Integrative Spatial Modeling: Utilizing Local Ecological Knowledge and Geospatial Applications to Model Ecosystem Services and Assess Their Vulnerability

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ABSTRACT

Defined as the benefits that humans receive from natural systems, ecosystem services (ES) are of great importance to human livelihoods and overall ecological health. Assessing the risks posed by anthropogenic disturbance drivers to processes that support resilient social-ecological systems is critical for resource management and conservation. With many rural populations having a high dependence on local natural resources and extensive knowledge of the landscape, the importance of identifying effective adaptive governance mechanisms that engage these stakeholders is paramount. This paper explores preliminary results of an ongoing "integrative spatial modeling" (ISM) methodology conducted in the south-central highlands of Ethiopia, which combines qualitative and quantitative approaches from the social and natural sciences. ISM seeks to 1) understand the nuances of local user valuation of provisioning ES through the important adaptive governance mechanism of knowledge integration, 2) model the suitable habitat of these culturally, economically, and ecologically significant service-providing species, 3) offer a unique platform for assessing ES vulnerability to anthropogenic disturbances including population growth, climate change and invasive species, and 4) actively engage the local community of interest throughout the iterative ISM process. The ultimate goal is the promotion of a robust tool for effective and legitimate community-centered collaborative conservation efforts, particularly with rural and indigenous peoples.

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INTRODUCTION

The powerfully intuitive, yet poorly understood concept of ecosystem services (ES), championed by the seminal global biodiversity and human well-being appraisal of the Millennium Ecosystem Assessment (MA, 2005), and continued by other national and global initiatives including The Economics of Ecosystems and Biodiversity[1] and the Natural Capital Project[2], tackles the inherent "messiness" of coupled social-ecological systems. Such efforts have revealed the acute and detrimental impacts of anthropogenic activities on global biodiversity, and the important links between human well-being and ecosystems (MA, 2005; Kremen, 2005). Broadly defined as the benefits that humans receive from natural systems and environments, ES are a key input of human livelihoods and overall ecosystem health, but the natural capital that underpins these services is not well understood or extensively monitored, increasing ES vulnerability and leading to their degradation and depletion. With this understanding, growing calls for the incorporation of ES into land management practices and environmental policymaking have been made (Daily *et al*, 2009; Daily & Matson, 2008; Ranganathan *et al*, 2008), but how do we best govern ES to protect biodiversity and ensure human-wellbeing in an increasingly connected and crowded world?

This paper seeks to lay the groundwork for bridging existing gaps present in the ecosystem services, adaptive governance, and species distribution modeling literatures, which have much to offer each other in regards to theory and practice, yet tend to talk past one another. Contributing preliminary results of ongoing research in Ethiopia, we explore the benefits and implications of integrative spatial modeling (ISM) methodology in promoting adaptive governance in community-based collaborative conservation, that explicitly connects ES to local beneficiaries, through a mix of qualitative and quantitative approaches. ISM attempts to: 1) understand the nuances of local resource user valuation of provisioning ES through the important adaptive governance mechanism of knowledge integration, 2) model the suitable habitat of these culturally, economically, and ecologically significant service-providing species, 3) offer a unique platform for assessing ES vulnerability to anthropogenic disturbances including population growth, climate change and invasive species, and 4) actively engage the local community of interest throughout the iterative ISM process. We contend that ISM can be a valuable interdisciplinary tool to address a variety of community-based conservation efforts in rural regions with mounting anthropogenic pressures.

Social-Ecological Systems and Adaptive Governance

Social-ecological systems (SES) are complex, adaptive systems (Berkes & Folke, 1998; Berkes *et al*, 2003) comprised of dynamic and interacting processes. SES are affected by an array of environmental and anthropogenic drivers of change, occurring across spatial and temporal scales. Intimately linked with the concept of SES is resilience, which is the capacity of a system to absorb or recover from environmental and anthropogenic perturbations and reorganize, while still maintaining the same overall structure and function (Holling, 1973; Carpenter & Gunderson, 2001; Folke *et al*, 2004; Folke *et al*, 2005). This inherent complexity requires flexibility in managing for resilience and moving beyond overly simplistic institutional prescriptions to mitigate pressing environmental problems (Ostrom & Cox, 2010). In response to this understanding, the concept of adaptive governance has emerged, addressing the array of interactions inherent in SES, including the structures, rules, processes, and traditions that determine environmental management.

In the broadest sense, "governance is the structures and processes by which people in societies make decisions and share power" (Folke *et al*, 2005, 444), and as human beings we have a wide range of governance options at our disposal when seeking to address global environmental challenges

[1] http://www.teebweb.org/
[2] http://www.naturalcapitalproject.org/

(Dryzek, 2012). A diversity of literature can be found exploring various facets of environmental governance, including definitions and characteristics of global environmental governance (Biermann & Pattberg, 2008), sustainable processes and outcomes (Adger & Jordan, 2009), multilevel governance arrangements (Betsill & Bulkeley, 2006), issues of transparency (Gupta, 2010), and the role of science (Jager, 2009). Adaptive governance more specifically, is defined as "...an evolving research framework for analyzing the social, institutional, economical and ecological foundations of multilevel governance modes that are successful in building resilience for the vast challenges posed by global change, and coupled complex adaptive social-ecological systems" (SRC, 2012). Beyond the actors and institutions involved, adaptive governance arguably necessitates a deep understanding of a system's biotic, abiotic and social processes, providing a framework and vision for socially and ecologically desirable outcomes. With widespread discussions of adaptive governance as a useful framework for addressing environmental issues across scales, a number of important mechanisms of adaptive governance have been addressed by various scholars. These often overlapping and interacting features include knowledge generation and integration (Gadgil *et al*, 1993; Fernandez-Gimenez *et al*, 2006; Brown, 2009), organizational learning (Westley, 1995; Epstein & Roy, 1997; Daniels & Walker, 2001; Ostrom, 2005), collaboration (Ostrom, 1990; Wondolleck & Yaffee, 2000; Daniels & Walker, 2001; Schusler *et al*, 2003; Ostrom, 2007; Plummer & Armitage, 2007), social capital (Flora, 1998; Pretty & Ward, 2001; Titeca & Vervisch, 2008; Leahy, & Anderson, 2008), leadership (Shannon, 1991; Danter *et al*, 2000), diversity of actors and institutions (Low *et al*, 2003; Ostrom, 2005), and monitoring (Boyle *et al*, 2001; Wilhere, 2002; Fernandez-Gimenez *et al*, 2008; Lyons *et al*, 2008; Cundill & Fabricius, 2010).[3]

Local Ecological Knowledge Integration

The ISM approach employed in this study explores local ecological knowledge (LEK) integration as an important mechanism for adaptive governance. A deep understanding of ecosystem dynamics and effective management practices can be found with rural communities that interact with their local landscapes for their livelihoods on a daily basis. An array of cross-disciplinary research denotes the potential benefits of integrating ecological knowledge of resource users with conventional scientific knowledge. This scholarly inquest has gained much attention in the fields of anthropology, sociology, political science, and natural resource management over the past two decades. Such experiential and applied knowledge of the environment holds utility for contemporary science, stemming from local resource users' physical connection to place, and constitutes a rich, deeply-rooted "practical environmentalism" (Pickering-Sherman *et al*, 2010). Examples demonstrate how local and traditional knowledge may have meaningful contributions to long-term local economic development studies (Sillitoe, 1998), provide a complementary perspective to adaptive ecosystem management (Berkes *et al*, 2000; Fernandez-Gimenez & Estaque, 2012), facilitate effective co-management between resource users and government agencies (Fernandez-Gimenez *et al*, 2006), promote decision-making authority for community stakeholders (Ballard *et al*, 2008), and afford a more holistic assessment about the environmental attributes and processes in question (Gagnon & Berteaux, 2009). Despite this, well-placed criticism of such knowledge integration also exists. Critics of this process note an array of challenges, including the potential for co-optation of local knowledge (Chalmers & Fabricius, 2007), oversight of critical power relations (Nadasay, 1999), lack of institutional legitimacy (Kofinas, 2005), and legalistic issues of intellectual property rights (Shingu, 2005). Continued work is thus needed to refine and assess the practical application of integrating LEK and conventional scientific knowledge, as "...integrating different sources of knowledge acts as a critical social source of resilience for adaptation

[3] Folke et al (2005) and Armitage et al (2009) additionally provide useful syntheses of many of these predominant mechanisms.

and transformation" (Folke *et al*, 2005, 462). Yet upon reviewing species distribution modeling (SDM) and ecosystem services (ES) literature, noticeable gaps in engaging local and traditional ecological knowledge integration in theory and application become apparent.

For this study we defined LEK according to Olsson and Folke (2001), as "knowledge held by a specific group of people about their local ecosystems". Calling it LEK instead of traditional ecological knowledge (TEK) was a conscious decision as TEK is distinct, being "...culturally embedded and transmitted among members of a geographically- and socially-defined community" (Fernandez-Gimenez & Estaque, 2012, 287). In the case of our study site in Ethiopia, the recent legacy of the communist Derg government included extensive relocation of people from their homelands to other parts of the country as recently as the early 1990s, in an attempt to deter civil unrest (Keller, 1988; Bussmann *et al*, 2011). Relocation is still practiced with the current government as an option for people who have exhausted resources in their traditional homelands, thus holding great potential for disrupting the historical and cultural continuity of TEK across Ethiopia.

