science in the context of seasonal migratory habits and population biology. This compilation of knowledge provided concordant and additional information about population viability, breeding areas, and migration patterns of divergent populations, which was used in the maintenance of population diversity.

Indigenous biodiversity documentation, stewardship, and learning. Participatory research involving the documentation of biodiversity is being undertaken in *Diidxazá*, or Isthmus Zapotec spoken in La Ventosa, Oaxaca (Pérez Báez 2015). Together with biologists, a photographer, an applied linguist, and local assistants, they have collected over 1360 plant samples of over 400 species deposited in herbaria, which are paired with over 1000 lexical entries and over 5000 high-quality photographs. This effort is based on addressing local community concerns regarding the loss of lexical items and local knowledge associated with plants. In addition, the project aims to create consciousness of the loss of biodiversity among children through 10 intergenerational workshops with 6 local teachers and the development of bilingual (in *Diidxazá* and Spanish) material regarding the local flora.

Recovering, revitalizing, and passing on traditional knowledge across generations. Over the last century, the means by which traditional ecological knowledge is passed on between generations have shifted dramatically as formal education and social media have eclipsed oral transmission from elders. Nevertheless, Zent (1999) and others (e.g., Nabhan 2003) have pioneered means by which indigenous communities can track the rate of loss of traditional knowledge between generations and use environmental education programs to counter these losses.

Traditional knowledge is most comprehensively transmitted by elders to very young but attentive children through subsistence activities in camps, harvesting sites, and traditional hunting and fishing grounds rather than in indoor classrooms (Hunn 2002, Nabhan 2016). It is our experience that the elders of indigenous communities have welcomed the collaborations of field biologists who have helped take youth and their elders to field sites of rare and endemic species and to culturally symbolic or spiritually important gathering grounds. While *in situ*, oral histories as well as conservation-oriented harvesting practices can be transmitted both through native languages and hands-on practice, aiding retention (Nabhan 2016).

Knowledge transmission and indigenous leadership. Indigenous-led social institutions provide the means by which societies can act on their local knowledge to support livelihoods based on the environment (Berkes 2012). For example, the Northern Australian Indigenous Land and Sea Management Alliance (NAILSMA) is a modern indigenous-led institution that interfaces with the Australian government and academic institutions to facilitate land stewardship across the Aboriginal lands of northern Australia. NAILSMA does this through the Kimberly Ranger Network, a group of 14 Aboriginal land-manager units that collectively manage over 25 million hectares of land (NAILSMA 2016). The Ranger Network provides robust tools, skills, and training that enable the rangers to apply both traditional ecological knowledge and Western science, as well as train other indigenous conservation leaders from around the world, including the Comcaac discussed in the case study found in this article (Kennett et al. 2010).

Prioritizing actions

As Gewin (2002) has described, there are many new emerging collaborations aimed at adapting taxonomic inventories for the Internet age. These innovative approaches often involve broader collaborations and participatory strategies to inventory the world's remaining biodiversity before it is too late. Some of these engage citizen scientists as "parataxonomists" to assist academic scientists with All Taxa Biodiversity Inventories, such as those initiated in the Guanacaste Conservation Area of Costa Rica (Janzen 2004); the NaturaLista program, spearheaded by the Mexican National Commission for the Knowledge and Use of Biodiversity (CONABIO, *http://conabio.inaturalist.org*); and those in Great Smoky Mountains National Park in the United States (Sharkey 2001). However, we encourage comprehensive collaborative work toward documenting inventories of indigenous and Western knowledge for local biodiversity, such as the case study we present below. We stress that knowledge maintained in rural communities is equally valuable to that of Western origin.

Given that the crisis in biocultural diversity is more complex and time sensitive than that of merely inventorying species, we argue that before more species and languages (or merely lexical items) are lost, indigenous, rural, citizen, and professional scientists should collaborate to accomplish four tasks:

(1) Document in understudied/minority and endemic languages not only the local names (simple or compound lexemes) for but also the descriptive natural-history knowledge about as many plants and animals as possible, with particular focus on endangered endemic species, as well as species that appear to have culturally influenced distributions and abundances.
(2) Document more precisely the convergence and congruency between local taxonomies and Western-knowledge schemas, as well as how they are aberrant or incongruous with the Western (or Linnaean) scientific classification system.
(3) Engage indigenous or local communities in biodiversity documentation and stewardship through culture-driven intergenerational learning, using native language–based approaches as well as other ecological knowledge tools and strategies.
(4) Empower and support indigenous or local communities that choose to develop their own programs for managing and recovering rare species in their homelands and waters as a means to maintain or revitalize native languages and customs in order to sustain traditional livelihoods.

