DISSERTATION

INTEGRATIVE GEOSPATIAL MODELING: COMBINING LOCAL AND INDIGENOUS

KNOWLEDGE WITH GEOSPATIAL APPLICATIONS FOR ADAPTIVE GOVERNANCE

OF INVASIVE SPECIES AND ECOSYSTEM SERVICES

Submitted by

Matthew Wayne Luizza

Graduate Degree Program in Ecology

In partial fulfillment of the requirements

For the Degree of Doctor of Philosophy

Colorado State University

Fort Collins, Colorado

Summer 2015

Doctoral Committee:

    Advisor: Michele Betsill
    Co-Advisor: Paul Evangelista

    Maria Fernandez-Gimenez
    Tom Stohlgren

ABSTRACT

INTEGRATIVE GEOSPATIAL MODELING: COMBINING LOCAL AND INDIGENOUS KNOWLEDGE WITH GEOSPATIAL APPLICATIONS FOR ADAPTIVE GOVERNANCE OF INVASIVE SPECIES AND ECOSYSTEM SERVICES

With an unprecedented rate of global change, diverse anthropogenic disturbances present growing challenges for coupled social-ecological systems. Biological invasions are one such disturbance known to cause negative impacts on biodiversity, ecosystem functioning and an array of other natural processes and human activities. Maps facilitated by advanced geospatial applications play a major role in resource management and conservation planning. However, local and indigenous knowledge are overwhelmingly left out of these conversations, despite the wealth of observational data held by resource-dependent communities and the potential negative impacts biological invasions have on local livelihoods.

My integrative geospatial modeling research applied adaptive governance mechanisms of knowledge integration and co-production processes in concert with species distribution modeling tools to explore the potential threat of invasive plants to community-defined ecosystem services. Knowledge integration at the landscape scale in Alaska provided an important opportunity for re-framing risk assessment mapping to include Native Alaskan community concerns, and revealed the growing potential threat posed by invasive aquatic *Elodea* spp. to Chinook salmon (*Oncorhynchus tshawytscha*) and whitefish (*Coregonus nelsonii*) subsistence under current and future climate conditions. Knowledge integration and co-production at the local scale in northeastern Ethiopia facilitated shared learning between pastoral communities and researchers, leading to the discovery of invasive rubber vine (*Cryptostegia grandiflora*), which was

previously unknown to my research team or a number of government and aid organizations working in the region, thus providing a potentially robust early detection and monitoring approach for an invasive plant that holds acute negative impacts on a number of endemic ecosystem service-providing trees.

This work revealed knowledge integration and co-production processes and species distribution modeling tools to be complimentary, with invasive species acting as a useful boundary-spanning issue for bringing together diverse knowledge sources. Moreover, bridging and boundary-spanning organizations and individuals enhanced this rapid appraisal process by providing access to local and indigenous communities and fostered a level of built-in trust and legitimacy with them. Challenges to this work still remain, including effectively working at broad spatial and governance scales, sustaining iterative processes that involve communities in validating and critiquing model outputs, and addressing underlying power disparities between stakeholder groups. Top-down, discipline-specific approaches fail to adequately address the complexity of ecosystems or the needs of resource-dependent communities. My work lends evidence to the power of integrative geospatial modeling as a flexible transdisciplinary methodology for addressing conservation efforts in rural regions with mounting anthropogenic pressures at different spatial and governance scales.

ACKNOWLEDGEMENTS

bottom of my heart for your love and support. I am forever indebted to you all.

TABLE OF CONTENTS

Integrative geospatial modeling: Seeking adaptive and collaborative management of invasive species and ecosystem services through an adaptive governance framework

Invasive Species: A Pressing Social-Ecological Problem

With an unprecedented rate of global change, diverse anthropogenic and environmental disturbance drivers present growing challenges for coupled social-ecological systems (Chapin III et al. 2009). Social-ecological systems (SESs) are complex, adaptive systems (Berkes et al. 2003) comprised of dynamic and interacting ecological, physical, social, cultural, and political processes occurring across spatial and temporal scales (Figure 1). Their inherent complexity makes for great uncertainties when trying to predict the outcomes of management practices, effects of unpredictable disturbances, and values and needs of diverse stakeholders. Sustainability of SESs in part involves supporting their resilience, or ecological integrity (Walker et al. 2002; Chapin III et al. 2009), which is the capacity of a given system to absorb or recover from environmental and anthropogenic perturbations and reorganize, while still maintaining the same overall structure and function (Holling 1973; Folke et al. 2004). This structure and function can prove critical for fostering human well-being and transformation within social systems (Walker et al. 2004; MEA 2005).