Species Distribution Modeling, Knowledge Integration and Ecosystem Services

Although the creation and use of new geospatial mapping and modeling applications is rapidly increasing across disciplines, the integration of local and traditional ecological knowledge is noticeably lacking in theory and applied studies. An array of information science and technology options are available to researchers, with increased accessibility and speed of these tools. This has allowed important advancements in the quality and speed of information acquisition, analysis and dissemination, in addition to more effectively addressing important social and environmental concerns. Despite this, the human element is often absent from these analyses, with local and traditional forms of ecological knowledge rarely acknowledged, albeit with some noteworthy exceptions (Calamia, 1999; Naidoo & Hill, 2006; Graham *et al*, 2010)[4]. Within species distribution modeling (SDM) literature, this gap is especially prevalent. SDM combines information on species locations with environmental data, to quantify species distributions across environmental gradients and map those distributions through the use of statistical models (Elith & Leathwick, 2009; Franklin, 2009).

Useful applications of SDM can be found across a wide range of research and management endeavors including risk assessment of invasive species (Stohlgren *et al*, 2010; Jarnevich *et al*, 2011; Lindgren, 2012), extrapolating future climate change impacts on forest pest outbreaks (Evangelista *et al*, 2011), food security (Evangelista *et al*, In Review), and endemic flora (Davis *et al*, 2012), characterizing livestock production systems (Cecchi *et al*, 2010), conservation planning (Ferrier, 2002; Kremen *et al*, 2008 Thorn *et al*, 2009), ecological restoration efforts (Carroll *et al*, 2003; Hirzel *et al*, 2004), and predicting suitable habitat for cryptic and endangered species (Pearson *et al*, 2007; Evangelista *et al*, 2008; Kebede *et al*, In Review). These mapping and modeling techniques allow for comparison of various management approaches that can be tested on the ground (Ashton *et al*, 2011). SDM applications often hold a central role in conservation planning and policy-making, yet rarely incorporates or acknowledges LEK, despite the important benefits that local and traditional forms of knowledge have brought to scientific research around the world.

Focusing on ecosystem services (ES) literature, reveals numerous studies addressing ES governance and ES mapping and modeling. Kenward et al (2011) offers the largest systematic investigation of 34 local and international case studies, addressing what governance strategies best afford outcomes for the following environmental response variables of ecosystem service enhancement,

[4] Furthermore, participatory GIS and citizen science literature has made important advances in engaging local communities in scientific data collection and democratizing scientific analysis. See McCall (2003), Cooper et al (2007), and Gallo et al (2011). Although much of this work tends to be conducted in developed countries, calls for engaging local and traditional ecological knowledge are starting to occur. See Newman et al (2012) and Pandya (2012).

biodiversity maintenance and sustainable use of natural resources. Their results confirm the beneficial nature of adaptive management in regards to ES with emphasis on the importance of knowledge integration and leadership, which had a strong positive effect on all response variables assessed. Although empirical cases of ES mapping and modeling are prevalent, and have proven beneficial for comparing the trade-offs between different land use/land cover change scenarios (Nelson & Daily, 2010; Nelson *et al*, 2009), in addition to broader theoretical and technical discussions (Naidoo *et al*, 2008), most focus explicitly on market valuation of services. Moreover, in similar fashion to SDM literature, existing ES mapping and modeling approaches overall fail to incorporate local and traditional ecological knowledge of resource users, and fail to connect the services assessed to actual beneficiaries on the ground (Ricketts, 2013). This trend exists despite rural communities often being disproportionately dependent on critical services derived from local landscapes, and the Millennium Ecosystem Assessment calling for increased engagement of local communities for ES conservation and monitoring efforts (MA, 2005).

Focusing on particularly vulnerable landscapes like Ethiopia, we see the necessity of adaptive, flexible, interdisciplinary approaches. Ethiopia's flora, comprised of approximately 6-7,000 higher plant species (Asfaw & Tadesse, 2001), is essential to human well-being and ecological diversity, but is increasingly threatened by a range of anthropogenic pressures. The United Nations Environmental Programme (UNEP) lists a number of important and linked environmental issues facing Ethiopia, including water access and availability, livestock and land degradation, and threats to biodiversity and endemism (UNEP, 2008). These longstanding problems have acute impacts on plant communities, and are further heightened by a rapidly growing rural population. Some 85% of Ethiopians live in rural areas, with the vast majority of these people (approximately 90%) living in the highlands and dependent on small-scale, rain-fed subsistence agriculture (Zeleke, 2010, 6). Furthermore, between 70 and 80 percent of the population depend on traditional plant-derived medicine for their primary healthcare (Abebe, 1984; Bekalo *et al*, 2009; Assefa *et al*, 2010; Zenebe *et al*, 2012). Such increased pressures in places like Ethiopia place "...a region on a trajectory of greater risk to the panoply of stresses and shocks that occur over time" (Folke *et al*, 2005, 460), reducing the ability and capacity to adapt from shock, and thus making the social-ecological system more vulnerable (Adger, 2006).

STUDY AREA

Our study concentrated on three sites located in the Oromia Region of Ethiopia, each broadly representing a level of human incursion and a similar range of elevation and disturbance gradient, including the town of Dinsho at the northern edge of the Bale Mountains National Park (BMNP), and two villages adjacent to protected hunting concessions called Odo Bulu and Demaro, located east of BMNP (Figure 1). The elevation of Dinsho is about 3,200m, with a more varied elevational gradient for Odo Bulu and Demaro, ranging from 1,500-3,300m (Bussmann *et al*, 2011). Mean annual temperatures ranging from 2.4C° to 15.5C° in Dinsho and 10.2 C° and 21.3 C° in Odo Bulu and Demaro respectively. Precipitation for Dinsho averages 1,218.6mm annually (Assefa *et al*, 2010), and 68 to 93mm in Odo Bulu and Demaro (Busmmann *et al*, 2011), with the entire region having a bimodal distribution pattern with the "small rains" called *belg* occurring from February to May and the "big rains" called *kiremt* occurring from June to September. The residents of all three study sites are predominately of Oromo heritage, the main ethnic group of Ethiopia's southern highlands. Traditionally the Oromo people are agro-pastoralists and small-scale subsistence farmers that cultivate wheat and barley as a dietary staple and cash crop. To a lesser extent, cattle, goats and sheep are kept by most households. During the months of cultivation, the livestock are moved into open areas within BMNP where they are grazed until the end of harvest (Stephens *et al*, 2001; FZS, 2007).

The region is also an area of high biodiversity, with rare endemic species including the endangered mountain nyala (*Tragelaphus buxtoni*: Evangelista *et al*, 2007) and the critically

endangered Ethiopian wolf (*Canis simensis*: Waltermire, 1975). Additionally, the area is the product of a varied elevational and climatic gradient. The landscape is comprised of dense forests populated by immense trees including *Juniperus procera* in the predominately dry southern expanses of Gaysay, *Hagenia abyssinica*, *Hypericum revolutum*, *Schefflera abyssinica* and *S. volkensii* in the wetter, northern reaches, in addition to an abundance of *Artemisia*, *Helichrysum*, *Ferula* and *Kniphofia* genera in the flatter sections of the valley (UNESCO, 2013). Furthermore the area's topography and vegetation reflect the extended weathering of lava outflows stemming from the Oligocene Epoch (33.9 -23 million years B.P.) (Assefa *et al*, 2010), which have resulted in the loamy, fairly fertile, and low-density Mollic Andosol soils commonly associated with these volcanic sites (Yineger *et al*, 2007). Threatened by deforestation and grazing pressure from a rapidly expanding population of people and livestock, the distinct vegetation of the region is critically important to human well-being and biodiversity as "...both the conditions and the isolation of these areas have led to the evolution of unique plant communities that are found nowhere else" (UNEP, 2008, 11).