Case study involving the Comcaac of the Gulf of California, Mexico

Let us consider as a case study the progress made on these four tasks through long-term collaborations between the Comcaac (Seri people) of Sonora, Mexico, and a group of linguists, ethnobiologists, anthropologists, geographers, land managers, and conservation biologists that has gained momentum over the last quarter century (figure 1). The Comcaac are a seafaring and hunter–gatherer culture. They or their ancestors or predecessors have lived in the arid coastal region of the Sonoran Desert and Gulf of California

Figure 1. Collaboration among the Comcaac and outside researchers. (a) Students in ecology and conservation courses with Dr. Enriqueta Velarde (center). Photograph: Benjamin Wilder. (b) Benjamin Wilder (right) and Humberto Romero Morales in the Sierra Kunkaak of Tiburón Island. Photograph: Servando López Monroy. (c) Pico Johnson on mainland Sonora opposite Tiburón Island. Photograph: Benjamin Wilder. (d) A Seri basket festival at Punta Chueca, Sonora. Photograph: Benjamin Wilder. (e) A leatherback sea turtle (**mosnipol**) *festival. Photograph: Mayra Estrella. (f) Sierra Kunkaak, Tiburón Island. Photograph: Benjamin Wilder. (g) Carlos Armando Mendes Romero (left) and José Ramón Torres Molina identifying* **Plumbago zeylanica** *on Isla Tiburón. Photograph: Benjamin Wilder. (h) Seri new year festival. Photograph: Benjamin Wilder.*

for millennia (figure 2; Bowen 2009). There are around 900 speakers of *Cmiique Iitom* (the Seri language) as of 2007 (Lewis et al. 2015), almost all of which are bilingual in Spanish. *Cmiique Iitom* has been described as vibrant and its status as "vigorous" (Lewis et al. 2015), even when taking into consideration its status as an endangered language (Moser and Marlett 2010). *Cmiique Iitom* is not genealogically related to the neighboring Uto-Aztecan languages, and has been classified as a language isolate, meaning that we do not know with any precision its linguistic relatives.

A group of professional scientists from Mexico and the United States has been engaged with Comcaac community leaders and young "para-ecologists" in what began *ad hoc* but has emerged as an All Taxa Biodiversity Inventory presented collectively here for the first time (table 2, supplemental material 1). It encompasses both landscapes and seascapes along the Sonoran Desert coast of the Gulf of California of Sonora and among the Midriff Islands, an archipelago that stretches from the Baja California peninsula to mainland of Sonora. These efforts have documented several sets of taxa in *Cmiique Iitom* and Western or Linnaean scientific terminology to classify the biodiversity of the region.

In recent years, young Seri para-ecologists as well as elders have been coauthors on or listed contributors to several significant studies of biodiversity inventory, habitat conservation, and restoration published in half a dozen refereed journals and four books from academic presses (see supplemental material 2). Substantive collaborative studies