Caution must be taken when attributing "resilience" as always normatively desirable. A growing number of critiques point out the extensive use of resilience as a prescriptive concept, and one that is universal for social and ecological systems across spatial and governance scales. However, resilience is often vaguely defined (e.g. theory versus framework and simultaneously resisting change while embracing transformation), and often does a poor job of explaining social systems (Davidson 2010; Cote & Nightingale 2011; Berkes & Ross 2013; Olsson et al. 2015). Moreover, resilience may not be desirable, as it can pertain to "trapped" systems on "pathologic

trajectories" that limit their ability to adapt over time (Gunderson & Light 2006: 324). For this

reason, when discussing the ecological structure and function of a system that can support human

well-being and enhance what Crane (2010) describes as "cultural resilience", or "the ability to

maintain livelihoods that satisfy both material and moral (normative) needs in the face of major

stresses and shocks; environmental, political, economic, or otherwise" (pp. 20), I use the term

"ecological integrity" (Chapin III et al. 2009).
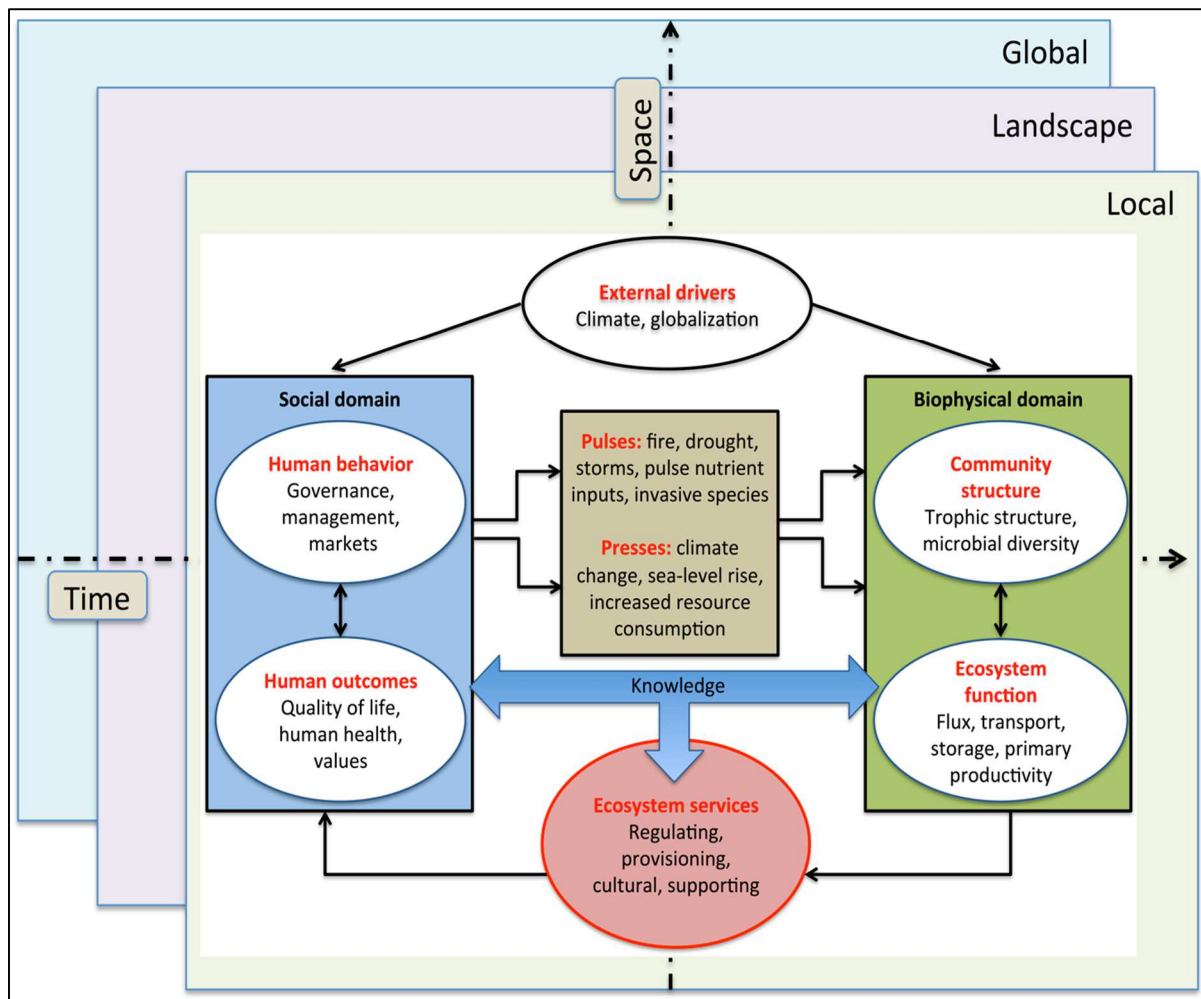
Figure 1. Conceptual model of dynamic and complex social-ecological systems (SESs), adapted from Collins et al. (2011). Social and biophysical domains are connected by a range of materials, processes, and feedbacks occurring across spatial and temporal scales. Key features of the social domain, including governance and management shape and are shaped by the biophysical domain and external drivers. Knowledge is diffuse across these realms, coming out of social processes and influencing interactions with the biophysical domain and ecosystem service that support human well-being.