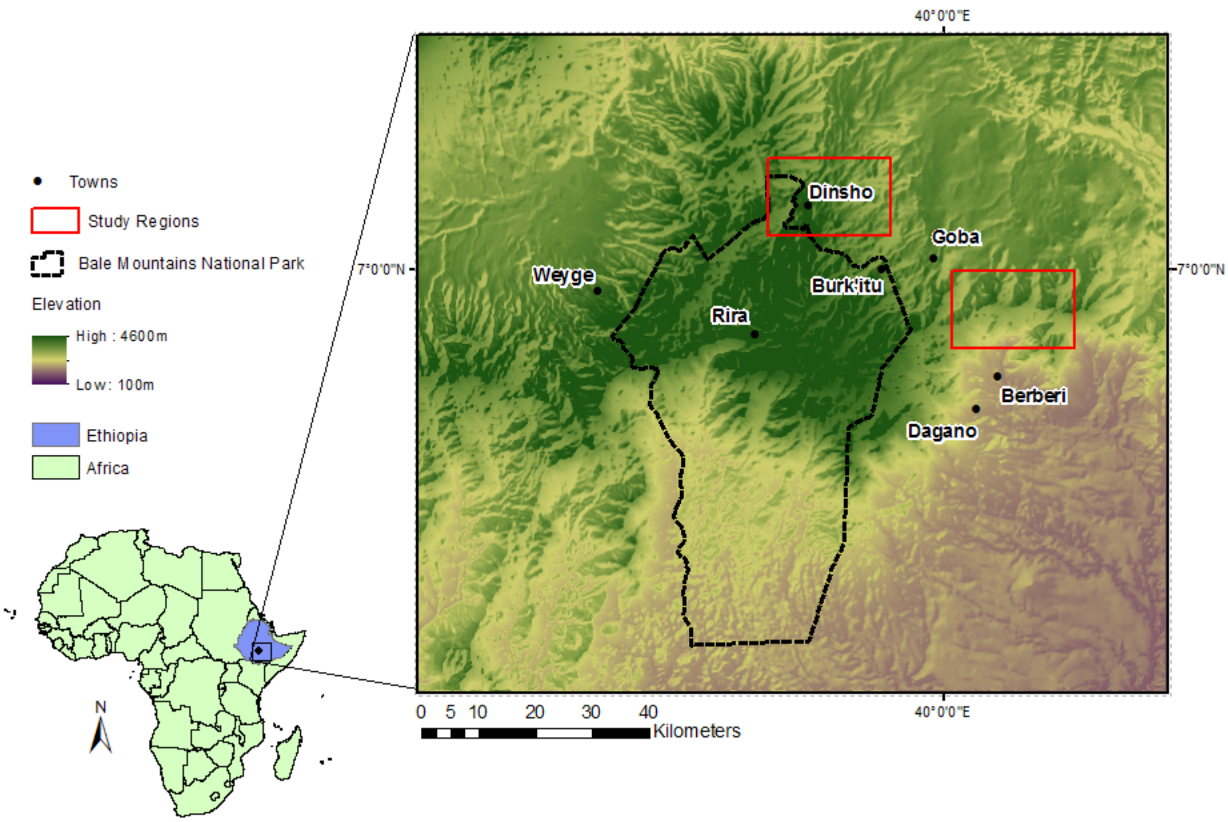

Figure 1. Study sites located in the south-central highlands of Ethiopia

METHODS

Our integrative spatial modeling (ISM) methodology (Figure 2) consists of a mixture of qualitative and quantitative approaches crossing social and natural science disciplines, with the ultimate goal of promoting adaptive governance in community-based collaborative conservation efforts. The components of ISM are: 1) to understand the nuances of local user valuation of provisioning ES through the important adaptive governance feature of knowledge integration, 2) Modeling the suitable habitat of these culturally, economically, and ecologically significant service-providing species, 3) Offer a unique platform for assessing ES vulnerability to anthropogenic disturbances including population growth, climate change and invasive species, and 4) actively engage the local community of interest throughout the iterative ISM process. This paper focuses on the first two steps, and concludes by discussing necessary next steps. We find through this preliminary assessment, that ISM holds great potential as a useful interdisciplinary tool for community-based conservation efforts.

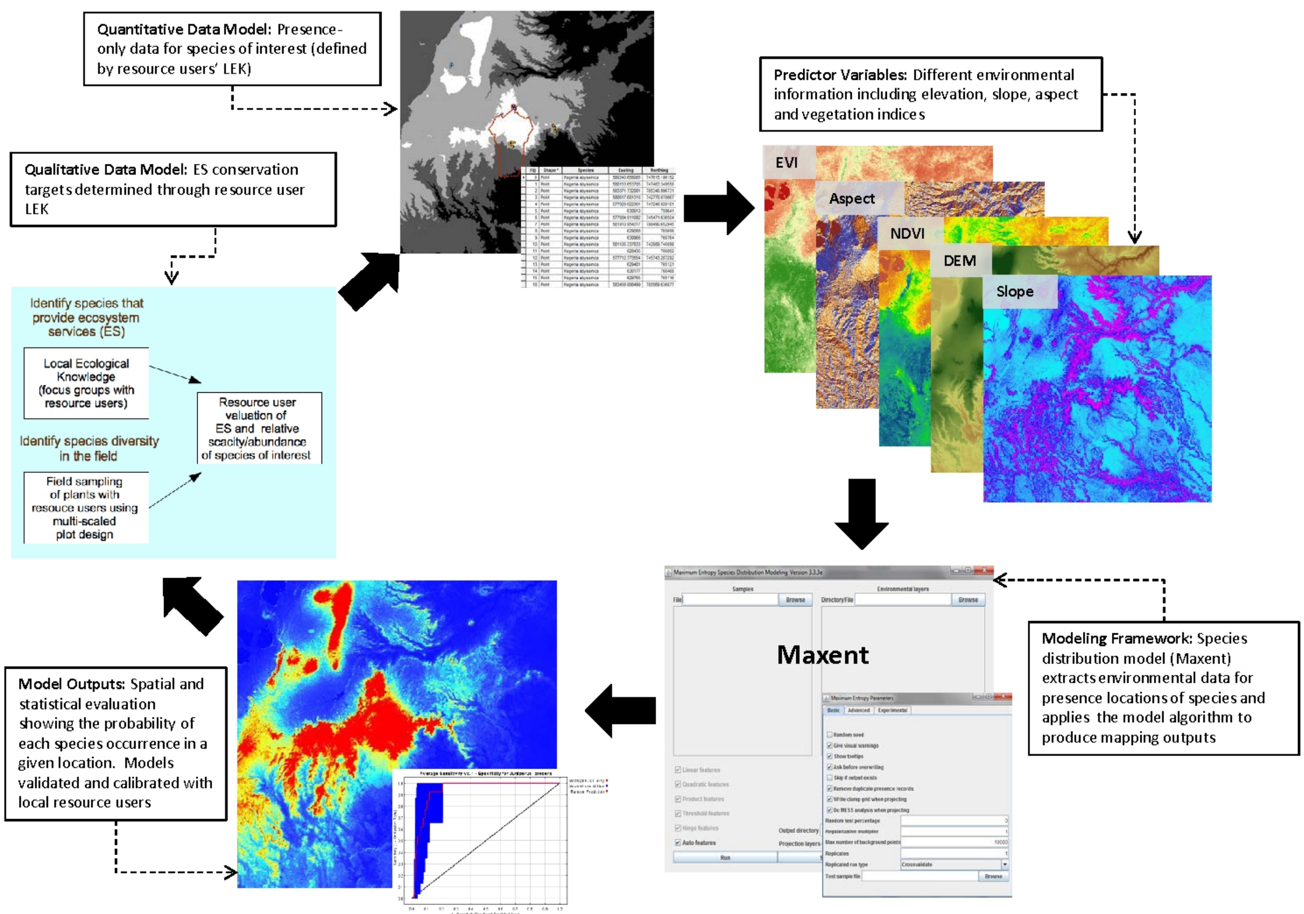

Figure 2. Integrative spatial modeling methodology (ISM) workflow. The model relays the first two stages of ISM; integrating qualitative data (local ecological knowledge), used to define ecosystem service (ES)-providing species of interest and locate species in the field, with quantitative statistical modeling (species distribution modeling), to map suitable habitat of critical ES. These models are brought back to the community to validate and calibrate in an iterative process. The final, future addition to the workflow and methodology is utilizing similar modeling procedures to assess the vulnerability of ES-providing species to anthropogenic disturbances (e.g. climate change, population increase and invasive species).

Qualitative data (local ecological knowledge)

We focused on applying techniques inherent to ethnobotanical studies, while incorporating a necessary understanding of gendered-knowledge, more explicitly addressed in anthropology, sociology, and political science research. Although ethnobotanical research is a prime example of integrating local knowledge and conventional scientific methodologies (Vandebroek *et al*, 2011), many published studies have overlooked the importance of women's plant knowledge (Pfeiffer & Butz, 2005). This “lack of gender consciousness” (Garibay-Orijel *et al*, 2012, 10) is especially pervasive in Ethiopia, with many studies implicitly assuming homogeneity of a given community's LEK, although recent work has revealed the importance of women's distinct plant knowledge in the Bale Mountains region (Luizza *et al*, in review). With the paucity of data on women's ethnobotanical knowledge in Ethiopia, it was imperative to catalogue this understanding of local flora to compare with that of men's plant knowledge.

In this study we catalogued women's knowledge of a wide array of plant-derived provisioning services through the use of a focus group approach, which afforded a view of different perspectives about the topic simultaneously (Morgan, 1997) and allowed unanticipated information to emerge (Huntington, 1998). Data on men's uses of plants in the region (specifically the villages around the hunting concessions, Odo Bulu and Demaro) had already been collected through semi-structured interviews during a recent study which included three of the authors of this paper (Bussmann *et al*, 2011). Additionally, men in all three study sites were engaged during this most recent trip to gain insight into some of the most important provisioning service plants in the region for both men and women.

Our study design was pre-approved by the Social, Behavioral, and Education Research Institutional Review Board at Colorado State University (Protocol # 12-3795H). The focus groups were conducted by Young, Kuroiwa and Luizza in December, 2012 with interpretive support by Worede. Participants included 13 local women that resided in or around the town of Dinsho and the villages adjacent to the Odo Bulu hunting concession. The women from Dinsho were recruited through a women's micro-loan program managed by a local non-profit organization, and the women from the village near Odo Bulu were recruited by Worede with the help of local villager who works as the head tracker for the hunting concession. Twelve local men participated in semi-structured interviews in 2011, recruited through a random sampling technique (Bussmann *et al*, 2011). We compiled 337 pictures of plants collected by (Bussmann *et al*, 2011), which were also used for the men's interviews, and found within the TROPICOS botanical database[5] managed by the Missouri Botanical Garden. These pictures were organized and formatted to contain either one or two full-color images of each individual plant, in the field (often with one close-up shot of the flower, fruit or leaves), with the scientific name and local name (if known) printed on each picture. The nomenclature of all species also follows TROPICOS.

At the beginning of each women's focus group, a formal introduction was made, explaining the project and its goals before receiving verbal consent by each participant. Pictures were laid out on tables in groups based on growth type (e.g. fern, grass, tree, shrub) and the women were encouraged to walk around, view the pictures and talk with each other as long as they needed. Each respondent collected pictures of plants they recognized, and once everyone had finished, the respondents and interviewers discussed each collected plant's local Oromiffa name and the use(s) derived from it (Figure 2). All participants had the opportunity to contribute their knowledge for each plant species. Each focus group lasted for approximately six hours and was conducted in Oromiffa with the help of Worede, who is conversant in Oromiffa and fluent in Amharic and English. In addition to Worede's

[5] http://www.tropicos.org

translation help, the use of hand gestures helped transcend language barriers between the interviewers and focus group respondents. Plants that remained on the table were collected and placed in a folder labeled "unidentified" and the process was repeated until all 337 plants were accounted for. Plant uses were later grouped into a set of 15 ethnobotanical provisioning service categories (Table 1), in part drawn from Bussmann et al (2011) and supplemented with new categories coming out of the focus group. Bussmann et al's (2011) data on men was subsequently re-assessed with this modified provisioning service category list.