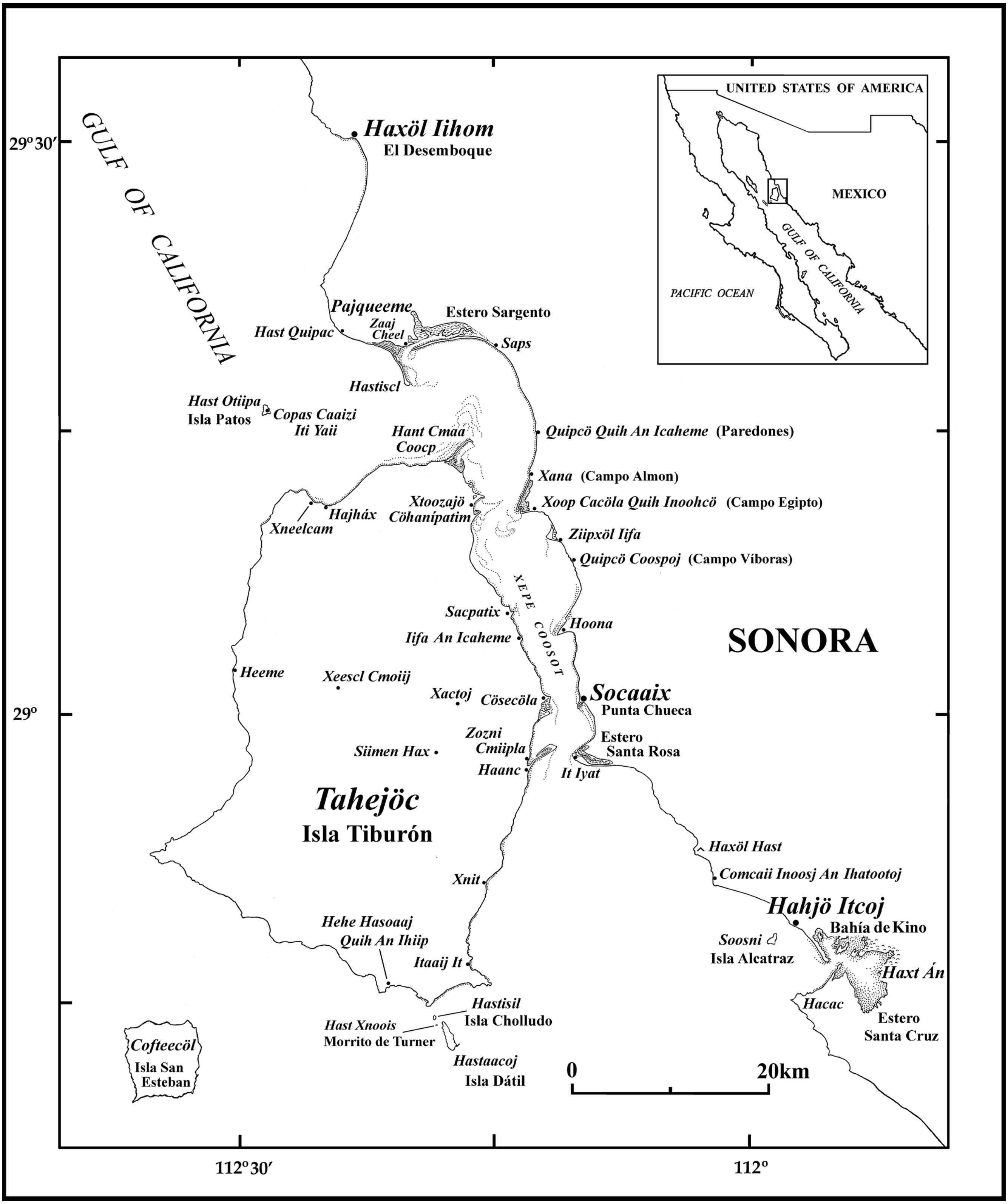

Figure 2. The region of the Comcaac. Source: Cathy Moser Marlett.

with the Comcaac have been undertaken regarding vascular plants, mollusks, fish, reptiles, birds, and mammals; species migration; endangered-species recovery; habitat restoration; and indigenous (economic) uses. These multicultural assessments of biodiversity serve as the departure point for a more refined grasp of a region, in this case the remarkably diverse Gulf of California and the surrounding Sonoran Desert. What follows is a series of examples of the nexus of

Table 2. An inventory of ethno and Western taxa recorded in the territory of the Comcaac.

	Ethnotaxa	Western taxa
Vascular plants	291	493
Mollusks	264	188
Marine fishes[a]	156	115
Marine reptiles	14	6
Terrestrial reptiles	42	46
Birds	139	262
Marine mammals	19	20
Terrestrial mammals	48	45

Note: Ethnotaxa is defined as the number of unique names used by the Comcaac for a species. *Western taxa is defined* as the number of unique species names. Taxa numbers represent the nomenclatural diversity as currently known for the territory of the Comcaac, defined here as the Sonora mainland from Puerto Libertad at the north, highway 36 on the east, Bahía de Kino at the south (including Estero Santa Cruz), and the coast on the west. Only the following six islands were considered: Tiburón, Patos, Datil, Cholludo, Alcatraz, and San Esteban. Marine diversity only considered the Midriff Island region.
Source: Plants (Felger and Wilder 2012); mollusks (Marlett 2014); marine fishes (Torre and Findley unpublished data); marine reptiles (Nabhan 2003); terrestrial reptiles (Nabhan 2003); birds (Morales 2006); marine mammals (Peréz unpublished data; Moser and Marlett 2010); and terrestrial mammals (Moser and Marlett 2010).
[a]The count for Western taxa among the fishes is conservative due to the inability to precisely identify to species level the fishes discussed with Seri consultants at the time of the interviews when the data were recorded, especially for the groups of sea catfishes (Ariidae), needlefishes (Belonidae), sardines (Clupeidae), anchovies (Engraulidae), flyingfishes (Exocoetidae), clingfishes (Gobiesocidae), gobies (Gobiidae), grunts (Haemulidae), halfbeaks (Hemiramphidae), sea chubs (Kyphosidae), and pipefishes (Syngnathinae).

traditional and Western knowledge in the case study of the Comcaac.