These complex, interconnected challenges becomes all the more salient and urgent in light of increased global human impacts, with a near 7.2 billion human global population and increasingly interconnected activities worldwide, fueled by rapid technological advancements and integrated markets. For example, we live in an era of "conservation-reliant" species, with 84 percent of those listed as threatened or endangered under the U.S. Endangered Species Act requiring long-term, concerted management investments (Scott et al. 2010). Moving beyond a species-specific focus, which belies many of the complex interactions of SESs and thus limits their holistic management, we arguably live in an era of conservation-reliant systems as well, with increasingly vulnerable and fragmented ecosystems and habitats needing a similar measure of long-term management commitments. This is made apparent by the legacy of a historical fire exclusion paradigm in forest management in the United States (Cohen 2008), which has undermined the ecological integrity of forest ecosystems and heightened the risk of catastrophic fires, especially at the wildland-urban interface. Moreover, we see these effects with extensive global habitat alteration and fragmentation that impacts not just individual keystone species but entire biotic communities, underlying ecosystem functions, and human livelihoods (MEA 2005). The social complexity inherent to anthropogenic disturbances, linked with the innate ecological complexity of ecosystems requires flexibility in managing for sustainability and ecological integrity, and moving beyond overly simplistic institutional prescriptions (Ostrom & Cox 2010).

Non-native invasive species are a critical disturbance driver that increases the vulnerability of SESs. Vulnerability refers to a state of susceptibility to harm from exposure and lack of capacity to adapt to stresses associated with dynamic, complex, and interacting social and ecological variables, based on both internal and external dynamics (Adger & Kelly 1999; Adger 2006). Invasive species are known to cause negative impacts on biodiversity, ecosystem

functioning, and an array of other natural processes and human activities (Vitousek 1990; Vitousek et al. 1997; IUCN 2000; White et al. 2008; Hejda et al. 2009). Biological invasions are responsible for an estimated $120 billion in damages each year in the United States alone and further have direct and indirect costs equaling nearly five percent of the world's annual economy (Pimentel 2005).