Figure 2. Focus group respondents identifying plants in Dinsho (L), and discussing plant uses in Odo Bulu (R).

Plant Use	**Description**
Construction	Plants utilized in the assemblage of buildings, including homes and other habitable structures, fencing and large farming implements like ploughs
Cooking	Plants utilized as cooking implements for the preparation of food, sieves, containers for food storage, or as non-stick spread for greasing clay injera pans
Cosmetics	Plants utilized as care substances or implements to enhance the appearance and/or odor of the human body
Detergent	Plants utilized as cleaning agents for clothing or cookware/dishware
Firewood	Plants gathered and utilized as fuel material
Fodder	Plants gathered and utilized as feed for domesticated livestock
Food	Plants gathered and consumed to provide nutritional support for the human body
Forage	Plants consumed in the wild by livestock and/or wildlife
Honey	Plants utilized in any aspect of honey production, including plants pollinated/nectar collected by bees or used in construction of beehives
Medicinal	Plants utilized for their actual or perceived curative properties for a variety of human physical ailments
None	Plants with no use

Other	Plants utilized for in a variety of other less prevalent processes (leather softeners, aromatics, paint, cleaning implements, baskets and other non-food storage containers, hats, furniture, decoration, food for non-ungulate wildlife or livestock, non-construction related rope/twine, toothbrushes)
Spiritual/Ceremonial	Plants utilized for alleviating spiritual ailments or afflictions or for special ceremonial events
Unknown/Unidentified	Plants with no known use or not identified in the interview process
Veterinary	Plants utilized for their actual or perceived curative properties for a variety of livestock physical ailments

Table 1: Description of each ethnobotanical provisioning service category with detailed explanation of each plant use.

Quantitative Spatial Data

Vegetation field sampling was conducted at all three study sites and supplemented with species occurrence data for modeled ES-providing plant species, acquired from the Global Biodiversity Information Facility (GBIF) database[6]. Field data was conducted using Modified-Whittaker plots (Stohlgren *et al*, 1995), which have proven extremely effective at capturing plant diversity and species richness, by utilizing a nested plot approach of multiple sampled spatial scales at 1m², and 100m² subplots within a 1,000m² main plot (Campbell *et al*, 2002; Ghorbani, *et al*, 2011). These field plot data were used for the majority of ES-providing species occurrence points. To predict suitable habitat of the local user-defined ES-providing plants, we used five independent spatial variables in our analyses that were derived from remotely sensed data and GIS computations. All data was projected in the Universal Transverse Mercator system (WGS 84, Zone 37N) with 30m resolution. Coarse resolution moderate resolution imaging spectroradiometer (MODIS) imagery was re-sampled to 30m. The MODIS data acquired from instruments aboard NASA's Terra satellite were downloaded from the United States Geological Survey Global Visualization Viewer (GLOVIS)[7]. A 30m resolution Digital Elevation Model (DEM) from the National Aeronautics and Space Administration's (NASA) Shuttle Radar Topography Mission was used, with slope in degrees and aspect raster layers generated in ArcGIS 10.0 Spatial Analyst. Two vegetation indices- Normalized difference vegetation index (NDVI) and enhanced vegetation index (EVI)- were derived from MODIS and additionally run as environmental predictors in concert with the DEM, slope, and aspect raster layers. Both vegetation indices were acquired for a single MODIS scene during the end of the dry season (December, 2012) when the team was most recently in the Bale Mountains conducting the women's focus groups.

Data were processed through Maxent statistical software package version 3.3.3e (Phillips *et al*, 2004; Phillips *et al*, 2006). This species distribution modeling approach is a general-purpose machine learning method that models species distributions from presence-only species occurrence records (Elith *et al*, 2011), and been shown to have high accuracy in predicting species distributions (Franklin, 2009; Stohlgren *et al*, 2011), even with small sample sizes (Pearson *et al*, 2007). The principle of maximum entropy states that a probability distribution that is the most spread out, or closest to uniform (i.e. having "maximum entropy"), subject to known constraints, is the most appropriate estimation of an unknown distribution, because it concurs with all knowns and avoids all that is not known (Phillips *et al*, 2006). The Maxent modeling output creates a surface with a continuous habitat suitability gradient, with values ranging from 0 (least suitable or dissimilar) to 1 (most suitable or most similar to cells with

[6] http://www.gbif.org/

[7] http://glovis.usgs.gov/

presence points) and provides a calculation of the percent contribution of the different environmental variables used in the model (Stohlgren *et al*, 2011). For our study, models for each user-defined ES-providing species of interest were run 15 times, and averaged. This approach combined with the Maxent feature of withholding a specified portion of the data for testing, facilitated enhanced model performance while utilizing all available data without having an independent dataset. Furthermore, these multiple model runs provided a measurement of the amount of variability in the model. For the random test percentage, we withheld 10% of the data across all three models run. Furthermore our models were run with 5,000 iterations to allow for adequate convergence time, which reduces the likelihood that the model will over-predict or under-predict the species-environmental relationships. Maxent default settings were used for regularization parameterization and creation of background points, as other studies have shown these default settings to achieve strong performance in predicting habitat suitability (Phillips & Dudík, 2008).

RESULTS

LEK Data

The women's focus groups resulted in the identification of 181 plants, and the men's interviews, 294 plants. Species identified spanned an array of growth types including herbs (seed-producing annuals, biennials, or perennials that do not develop persistent woody tissue and die down at the end of a growing season), shrubs (relatively low height woody plants, often with several-stems), trees (woody perennial plants with a single, often elongated main stem and generally few branches on their lower extent), ferns (flowerless, seedless vascular plants, with roots, stems, and fronds, that reproduce by spores), climbers (weak-stemmed plants, including vines, that gain support from climbing, twining, or creeping along a surface), and grasses (predominately herbaceous plants with jointed stems, slender sheathed leaves, and flowers produced in spikelet bracts).

A broad range of provisioning services were associated with the identified species and revealed distinct types of knowledge for men and women (Figure 3). For example, men identified nearly six times as many plants with forage uses and twice as many firewood uses than women, but women identified nearly twice as many plants providing honey production uses and medicinal and veterinary uses. Respondents were detailed and forthcoming in their descriptions of the plant uses. For the women, this was particularly because of the relationship that had already been built with the group by the micro-loan program. Having this established trust was critical for our study, which enacted a rapid rural appraisal approach, seeking cost-effective ways to learn about rural conditions (Chambers, 1981). Such brief assessments can hold important trade-offs of data collection efficiency, and richness and potential accuracy of the data. A broad array of LEK and TEK literature acknowledges the merits of different approaches for cataloguing local and traditional knowledge. These approaches involve different data collection methods and levels of engagement and embededness in a community of interest, ranging from rapid appraisal workshops with local stakeholders, conducted in a matter of hours (Merritt *et al*, 2009), to more traditional ethnographic approaches, which are often characterized by individual interviews and involve long-term community engagement spanning a number of years (Peloquin & Berkes, 2009). With any approach having established trust is paramount.These findings of the rich extent and unique contribution of rural people's LEK in the Bale Mountains reveals the urgent need to include this gender-distinct understanding of local flora when conducting management of plant resources and attempts at community-based conservation planning. For our ISM methodology, this is a critical step in determining ecosystem service conservation targets.

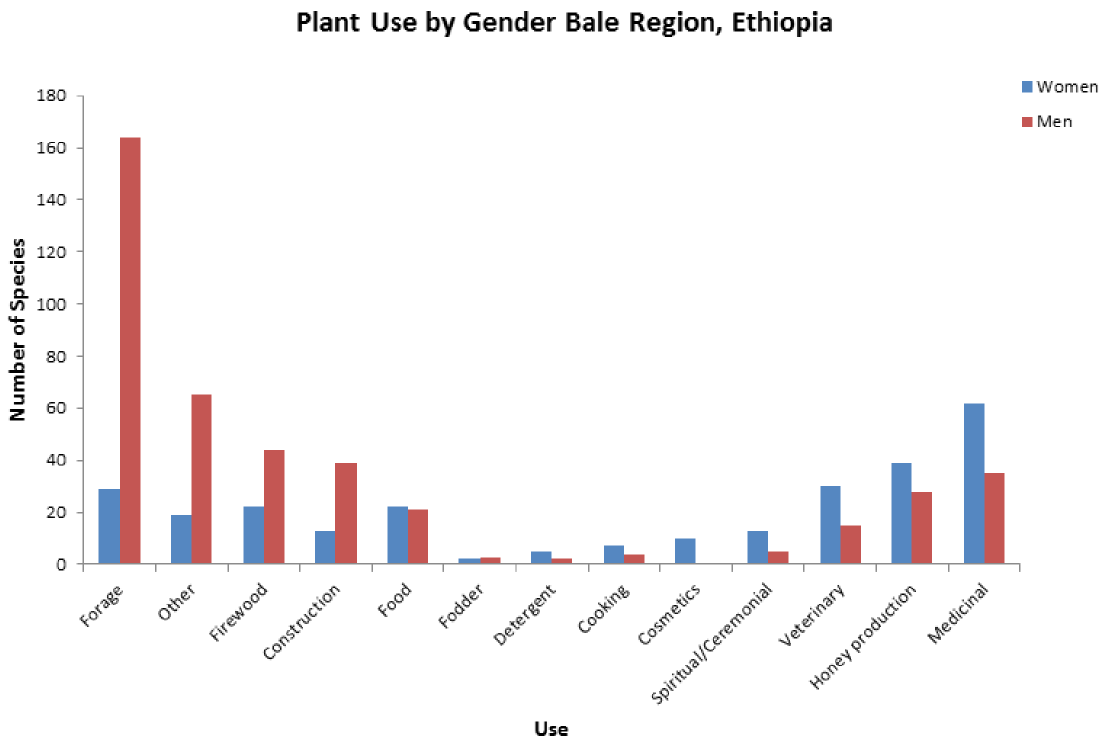

Figure 3. Identified provisioning services derived from plants by men an women in the Bale Mountains of Ethiopia. Stark differences in provisioning service categories reveal distinct "gendered" knowledge about plant uses.