Landscapes and place names. Researchers (e.g., O'Meara 2010) have studied the way that the Comcaac conceptualize and talk about their land and seascapes. Place names that contain abundant references to plants and animals as well as other "affordances" convey the links between humans and their environment. Examples include *Moosni Oofija*, "what the green sea turtles encircle," which refers to a shoal in the ocean where *Chelonia mydas* individuals of certain age classes aggregate, and *Seenel Iitxo*, "where there are many butterflies," an aggregation site around scarce springs, seeps, or floral resources. The latter term may have offered human survival value, because it refers to a place where one would find fresh water after rains on the extremely arid San Esteban Island. These names clearly provide a context regarding biological resources located at culturally significant sites.

O'Meara (2010) showed that the landscape domain conceptualized by the Comcaac (based on generic landscape terms) describes unique environmental characteristics. The terminology is primarily made up of a generic term that indicates the material substance being referred to and another term that restricts its reference possibilities. This pattern of a semantically broad term (e.g., *ziix*, "thing"; *eenim*, "metal"; or *hast*, "stone") as the head of a landscape term is a characteristic that permeates the Seri grammar. Consider, for instance, the two nominal expressions *ziix coqueht*, "ball" or, literally, the "thing that bounces," and *ziix cozíp*, "round-tailed ground squirrel" or, literally, the "thing that kisses." These highly descriptive expressions provide a glimpse into the way that the Comcaac conceptualize the world around them.

We also see that, unsurprisingly, the Comcaac have generic names for the various parts of the intertidal zone that border between the sea, *xepe com*, "seawater lying," and the beach, *xepe quih iteel*, "edge of the sea." These intertidal zones are home to many sea creatures and are favorite spots to explore while looking for shells. Understanding the local conceptualization of the landscape where plants and animals live can provide a link to understanding the distribution patterns of local species guilds, their local uses, and their behavior.

Seri place names also encode biological knowledge that has otherwise been lost. The name in *Cmiique Iitom* for Rasa Island, a small but globally important sea bird island in the middle of the Gulf of California, is *Tosni Iti Ihiiquet*, "where the pelicans have their offspring." Yet, the island has not had breeding pelicans in the recent past (Anderson et al. 2013). However, a translation of Italian naturalist Federico Craveri's journals from an 1856 voyage in the Gulf reveals the presence of young pelicans on Rasa Island and corroborates the accuracy of the Seri name (Bowen et al. 2015).

New discoveries. The collective knowledge of biodiversity among the Comcaac that evolved over millennia is embedded in complex local linguistic expressions and cultural practices, which contributes new and often surprising information to regional conservation efforts, particularly with regard to endemic or endangered species (Nabhan 2003). Collaborations have often led Western taxonomists to populations of plant species previously uncollected in the region, as is the case with the wild tepary bean (*Phaseolus acutifolius* or *haap*), a once-important food crop for the Comcaac who lived in the interior of Tiburón Island (Felger and Moser 1985, Felger and Wilder 2012). Tiburón was thought to be too arid to support this variety of native bean. However, botanist Richard Felger was led to the remote site *Haap*

Caaizi Quih Yaii, "tepary bean users' place," by a Seri elder, Rosa Flores, who had not been to this volcanic hill for over three decades. However, multiple kilometers inland and on the other side of a large mountain range, there was a healthy population of *haap* growing up through the rocks (Felger 2000). The Comcaac have also documented observed behaviors and interspecific interactions not initially encountered by academic scientists (Nabhan 2000), such as the undocumented overwintering population of sea turtles previously thought by scientists to migrate away from the region during cold periods (Felger et al. 1976).

Other studies reveal major knowledge gaps, such as the names of mollusks that refer to species currently unidentified by scientists or have possibly been locally extirpated (Marlett 2014). Accounts of mythological sea creatures and reptiles also unknown to Western science are embedded within the songs and stories of their ancient navigation journeys throughout the Gulf of California (Monti 2002).