Recent studies continue to show the facilitation of invaders by other interacting disturbance drivers such as climate change (Springer et al. 2015), habitat alteration and fragmentation (Joshi et al. 2015; Liendo et al. 2015), and human development and recreation (Dar et al. 2015; Roche et al. 2015). Assessing the risks posed by invasive species to processes that support ecosystem functioning and an array of ecosystem services (i.e. the benefits humans receive from natural systems and environments), including biodiversity, nutrient cycling, disturbance regimes, *inter alia*, is critical for resource management and conservation (MEA 2005; Keller et al. 2009; Vilà et al. 2010; Carey et al. 2012), and may provide an important focal point for highlighting the connectivity of diverse and detrimental disturbance drivers that impact local and indigenous livelihoods and broader SES integrity. Provisioning ecosystem services in particular, which are the environmental goods that are directly consumed by society (e.g. food, fiber, fuel and water), provide the most direct link between ecological and social systems, and are fast variables that often show rapid, non-linear responses to environmental changes (Chapin III et al. 2009). Conducting risk assessments for these services necessitate the use of novel, transdisciplinary approaches, which are above all community-driven. Transdisciplinary refers to research and approaches that involve "coordinated interaction and integration across multiple disciplines resulting in the restructuring of disciplinary knowledge and the creation of new shared knowledge" (Jakobsen et al. 2004: 17).

Within the field of ecology, the study of biological invasion is one of the fastest growing areas of research (Pyšek et al. 2004), and a central topic for scholars across a range of other disciplines, including biology, environmental policy, geography, and natural resource management. The utility of risk assessment procedures for addressing invasive species has also grown in recent years (Powell 2004; Buckley 2008; Lindgren 2012), including powerful applications of species distribution modeling techniques (Cutler et al. 2007; Evangelista et al. 2008; Rodda et al. 2009; Elith et al. 2010; Stohlgren et al. 2010; Jarnevich et al. 2014). This modeling combines and quantifies species location information with environmental data to predict a given species' distribution across a defined geographic space (Franklin 2009), and can allow for comparison of various management approaches that can be tested on the ground (Drew et al. 2011).

Despite the growth of this literature, the human dimensions component is predominately missing, even though an array of studies have espoused the benefits of integrating local and traditional (i.e. indigenous) ecological knowledge for effective conservation planning and resource management (Berkes et al. 2000; Fernandez-Gimenez et al. 2006; Gagnon & Berteaux 2009; Luizza et al. 2013). Recently, a growing body of scholarship has called for the inclusion of broader stakeholder knowledge and perceptions in invasive species research (Garcia-Llorente et al. 2008; Liu et al. 2011; Kapler et al. 2012). Although this work is rapidly expanding, the views of indigenous peoples have been all but absent, and when knowledge and stakeholder engagement are mentioned in the broader environmental modeling world, it tends to be limited in scope or in some instances mere "lip service" paid to popularized buzz words (Voinov & Bosquet 2010: 1268).

Furthermore, there is limited assessment of the interactions between invasive species and ecosystem services that indigenous and rural communities rely on for their livelihoods.[1]

This oversight is important, as invaders can often have detrimental impacts on an array of services, posing major threats to local livelihoods (Pejchar & Mooney 2009), yet in some instances derived benefits of invasive species can be found (Foster & Sandberg 2004; Garcia-Llorente et al. 2008; Marshall et al. 2011; Shackleton et al. 2011; Belnap et al. 2012). This knowledge can reveal important adaptations of local communities and thus warrants a more holistic interpretation of the inherently political term "invasive species" (Sagoff 2005; Evans et al. 2008), including an understanding of the array of interactions in a given ecosystem, the potentially negative and beneficial impacts that invasive species may have, and the distinct knowledge and perceptions different stakeholders maintain. "In general, for every case of invasion some sector of society makes a profit" (Garcia-Llorente et al. 2008: 2970). Beyond solely economic gains, other less tangible benefits also are present. For instance, many Native American tribes hold nuanced views of invasive plants, in some cases describing them as "healers" of the Earth, particularly in systems under stress or recent anthropogenic disturbance (Parker 2001). As Parker (2001) astutely notes, "While Native American people have themselves been the victims of invasions of their homelands by the arrival of immigrants on this continent, they have generally not viewed new plant introductions with the same alarm that western scientists have" (Parker 2001: 49). Moreover, on the African continent, some invasive plants can benefit livelihoods of rural and indigenous communities. For example, non-native prickly pear cactus (*Opuntia ficus-indica*) is used to make jams, syrups, beer, and medicine in South Africa

---

1) A notable exception is Urgenson et al.'s (2013) study with private landowners in South Africa, which reveals the importance of understanding different points of view and unique contexts of different stakeholders for achieving insight into the opportunities and constraints faced by ecosystem service conservation attempts and invasive plant management at the local level.