Maxent Modeling

Plants with human medicinal applications were the most prevalent use categories identified by the women respondents (approximately 23% of uses), whereas plants providing forage for livestock and wildlife was the dominant category identified by men (approximately 40% of uses). With this understanding and the fact that plant-based medicines constitute a major part of rural Ethiopian's primary health care, we focused preliminary modeling efforts on three tree species with medicinal properties, which male respondents additionally noted to be of high local value (whether for medicinal properties or other uses). Each species had between 15 and 30 presence points derived from our field plots and supplemented with existing occurrence records for the region. This included: 1) *Hagenia abyssinica* (*Heto* in Oromiffa), a tree from the Rosaceae family which acts as an anthelmintic to combat tapeworm, in addition to being a critical timber source for house construction and furniture, 2) *Hypericum revolutum* (*Garramba* in Oromiffa), a tree from the Hypericaceae family, the leaves of which are boiled with *Juniperus procera* leaves to make a tea that alleviates flu symptoms, and also used to make house frame beams, and 3) *Juniperus procera* (*Hindesa* in Oromiffa), a tree from the Cupressaceae family, the leaves of which are boiled and made into a tea which is drank and the vapors inhaled to alleviate a "swollen stomach", in addition to being used for house construction. Modeling of user-defined provisioning ES plants (derived from LEK) were extrapolated to a broader spatial extent

beyond the BMNP boundaries and encompassing a broad elevational gradient between 1500 and 4400m. 1500 meters was chosen as the low elevation cut-off, as existing research on the endangered and endemic mountain nyala (*Tragelaphus buxtoni*), reveal this large spiral-horned antelope to prefer dense highland forest concealment and have been found occurring at elevations as low as 1500m (Evangelista *et al*, 2008). These upper and lower Afro-montane zones tend to be dominated by our study species *Hagenia abyssincia*, *Hypericum revolutum* and *Juniperus procera*. Background points were pulled from this defined area to facilitate a more accurate model (Elith *et al*, 2011). A binary logistic threshold was processed to convert the medicinal plant suitable habitat models from a continuous gradient suitability (ranging from 0 to 1), to a binary threshold of sensitivity = specificity, matching the original model output values, and thus creating a binary threshold cut-off where a value of one equals “suitable habitat” and a value of zero equals “unsuitable habitat”. These threshold values are unique to each species model run and can be found in the Maxent output .csv file.

The following output tables relay the accuracy statistics of each model and the ranking of variable importance for each medicinal tree model. Our preliminary results reveal strong Area Under the Receiver Operating Characteristic Curve (AUC) values. The AUC values facilitate easily interpreted comparisons of model performance, with an AUC value of 0.5 indicating that the model performance is no better than random, while values closer to 1.0 (the highest value) indicates stronger model performance. AUC plots the true positive error rate on the x-axis (sensitivity) against the false positive rate (specificity) on the y-axis for every probability value predicted for the data in question (Franklin, 2009, 222). In other words, AUC “...has a natural statistical interpretation. Pick a random positive example and a random negative example. The area under the curve is the probability that the classifier correctly orders the two points...A perfect classifier therefore has an AUC of 1 (Phillips, 2004, 659).

Hagenia abyssinica (model AUC: 0.993; standard deviation: 0.003)

Variable	**Percent Contribution**
Normalized difference vegetation index (NDVI)	42.1
Digital elevation model (DEM)	39.8
Slope	9.5
Enhanced vegetation index (EVI)	6
Aspect	2.6

Hypericum revolutum (model AUC: 0.971; standard deviation: 0.040)

Variable	**Percent Contribution**
Digital elevation model (DEM)	75.3
Enhanced vegetation index (EVI)	9.1
Slope	6.5
Aspect	4.8
Normalized difference vegetation index (NDVI)	4.3

Juniperus procera (model AUC: 0.935; standard deviation: 0.053)

Variable	**Percent Contribution**
Digital elevation model (DEM)	76.9
Normalized difference vegetation index (NDVI)	17.9
Slope	2.5
Aspect	1.5
Enhanced vegetation index (EVI)	1.2

Assessing variable importance is done through the analysis of variable contributions output. This shows the environmental predictors used in the model and their percent predictive contribution of each variable. The higher the contribution, the more impact that particular variable has on predicting the occurrence of the species modeled. Our results show the digital elevation model to consistently be a high predictor, which makes ecological sense, as observations in the field have shown each species to create somewhat distinct bands by elevation with some overlap, especially between *Hagenia abyssinica* and *Hypericum revolutum*. It is important to emphasize that models with small presence point sample sizes, such as our medicinal tree models, should not be interpreted as predicting limits to the range of each species but as predicting areas with similar environmental conditions to known locations of that species (Pearson *et al*, 2007).

Individual medicinal plant models were subsequently combined (Figure 4) in ArcGIS 10.0 to produce a medicinal tree biodiversity "hot-spot" map (Figure 5), highlighting regions where all three trees share suitable habitat, where two species share suitable habitat, and where only a single species has suitable habitat.

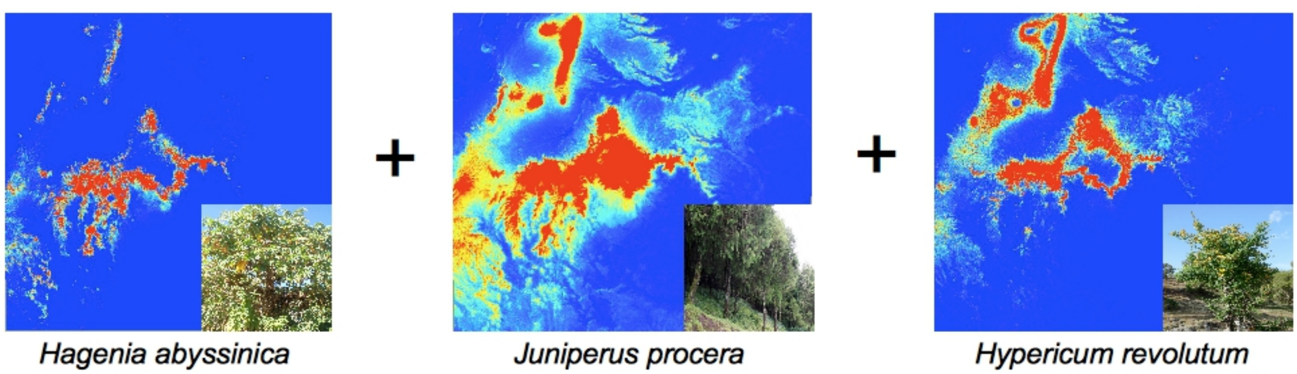

Figure 4. Individual medicinal plant model output were combined in ArcGIS 10.0 "Raster Calculator" to produce a medicinal tree biodiversity "hot spot" map (Figure 5).

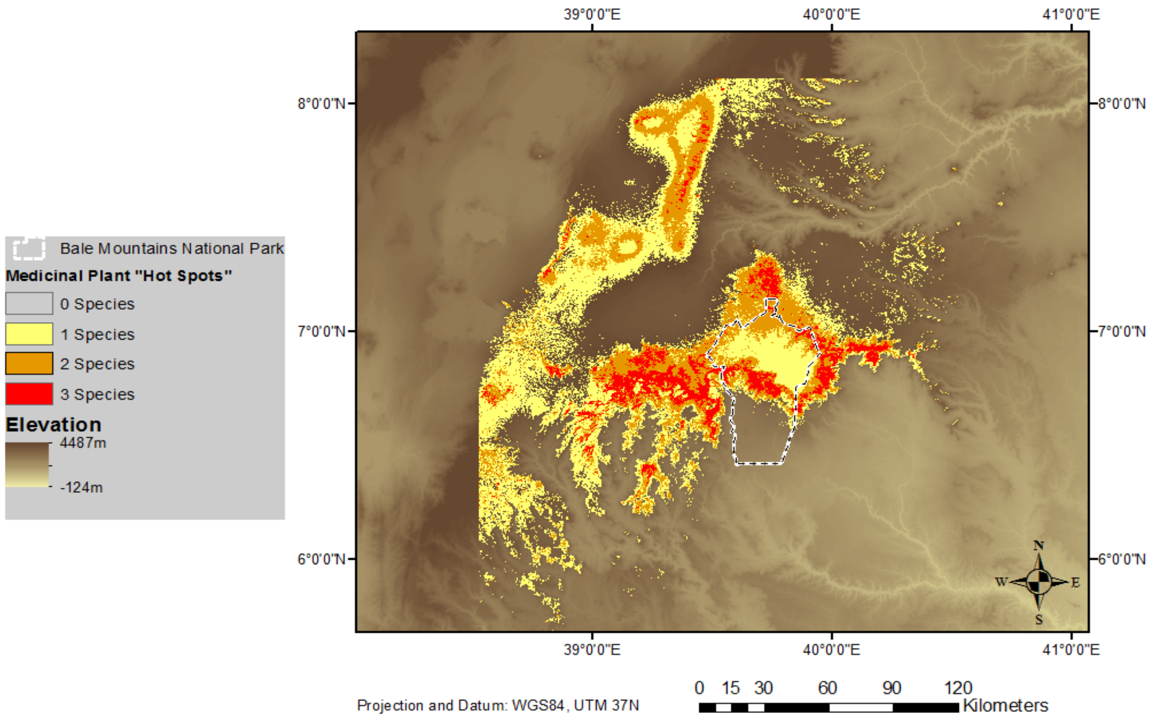

Figure 5. Combined model outputs produced a medicinal tree biodiversity "hot spot" map, revealing zones across the Bale region where suitable habitat exists for all three medicinal service providing species, two species, and only one species, respectively. This model once validated and calibrated with local resource users can provide important data for community-based conservation efforts.