Introductions and extirpations. The role of humans in the current distribution of plants and animals is often overlooked (Nabhan 2002). There is an ever-growing body of evidence from around the world that supports the causal link between human agency, either deliberate or unknowingly, and anomalous species distributions (e.g., Heinsohn 2003, Rangan and Bell 2015). Several studies in the Seri region have specifically focused on refining the scientific taxonomy and geography of desert plants and animals in this region in the context of the Comcaac as agents of dispersal. Nabhan (2003), among several case studies, examined the translocation of the chuckwalla (*Sauromalus varius*) between San Esteban and Alcatraz islands. It is widely regarded among the Comcaac that these reptiles were taken from San Esteban to the smaller islands—often breaking the legs of the lizards to aid their transportation—for food. These actions are believed to be responsible for the continued and otherwise mysterious presence of this species of chuckwalla on Alcatraz today. Using genetics, Davy and colleagues (2011) examined a similar situation by directly testing the hypothesis that humans mediated the divergence of two species of spiny-tailed iguanas on islands in the Gulf of California (Ctenosaura conspicuosa and C. nolascensis). In line with Seri traditional knowledge, which holds that *C. nolascensis* was not brought from San Pedro Nolasco Island to San Esteban Island, their molecular data show a divergence time between these two island populations predating human colonization of the New World. The study by Davy and colleagues (2011) showed how TEK can be harnessed as a basis for hypotheses: In this case, genetic analyses corroborate knowledge of the Comcaac. Bowen (2003) investigated the possible explanations, including the Comcaac as well as microclimate, past climate change, and bat dispersal, in the rare occurrence of the organ pipe cactus (*Stenocereus thurberi*) on San Esteban Island. Studies that combine traditional and Western scientific approaches can continue to refine which plant and animal taxa the Seris culturally dispersed among islands and coastal habitats.

Scholarly research can also be incongruous with knowledge held by indigenous societies. Seri mythology and historical records supported a long-standing absence of desert bighorn sheep on Tiburón Island. The recent finding of 1500-year-old dung of this ungulate on Tiburón demonstrates its presence there prior to its unintentional rewilding to the island in 1975 (Wilder et al. 2014). This is a situation in which science is finding something traditional knowledge has not preserved. We see opportunities to increasingly use Seri knowledge, such as place names (e.g., islands named for plant or animal species no longer found there), cultural practices (e.g., burying the placenta of newborns next to translocated columnar cacti that often have anomalous distributions), and mythology (e.g., Comcaac ancestors fleeing a giant flood and turning into boojoms, *Fouquieria columnaris*, still seen in Sonora—the only occurrence of this species outside of the Baja California peninsula) to inform scientific hypotheses to be tested through cross-cultural collaboration.

Challenges. The Seri and other indigenous communities are experiencing persistent external pressures on their language and homelands. The loss of traditional livelihoods is linked to economic pressures and changes in their way of life as they adapt to globalization processes. Efforts to appropriate indigenous territory and natural resources by outside forces are unabated in many parts of the world. Strategies to conserve and honor TEK must take into account the rights of indigenous communities for self-governance, intellectual property, prior informed consent, and the maintenance of their language and culture while seeking sustainable economic-development options as affirmed in the United Nations Declaration on the Rights of Indigenous Peoples in 2008. Conservation and language-maintenance or -revitalization projects can benefit collaborators not only economically through remuneration but also mentally and emotionally through skill building and empowerment.

A host of challenges also exist in the collaborative process. One of the larger hurdles is how to have projects continue and not require the full time presence of the external collaborator. Often, projects are successfully implemented but quickly dissolve or take less effective directions shortly after the external researcher leaves. Collaboration among the diverse stakeholders and partners is likewise complicated given limited time, budgets, diverse mission statements, and schedules. A pervasive issue in collaboration with indigenous communities is the failure to return information collected by outside researchers in a format that is legible, either in their native or adopted language, and understandable by nonacademics. The lack of follow-through with the results and benefits of the collaboration hampers incentive for further joint efforts.