(Shackleton et al. 2011) and acts as an important livestock fodder, erosion control, fuel, and fencing source in Tigray and Ethiopia (Barbera 1995; Musimba & Bariagabre 2003). Still, the inherently negative context of the term "invasive species" tends to provoke strong, equally negative reactions in people (Gobster 2005; Selge et al. 2011). Therefore, acknowledging, engaging, and incorporating local and indigenous knowledge is important, as it can provide not only a more nuanced understanding of SESs and invasive species impacts, but may additionally offer insight into areas of conflict regarding management approaches, depending on the consensus or contestation over how an "invasive species" is perceived.

In response to such complex challenges like biological invasions, the concept of adaptive governance has emerged, addressing the array of interactions inherent in SESs, including the structures, rules, processes, and traditions that determine environmental management. In the broadest sense, governance denotes forms, structures, and processes of authority that go beyond hierarchical state activities (Biermann et al. 2010). "Governance in other words, encompasses the activities of governments, but it also includes the many other channels through which 'commands' flow in the form of goals framed, directives issued, and policies pursued" (Rosenau 1995: 14). Governance sets the vision for the appropriate interactions of stakeholders and the formulation of principles to address problems and achieve desired outcomes. Within a governance framework, institutions are embedded as a system of rights, rules, and decision-making procedures that provide regularities, reduce uncertainties, and further shape stakeholder interactions (Kooiman et al. 2005). As humans we have a wide range of governance options at our disposal when seeking to address global environmental challenges (Dryzek 2012). These options entail different scales for exploring and engaging with governance approaches and tools, from global environmental governance frameworks (Biermann & Pattberg 2008), to multilevel

7

governance arrangements (Betsill & Bulkeley, 2006), and local and community governance practices (Bowles & Gintis 2002).

Adaptive governance 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). The nascence of this concept is noted by Chaffin et al. (2014) to come from the fields of resilience scholarship (Walker 2004; Folke et al. 2005) and community-based natural resource management (CBNRM) literature (Brunner et al. 2005 provides the first CBNRM-inspired approach to adaptive governance). In both conceptualizations, adaptive governance moves beyond a single scale of actors and institutions involved, requiring a deep understanding of a system's biotic, abiotic and social processes, and thus providing a transdisciplinary framework and vision for socially and ecologically desirable outcomes. For a CBNRM-inspired approach, adaptive governance embodies a more applied, context-specific management framework where local initiatives are not restricted, but rather organized and coordinated into larger scales of governance to achieve desired outcomes. In either form, "ideally, the scale of AG [adaptive governance] will be adapted to the social and ecological nature of the problem as well as to societal goals, through sufficient response flexibility within and between existing political boundaries"(Chaffin et al. 2014: 62).

With such a wide array of ecological and social factors, processes, and actors considered, isolating the most important features that support ecological integrity and cultural resilience can become extremely difficult. With the potential utility of adaptive governance as a framework for addressing environmental issues across scales, scholars have identified a number of important

social mechanisms for achieving desirable social and ecological outcomes (Table 1).

Table 1. Social mechanisms identified within the adaptive governance framework as being important for achieving desirable social and ecological outcomes within complex SESs. Selected key references draw from within and outside of the adaptive governance literature.