Our combined model reveal a medicinal tree "hot spot" belt spanning the middle of the BMNP and extending into its northern extents. Swaths of suitable habitat for two of the three species is also present in the northern reaches of the park, which encompasses the Bale Massif which includes elevations 3,000m and above (Hillman, 1988). Overall, these results agree with existing research on the extent of such tree species in the Bale region, although seemingly under-representing patches of suitable habitat in the southern escarpment of the BMNP, which through LEK data collection and visual confirmation, has revealed all three species to be present.

CONCLUSIONS & NEXT STEPS:

This study has enacted the first two components of our ISM methodology (understanding the nuances of local user valuation of provisioning ES through the important adaptive governance feature of knowledge integration and modeling the suitable habitat of these culturally, economically, and ecologically significant service-providing species). It reveals important distinctions in local ecological knowledge between men and women in the Bale Mountains of Ethiopia, and the efficacy of our rapid appraisal approach in cataloguing LEK. This assessment revealed the women participants were generally able to identify plants just as well as our male participant, and additionally possessed unique

knowledge about local flora. Furthermore, we show the importance of combining qualitative methods of cataloguing LEK with quantitative methods of habitat suitability modeling, to actively involve the community in defining conservation targets and relative importance of different species and ecosystem services in the region. Inherent trade-offs and different benefits of the varied LEK collection methods exist (Berkes & Berkes, 2009; Fazey *et al*, 2005; Fazey *et al*, 2006; Marie *et al*, 2009; Merritt *et al*, 2009; Peloquin & Berkes, 2009), but with any given methodology, gaining the trust of participants is critical. In our case, the focus group respondents were members of a micro-loan program, and had a pre-existing level of trust and comfort with each other. Additionally, they were trusting of our research team as the non-profit who has worked with these women over many years gave their full support of our research endeavors. The importance of trust-building is present in other LEK research as well. In a study of wetlands conservation management in Australia, researchers spent two months volunteering with land managers to gain a better understanding of existing conservation issues and to build trust between the research team and managers participating in the study (Fazey *et al*, 2005).

Our medicinal plant models produced high AUC scores, but these must be interpreted with care, as the unavoidable spatial autocorrelation of highly clustered presence points seen in this study and others, can artificially inflates AUC values (Stohlgren *et al*, 2011). Furthermore, caution in interpreting the relative importance EVI and NDVI predictors is also needed as both indices are shown to be highly correlated (Wardlow, *et al*, 2007). This necessitates continued iterations of LEK data collection and model validation and calibration with local resource users, to leverage the respective strengths of each qualitative and quantitative approach used in ISM.

Our LEK data collection supports the argument of strong links between resource knowledge and use (Reyes-Garcia *et al*, 2007). In addition to the added insights afforded, this “gender consciousness” is needed for effective and holistic management of plant resources and attempts at community-based conservation. this “gender consciousness” is needed for effective and holistic management of plant resources and attempts at community-based conservation. Engaging local resource users about their LEK in many ways provides a level of empowerment for participants. This was made apparent with the women focus group respondents. At first the women thanked our research team for coming to teach them about plants, but we quickly clarified that they were the teachers, and their excitement at this unexpected role change was quickly noticed. Moreover, the women noted that the focus group process made them aware of an existing disconnect they have overlooked yet perpetuated in their daily lives. One where “nature and plants” are separate from “people and livelihoods”, and more importantly revealed the strong connections between these critically interconnected parts.

Results of these preliminary medicinal plant models can hold utility with future community-based conservation efforts and lead into the next component of ISM, which entails conducting vulnerability assessments to LEK-defined conservation targets to pressing anthropogenic drivers of change including climate change, population increase and invasive species. The same qualitative methods used to explore local users knowledge of plants and their uses (e.g. focus groups and semi-structured interviews) will be conducted with the same community members to define the most pressing drivers of change. Following this assessment, the same species distribution modeling approaches will be employed to model the vulnerability of different plant-derived provisioning ES to these drivers of change. For example, observational data and discussions with a variety of Ethiopians has shown population increase linked with land-use conversion to be a major concern in the Bale region. Rural settlement expansion is prolific across the landscape including a surge of illegal housing settlements, fences and agriculture fields emerging within the protected BMNP boundaries. This likely poses a threat to the medicinal trees modeled in this study. Additionally, three varieties of non-native Eucalyptus (*E. globulus*, *E. melliodora*, and *E. rostrata*) are increasingly favored for lumber, with growing cultivation leading to the removal of broad swaths of native vegetation. Eucalyptus takes 3-6 years to be of harvest age, whereas the closest “fast-growing” native tree of good lumber quality, Cordia, takes 20-60 years to be of harvest age. The rapid economic return achieved with Eucalyptus

provides great incentive for removing native vegetation, but ISM can provide an important platform for understanding potential impacts on biodiversity hotspots of ES-providing species and allow for more effective, efficient and legitimate cost-benefit analyses that actively engage local resource users at all stages of the process.

Important next steps of this ISM approach includes assessing ES vulnerability to anthropogenic disturbances including population growth, climate change and invasive species, and continuing to actively engage the local community of interest throughout the iterative ISM process. Current models will be brought back to the Bale region and field validated with community members and calibrated based on continued inclusion of LEK of men and women. Furthermore, we will begin implementing this ISM approach to research beginning in the Yukon Watershed, which spans Interior Alaska and extends into the Yukon Territory. Working with the Native American and First Nation tribes of the Yukon Inter-Tribal Watershed Council, we will attempt to replicate the approaches used in this study in the Bale Mountains of Ethiopia.

WORKS CITED

Abebe, W. 1984. Traditional pharmaceutical practice in Gondar region, northwestern Ethiopia. *Journal of Ethnopharmacology* 11: 33-47.

Adger, N.W. 2006. Vulnerability. *Global Environmental Change*. 16: 268-281.

Adger, N., & Jordan, A. (eds.) 2009. *Governing Sustainability*. Cambridge, UK: Cambridge University Press. *Frontiers in Ecology and the Environment* 7(2): 95-102.

Armitage, D.R., Plummer, R., Berkes, F., Arthur, R.I., Charles, A.T., Davidson-Hunt, I.J., Diduck, A.P., Doubleday, N.P., Johnson, D.S., Marschcke, M., McConney, P., Pinkerton, E.W., & Wollenberg, E.K. 2009. Adaptive co-management for social-ecological complexity.

Asfaw, Z., & Tadesse, M. 2001. Prospects for sustainable use and development of wild food plants in Ethiopia. *Economic Botany* 55(1): 47-62.

Assefa, B., Glatzel, G., & Buchmann, C. 2010. Ethnomedicinal uses of *Hagenia abyssinica* (Bruce) J.F. Gmel. among rural communities of Ethiopia. *Journal of Ethnobiology and Ethnomedicine* 6: 20-29.

Ballard, H.L., Fernandez-Gimenez, M.E., and Sturtevant, V.E. 2008. Integration of local ecological knowledge and conventional science: a study of seven community-based forestry organizations in the USA. *Ecology and Society*, 13(2): 37-58.

Bekalo, T.H., Woodmatas, S.D., & Woldemariam, Z.A. 2009. An ethnobotanical study of medicinal plants used by local people in the lowlands of Konta Special Woreda, southern nations, nationalities and peoples regional state, Ethiopia. *Journal of Ethnobiology and Ethnomedicine* 5: 26-40.

Betsill, M.M., & Bulkeley, H. 2006. Cities and the multilevel governance of climate change. *Global Governance* 12: 141-159.

Berkes, F., Colding, J., and Folke, C. 2000. Rediscovery of traditional ecological knowledge as adaptive management. *Ecological Applications*, 10(5): 1251-1262.

Berkes, F., and Berkes, M.K. 2009. Ecological complexity, fuzzy logic, and holism in indigenous knowledge. *Futures*, 41: 6-12.

Biermann, F., & Pattberg, P. 2008. Global environmental governance: Taking stock, moving forward. *Annual Review of Environment and Resources* 33: 277-294.

Boyle, M., Kay, J., & Pond, B. 2001. Monitoring in support of policy: an adaptive ecosystem approach. In *Encyclopedia of Global Environmental Change*, Vol. 4, ed. T. Munn, pp. 116–37. New York: Wiley.

Brown, K. 2009. Human development and environmental governance: a reality check. In *Governing Sustainability*. Adger, N, and Jordan, A. (eds.) Cambridge, UK: Cambridge University Press.

Bussmann, R.W., Swartzinsky, P., Worede, A., & Evangelista, P. 2011. Plant use in Odo-Bulu and Demaro, Bale region, Ethiopia. *Journal of Ethnobiology and Ethnomedicine* 7: 28-48.

Calamia, M.A. 1999. A methodology for incorporating traditional ecological knowledge with geographic

information systems for marine resource management in the Pacific. *SPC Traditional Marine Resource Management and Knowledge Information Bulletin #10*: 2-12.

Campbell, P., Comiskey, J., Alonso, A., Dallmeier, F., Nuňez, Beltran, H., Baldeon, S., Nauray, W., de la Colina, R., Acurio, L., & Udvardy, S. 2002. Modified Whittaker plots as an assessment and monitoring tool for vegetation in a lowland tropical rainforest. *Environmental Monitoring and Assessment* 76: 19-41.