Next steps. Active efforts are being made not merely to archive but also to share this knowledge within indigenous communities. With respect to language conservation and maintenance, Moser and Marlett (2010) have compiled and published a trilingual Seri–Spanish–English dictionary documented over the course of a half-century. Their efforts also encompass the publication of numerous monolingual booklets of stories in *Cmiique Iitom* for community use (Marlett SA 2013). Intensive courses and workshops on native-language literacy have been offered in recent years, which support language maintenance and restoration that have involved dozens of younger Seri individuals. Thanks to these efforts, various Seri adults have some reading and writing ability in their own language. Now, the younger generation can assure that the traditional knowledge held by Seri elders is being documented, retained, and celebrated in their communities.

Seri individuals who underwent para-ecologist training are now working for Mexico's Commission for Natural Protected Areas (CONANP) and the tribal natural resources program. The quality of their work has been recognized by the Smithsonian Institution's Museum of the American Indian, National Geographic, Conservation International, Slow Food International, and many other international organizations. Many of the participating researchers (academics and Comcaac alike) are now members of the Next Generation Sonoran Desert Researchers (N-Gen; Wilder et al. 2013), a network of more than 350 of the leading scientists in the region—50% based in the United States and 50% based in Mexico. Indigenous leaders from different cultures together with academics in the region have convened the Biocultural Network of Sonora, an affiliate of the national Biocultural Network in Mexico, to address some of the most pressing ecological challenges confronting their communities.

Current efforts of the Biocultural Network, N-Gen, CONANP, Prescott College, and others are focused on supporting the Comcaac as leaders in science and conservation projects. The Program for the Development of Sustainable Conservation (PROCODES) of CONANP has been a significant stimulus and supporter of indigenous-proposed and -led projects. Under the PROCODES program, funding from the Mexican federal government is allocated to community-led projects throughout Mexico. These projects provide funds for both activities and moderate salaries for one year. The importance of financial compensation for natural resource–based livelihoods as an alternative to extractive and consumptive development-based earnings cannot be understated.

However, there is a profound gap in basic education and capacity training, including proposal writing, budget preparation, data analysis, and fiscal management, among many others. The collaborating organizations mentioned above are working with the Comcaac to provide opportunities to address these knowledge gaps through intensive field-based ecology courses, ongoing educational opportunities with Prescott College and outside researchers, and exchanges with other indigenous communities. Actions are also focused on strengthening intergenerational knowledge-transmission processes to engage the next generation in biodiversity stewardship. The collective goal of these efforts are to provide the Comcaac with the skills needed to lead efforts that address community-identified priority topics and create opportunities for livelihoods.

Conclusions

The complex nuances of local classification systems, both among the Comcaac and indigenous cultures worldwide, are a bountiful repository of understanding crafted over the millennia that is rapidly diminishing in scope and detail. By not fully honoring the real and potential value of indigenous science as it does professional academic and citizen science, our institutions risk ignoring the opportunity for consilience among the many sources of knowledge. The challenges we face both collectively as a species and independently as nations, societies, communities, and individuals are too great to not seek out knowledge that can advance our response to an impoverished world.

Acknowledgments

Many individuals among the Comcaac, fellow researchers, foundations, universities, nonprofit organizations, and federal agencies have been instrumental in making this collective work possible. Thank you in particular to Richard Felger, Lloyd Findley, Cathy Moser Marlett, Thor Morales, Héctor Pérez Puig, and Jorge Torre for assistance in developing the ethnotaxa and Western diversity numbers in the territory of the Comcaac. We particularly thank our many collaborators and students in the two Comcaac communities of Punta Chueca and Desemboque for what they have imparted to us in terms of knowledge and values. Foremost among supporting foundations have been the MacArthur Foundation; the Overbrook Foundation; the Agnese Lindley Haury Foundation; the Pew Charitable Trust; the W.K. Kellogg Foundation; the David and Lucille Packard Foundation; the Christensen Fund; the National Science Foundation; and Mexican federal and state agencies such as Consejo Nacional de Ciencia y Tecnología (CONACYT), Comisión Nacional de Áreas Naturales Protegidas (CONANP), Culturas Populares, and Instituto Nacional de Antropología e Historia; the US Fish and Wildlife Service Sonoran Joint Venture and Wildlife Without Borders; UC MEXUS; Comunidad y Biodiversidad; Prescott College Kino Bay Center for Cultural and Ecological Studies; and the Centro de Information y Desarrollo Indígena (CIAD).

Supplemental material

The supplemental material is available online at *http://bioscience.oxfordjournals.org/lookup/suppl/doi:10.1093/biosci/biw026/-/DC1*.

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