Carpenter, S.R., & Gunderson, L.H. 2001. Coping with collapse: ecological and social dynamics in ecosystem management. *Bio-Science* 6:451–57.

Carroll, C., Phillips, M.K., Schumaker, N.H., & Smith, D.W. 2003. Impacts of landscape change on wolf restoration success: Planning a reintroduction program based on static and dynamic spatial models. *Conservation Biology* 17: 536-548.

Cecchi, G., Wint, W., Shaw, A., Marletta, A., Mattioli, R., & Robinson, T. 2010. Geographic distribution and environmental characterization of livestock production systems in East Africa. *Agriculture Ecosystems and Environment* 135: 98-110.

Chambers, R. 1981. Rapid rural appraisal: rationale and repertoire. *Public Administration and Development* 1: 95-106.

Chalmers, N., and Fabricius, C. 2007. Expert and generalist local knowledge about land-cover change on South Africa's Wild Coast: Can local ecological knowledge add value to science? *Ecology and Society* 12(1): 10-24.

Cooper, C.B., Dickinson, J., Phillips, T.B., & Bonney, R. 2007. Citizen science as a tool for conservation in residential ecosystems. *Ecology and Society* 12(2): 11-21.

Cundill, G., & Fabricius, C. 2010. Monitoring the governance dimension of natural resource co-management. *Ecology and Society* **15**(1): 15-31.

Daily, Polasky, S., Goldstein, J., Kareiva, P.M., Mooney, H.A., Pejchar, L., Ricketts, T.H., Salzman, J., and Shallenberger, R. 2009. Ecosystem services in decision making: time to deliver. *Frontiers in Ecology and the Environment*, 7(1): 21-28.

Daily, G.C., and Matson, P.A. 2008. Ecosystem services: From theory to implementation. *Proceedings of the National Academey of Sciences of the United States of America*, 105(28): 9455-9456.

Daniels, S.E., and Walker, G.B. 2001. *Working Through Environmental Conflict: The Collaborative Learning Approach.* Westport, CT: Praeger.

Danter, K.J, Griest, D.L., Mullins, G.W., & Norland, E. 2000. Organizational change as a component of ecosystem management. *Society and Natural Resources* 13: 537–47.

Davis, A.P., Gole, T.W., Baena, S., & Moat, J. 2012. The impact of climate change on indigenous arabica coffee (*Coffea arabica*): Predicting future trends and identifying priorities. *PLoS ONE* 7(11): 1-13.

Dryzek, J. 2012. "Life in a Climate Challenged Society". Keynote speaker address at the Lund Conference on Earth System Governance- Towards a Just and Legitimate Earth System Governance: Addressing Inequalities conference. Lund University, Lund, Sweden (April 18-20, 2012).

Elith, J., and Leathwick, J.R. 2009. Species distribution models: Ecological explanation and prediction across space and time. *Annual Review of Ecology and Systematics*, 40: 677-697.

Epstein, M.J., & Roy, M.J. 1997. Using ISO 14000 for improved organizational learning and environmental management. *Environmental Quality Management* 7(1): 21-30.

Evangelista, P. Swartzinski and B. Waltermire. (2007). A profile of the mountain nyala (*Tragelaphus buxtoni*). African Indaba 5(2), Special Report. 48pp.

Evangelista, P.H., Norman, J., III., Berhanu, L., Kumar, S., & Alley, N. 2008. Predicting habitat suitability for the endemic mountain nyala (*Tragelaphus buxtoni*) in Ethiopia. *Wildlife Research* 35: 409-416.

Evangelista, P., Kumar, S., & Stohlgren, T. 2011. Assessing forest vulnerability and the potential distribution of three pine beetles under current and future climate scenarios in the Interior West of the U.S. *Journal of Ecology and Management* 262(3): 307-316.

Evangelista, P., Young, N., & Burnett, J. (In Review) How will climate change spatially effect agriculture production in Ethiopia? Case studies of important cereal crops. *Journal of Agriculture, Ecosystems and Environment*.

Fazey, I., Fazey, J.A., and Fazey, D.M.A. 2005. Learning more effectively from experience. *Ecology and Society*, 10(2): 4-25.

Fazey, I., Fazey, J.A., Salisbury, J.G., Lindenmayer, D.B., and Dovers, S. 2006. The nature and role of

experiential knowledge for environmental conservation. *Environmental Conservation*, 33(1): 1-10.
Fernandez-Gimenez, M.E., Huntington, H.P., and Frost, K.J. 2006. Integration or co-optatin? Traditional knowledge and science in the Alaska Beluga Whale Committee. *Environmental Conservation*, 33(4): 306-315.
Fernandez-Gimenez, M.E., Ballard, H.L., & Sturtevant, V.E. 2008. Adaptive management and social learning in collaborative and community-based monitoring: A study of five community-based forestry organizations in the western USA. *Ecology and Society* 13(2): 4-25).
Fernandez-Gimenez, M.E., and Estaque, F.F. 2012. Pyrenean pastoralists' ecological knowledge: Documentation and application to natural resource management and adaptation. *Human Ecology*, 40(2): 287-300.
Ferrier, S. 2002. Mapping spatial pattern in biodiversity for regional conservation planning: Where to from here *Systematic Biology* 51: 331-363.
Flora, J. 1998. Social capital and communities of place. *Rural Sociology* 63(4): 481-506.
Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., & Holling, C.S. 2004. Regime shifts, resilience, and biodiversity in ecosystem management. *Annual Review of Ecology, Evolution, and Systematics* 35:557–81.
Folke, C. T. Hahn, P. Olsson, and J. Norberg. 2005. Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources* 30: 441-473.
Frankfurt Zoological Society (FZC). 2007. Bale Mountains National Park, General Management Plan 2007-2017. Oromia Regional Government, Addis Ababa, Ethiopia. 222pp.
Gadgil, M., Berkes, F., and Folke, C. 1993. Indigenous knowledge for biodiversity conservation. *Ambio* 22:151–56.
Gagnon, C.A., and Berteaux, D. 2009. Integrating traditional ecological knowledge and ecological science: a question of scale. *Ecology and Society*, 14(2): 19-45.
Gallo, T., & Waitt, D. 2011. Creating a successful citizen science model to detect and report invasive species. *BioScience* 61: 459-465.
Garibay-Orijel, R., Ramírez-Terrazo, A., & Ordaz-Velázquez. 2012. Women care about local knowledge, experiences from ethnomycology. *Journal of Ethnobiology and Ethnomedicine* 8: 25-37.
Ghorbani, J., Taya, A., Shokri, M., & Naseri, H.R. 2011. Comparison of Whittaker and Modified-Whittaker plots to estimate species richness in semi-arid grassland and shrubland. *DESERT* 16: 17-22.
Graham, J., Newman, G., Kumar, S., Jarnevich, C., Young, N., Crall, A., Stohlgren, T., & Evangelista, P. 2010. Bringing modeling to the masses: A web based system to predict potential species distributions. *Future Internet*.
Gupta, A. 2010. Transparency to what end? Governing by disclosure through the biosafety clearing house. *Environment and Planning C: Government and Policy* 28: 128-144.
Hillman, J.C. 1988. The Bale Mountains National Park area, Southern Ethiopia, and its management. *Mountain Research and Development* 8(2/3): 253-258.
Hirzel, A.H., Posse, B., Oggier, P.A., Crettenand, Y., Glenz, C., & Arlettaz, R. 2004. Ecological requirements of reintroduced species and the implications for release policy: The case of the bearded vulture. *Journal of Applied Ecology* 41: 1103-1116.
Holling, C.S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology, Evolution, and Systematics* 4:1–23.
Huntington, H. P. 1998. Observation on the utility of the semi-directive interview for documenting traditional ecological knowledge. *Arctic* 51: 237-242.
Jäger, J. 2009. The governance of science for sustainability. In *Governing Sustainability*. Adger, N, and Jordan, A. (eds.) Cambridge, UK: Cambridge University Press.
Jarnevich, C., Evangelista, P., Stohlgren, T.J., & Morisette, J. 2011. Improving national-scale invasion maps: tamarisk in the Western United States. *Western North American Naturalist* 71(2): 164-175.
Kebede, F., Bekele, A., Moehlman, P., & Evangelista, P. (In Review). Predicting habitat suitability for the critically endangered African wild ass in the Danakil ,Ethiopia. *Conservation Biology*.
Keller, E.J. 1988. Revolution and state power in Ethiopia. *Current History* 87(529): 217-223.
Kremen, C. 2005. Managing ecosystem services: What do we need to know about their ecology? *Ecology Letters*, 8: 468-479.
Kremen, C., Cameron, A., Moilanen, A., Phillips, S.J., Thomas, C.D., Beentje, H., Dransfield, J., Fisher, B.L.,

Glaw, F., Good, T.C., Harper, G.J., Hijmans, R.J., Lees, D.C., Louis, E., Jr., Nussbaum, R.A., Raxworthy, C.J., Razafimpahanana, A., Schatz, G.E., Vences, M., Vieites, D.R., Wright, P.C., & Zjhra, M.L. 2008. Aligning conservation priorities across taxa in Madagascar with high-resolution planning tools. *Science* 320: 222-226.

Kofinas, G.P. 2005. Caribou hunters and researchers at the co-management interface: Emergent dilemmas and the dynamics of legitimacy in power-sharing. *Anthropologica* 47: 179-196.

Leahy, J.E., & Anderson, D.H. 2008. Trust factors in community-water resource management agency relationships. *Landscape and Urban Planning* 87:100-107.

Lindgren, C.J. 2012. Biosecurity policy and the use of geospatial predictive tools to address invasive plants: Updating the risk analysis toolbox. *Risk Analysis*, 32(1): 9-15.

Low, B., Ostrom, E., Simon, C., & Wilson, J. 2003. Redundancy and diversity: Do they influence optimal management? pp. 83–114. In Berkes F, Colding, J., Folke, C., eds. 2003. *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change.* Cambridge, UK: Cambridge Univ. Press.

Luizza, M.W., Young, H., Kuroiwa, C., Evangelista, P., Worede, A., Bussmann, R.W., & Weimer, A. (In Review). Local knowledge of plants and their uses among women in the Bale Mountains, Ethiopia. *Ethnobotany Research and Applications*.

Lyons, J. E., Runge, M. C., Laskowski, H. P., & Kendall, W. L. 2008. Monitoring in the Context of Structured Decision-Making and Adaptive Management. *The Journal of Wildlife Management* 72: 1683–1692.

MA (Millennium Ecosystem Assessment). 2005. Ecosystems and human well-being: a framework for assessment. Washington, DC: Island Press.

Marie, C.N., Sibelet, N., Dulcire, M., Rafalimaro, M., Danthu, P., and Carrière, S.M. 2009. Taking into account local practices and indigenous knowledge in an emergency conservation context in Madagascar. *Biodiversity Conservation*, 18: 2759-2777.

McCall, M.K. 2003. Seeking good governance in participatory-GIS: A review of processes and governance dimensions in applying GIS to participatory spatial planning. *Habitat International* 27: 549-573.

Merritt, W.S., Duncan, D., Kyle, G., and Race, D. 2009. Using local knowledge to identify drivers of historic native vegetation change. 18th World IMACS / MODSIM Congress, Cairns, Australia 13-17 July 2009 http://mssanz.org.au/modsim09.

Morgan, D.L. 1997. *Focus Groups as Qualitative Research* (2nd Ed.) Thousand Oaks, CA: Sage.

Nadasdy, P. 1999. The politics of Tek: Power and the "integration" of knowledge. *Arctic Anthropology*, 36(1/2): 1-18.

Naidoo, R., & Hill, K. 2006. Emergence of indigenous vegetation classifications through integration of traditional ecological knowledge and remote sensing. *Environmental Management* 38(3): 377-387.

Newman, G., Wiggins, A., Crall, A., Graham, E., Newman, S., & Crowston, C. 2012. The future of citizen science: Emerging technologies and shifting paradigms. *Frontiers in Ecology and the Environment* 10(6): 298-304.

Olsson, P., & Folke, C. 2001. Local ecological knowledge and institutional dynamics for ecosystem management: a study of Lake Racken Watershed, Sweden. *Ecosystems* 4(2):85-104.

Ostrom, E. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action.* Cambridge: Cambridge University Press.

Ostrom E. 2005. *Understanding Institutional Diversity.* Princeton, NJ: Princeton Univ. Press.

Ostrom, E. 2007. Sustainable Social-ecological Systems: An Impossibility? Presented at the 2007 Annual Meetings of the American Association for the Advancement of Science, "Science and Technology for Sustainable Well-Being," 15–19 February, San Francisco, CA.

Ostrom, E., and Cox, M. 2010. Moving beyond panaceas: a multi-tiered diagnostic approach for social-ecological analysis. *Environmental Conservation* 37(4): 451-463.

Pandya, R.E. 2012. A framework for engaging diverse communities in citizen science in the US. *Frontiers in Ecology and the Environment* 10(6): 314-317.

Pearson, R.G., Raxworthy, C.J., Nakamura, M., & Peterson, A.T. 2007. Predicting species distributions from small numbers of occurrence records: A test case using cryptic geckos in Madagascar. *Journal of Biogeography* 34: 102-117.

Peloquin, C., and Berkes, F. 2009. Local knowledge, subsistence harvests, and social-ecological complexity in James Bay. *Human Ecology*, 37: 533-545.

Pfeiffer, J.M., & Butz, R.J. 2005. Assessing cultural and ecological variation in ethnobiological research: The importance of gender. *Journal of Ethnobiology* 25(2): 240-278.
Phillips, S.J., Dudík, M., & Schapire, R.E. 2004. A maximum entropy approach to species distribution modeling. *Proceedings of the* 21st *International Conference on Machine Learning*, Banff, Canada.
Phillips, S.J., Anderson, R.P., & Schapire, R.E. 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modeling* 190: 231-259.
Phillips, S.J., & Dudík, M. 2008. Modeling of species distributions with Maxent: New extensions and a comprehensive evaluation. *Ecography* 31: 161-175.
Pickering-Sherman, K., Van Lanen, J. and Sherman, R.T. 2010. Practical Environmentalism on the Pine Ridge Reservation: Confronting Structural Constraints to Indigenous Stewardship. *Human Ecology*, 38: 507-520. Plummer, R., & Armitage, D. 2007. A resilience-based framework for evaluating adaptive co-management: Linking ecology, economics, and society in a complex world. *Ecological Economics* 61: 62-74.
Pretty J, & Ward H. 2001. Social capital and the environment. *World Development* 29:209–227.
Reyes-Garcia, V. 2010. The relevance of traditional knowledge systems for ethnopharmacological research: Theoretical and methodological contributions. *Journal of Ethnobiology and Ethnomedicine* 6: 32-43.
Ricketts, T. 2013. "Seeing the Forest for the Bees". Distinguished speaker for the Graduate Degree Program in Ecology Distinguished Lecture Series (ECOL-571). Colorado State University, Fort Collins, CO (March 27, 2013).
Schusler, T.M., Decker, D.J., and M. Pfeffer. 2003. Social Learning for Collaborative Natural Resource Management. *Society Natural Resources*. 16(4): 309-326
Shannon MA. 1991. Resource managers as policy entrepreneurs. *Journal of Forestry* 89: 27–30.
Shingu, GK. 2005. Ownership and sustainability issues of botanical medicines. *Ethnobotany Research & Applications,* 3:17-23.
Sillitoe, P. 1998. The development of indigenous knowledge: A new applied anthropology. *Current Anthropology*, 39(2): 223-252.
SRC (Stokholm Resilience Centre). 2012. Adaptive Governance. Retrieved from: http://www.stockholmresilience.org/research/researchthemes/adaptivegovernance.4.aeea46911a3127427980006994.html.
Stephens, P.A., dSa, C.A., Sillero-Zubiri, C., & Leader-Williams, N. 2001. Impact of livestock and settlement on the large mammalian wildlife in Bale Mountains National Park, southern Ethiopia. *Biological Conservation* 100: 307-322.
Stohlgren, T.J, Falkner, M.B., & Schell, L.D. 1995. A Modified-Whittaker nested vegetation sampling method. *Vegetatio* 117(2): 113-121.
Stohlgren, T.J., Ma, P., Kumar, S., Rocca, M., Morisette, J.T., Jarnevich, C.S., and Benson, N. 2010. Ensemble habitat mapping of invasive plant species. *Risk Analysis*, 30(2): 224-235.
Stohlgren, T.J., Kumar, S., Barnett, D.T., & Evangelista, P.H. 2011. Using maximum entropy modeling for optimal selection of sampling sites for monitoring networks. *Diversity* 3: 252-261.
Titeca, K., & Vervisch, T. 2008. The dynamics of social capital and community associations in Uganda: Linking capital and its consequences. *World Development* 36(11): 2205-2222.
Thorn, J.S., Nijman, V., Smith, D., & Nekaris, K.A.I. 2009. Ecological niche modeling as a technique for assessing threats and setting conservation priorities for Asian slow lorises (Primates: *Nycticebus*). *Diversity and Distributions* 15: 289-298.
United Nations Environment Programme (UNEP). 2008. *Africa: Atlas of Our Changing Environment*. Division of Early Warning and Assessment (DEWA). Nairobi: Kenya.
United Nations Educational, Scientific and Cultural Organization (UNESCO). 2013. UNESCO World Heritage Center List. Retrieved from: http://whc.unesco.org/en/tentativelists/5315/.
Vandebroek, I., Reyes-García, V., de Albequerque, U.P., Bussmann, R., & Pieroni, A. 2011. Local knowledge: Who cares? *Journal of Ethnobiology and Ethnomedicine* 7: 35-41.
Waltermire, R. 1975. A National Park in the Bale Mountains. *Walia* 6: 20-23.
Wardlow, B.D., Egbert, S.L., & Kastens, J.H. 2007. Analysis of time-series MODIS 250 m vegetation index data for crop classification in the U.S. central Great Plains. *Remote Sensing of Environment* 108: 290-310.
Westley F. 1995. Governing design: the management of social systems and ecosystems management. pp. 391–427. In Gunderson L, Holling CS, Light S, eds. 1995. *Barriers and Bridges to the Re- newal of*

Ecosystems and Institutions. New York: Columbia Univ. Press.
Wilhere, G. F. 2002. Adaptive Management in Habitat Conservation Plans. *Conservation Biology* 16: 20–29.
Wondolleck JM, Yaffee SL. 2000. *Making Collaboration Work: Lessons from Innovation in Natural Resource Management*. Washington, DC: Island.
Yineger, H., Kelbessa, E., Bekele, T., & Lulekal, E. 2007. Ethnoveterinary medicinal plants at Bale Mountains National Park, Ethiopia. *Journal of Ethnopharmacology* 112: 55-70.
Zeleke, G. 2010. *A Study on Mountain Externalities in Ethiopia* (Final Report). Food and Agricultural Organization of the United Nations: Sustainable Agriculture and Rural Development Mountain Policy Project. Addis Ababa: Ethiopia. Retrieved from:
http://www.fao.org/sard/common/ecg/3252/en/Mountain_Externalities_in_Ethiopia.pdf.
Zenebe, G., Zerihun, M., and Solomon, Z. 2012. An ethnobotanical study of medicinal plants in Asgede Tsimbila District, northwestern Tigray, northern Ethiopia. *Ethnobotany Research and Applications*, 10: 305-320.