Mechanism	Description	Selected Key References
Knowledge integration	Multiple evidence-based approaches that deal with the synthesis and validation of different knowledge systems. Different knowledge forms are viewed as distinct, yet complimentary and provide new insights to a given environmental problem.	Gadgil et al. 1993; Fernandez-Gimenez et al. 2006; Brown 2009; Blythe et al. 2012; Tengo et al. 2014
Knowledge co-production	The collaborative process of generating new knowledge that brings a plurality of knowledge sources and types together to address a defined environmental issue. Collaborative and participatory processes occur at all stages of knowledge generation.	Pohl et al. 2010; Armitage et al. 2011; Dale & Armitage 2011; Fazey et al. 2012; Tengo et al. 2014
Deliberation	Inclusive process of open debate, communication, discussion, and reflection among actors who have alternative worldviews, political viewpoints, and/or "social memory" (linking past experiences to desired future actions), to facilitate shared understanding and provide new and useful insight for design and implementation of participatory decision-making processes.	McIntosh 2000; Dietz et al. 2003; Lebel et al. 2006; Rodela 2012
Social and organizational learning	Ongoing dynamic process of knowledge acquisition, reflection, and transfer that involves engaging underlying assumptions, norms, and objectives (can occur over short or long time spans for individuals, communities, or organizations), which is highlighted by monitoring, experimentation and adaptation.	Westley 1995; McClain & Lee 1996; Epstein & Roy 1997; Dietz et al. 2003; Folke et al. 2005; Gunderson & Light 2006
Collaboration	A process where multiple stakeholders engage and cooperate with one another with respect to an issue, co-creating and co-managing that process to define and achieve outcomes they could otherwise not achieve alone.	Ostrom 1990; Wondolleck & Yaffee 2000; Daniels & Walker 2001; Schusler et al. 2003; Plummer & Armitage 2007
Social capital	Relations of trust, reciprocity, attitudes, common rules, norms, values, and the connected nature of networks among individuals and institutions that act as an asset, which can be accessed to benefit an individual or group.	Flora 1998; Pretty & Ward 2001; Olsson et al. 2004; Folke et al. 2005; Titeca & Vervisch 2008; Leahy & Anderson 2008; Wagner & Fernandez-Gimenez 2008
Leadership	Individuals and/or organizations that have the power and vision to guide and motivate others to achieve a goal. Important in shaping change and reorganization through innovation in agenda-setting, popularizing issues, bargaining, brokering deals, garnering support, building trust, and developing networks.	Shannon 1991; Danter et al. 2000; Brosius et al. 2005; Folke et al. 2005; Gunderson & Light 2006
Diversity of actors and institutions	Existence of an array of distinct stakeholders (individuals and organizations) across scales (local, regional, and global), which can produce important networks of collaboration that can help absorb disturbances and spread out risks.	Gunderson & Holling 2002; Dietz et al. 2003; Low et al. 2003; Folke et al. 2005; Ostrom 2005
Monitoring and evaluation	Process and activities undertaken to assess and characterize the state and quality of a given system and	Boyle et al. 2001; Wilhere 2002; Stem et al. 2005;

	appraise the merit, legitimacy, and effectiveness of defined goals.	Plummer & Armitage 2007; Lyons et al. 2008; Cundill & Fabricius 2010

Within this framework, a number of applied management approaches can be found that act to operationalize adaptive governance. These applied, and to a degree, overlapping concepts include co-management, adaptive management, adaptive co-management, and adaptive collaborative management (Table 2). Each concept applies a number of the aforementioned adaptive governance mechanisms (Table 1), but all four highlight the importance of diverse knowledge sources when seeking to understand and address the innate uncertainty and stochasticity of SESs and the context-specific nature of many environmental issues.

Table 2. Key applied management concepts found within the adaptive governance framework.

Management Concept	Definition, Features, and Limitations	Selected Key References
Adaptive management	Structured, iterative, multidisciplinary decision-making approach that embraces risk and uncertainty as a way to build understanding of a system. Learning is achieved through deliberate experimentation and flexible institutions capable of monitoring, evaluating, and taking corrective actions. Participatory processes and social learning are viewed as important, but issue definition is often focused on ecosystem outcomes and dominated by scientists, managers, and policy-makers, with little attention paid to social issues like institutions, leadership, or social capital.	Holling 1978; Walters 1986; McLain & Lee 1996; Gunderson & Light 2006; Stringer et al. 2006
Co-management	Collaborative power-sharing agreement (usually codified) among local resource users (often indigenous groups) and higher-level organizations (usually a government or resource management agency), where each has rights and responsibilities in regards to decision-making. Seeks to enhance equity, local capacity, and efficiency in management and decision-making through deliberation, negotiation, and joint learning, but limited acknowledgement of historical and latent power inequities, distinct value systems, and the potential for rigid institutional design can reinforce power imbalances.	Pinkerton 1994; Jenoft et al. 1998; Nadasdy 2003; Carlsson & Berkes 2005; Natcher et al 2005; Armitage et al. 2011
Adaptive co-management	Evolutionary process that merges principles and practices of co-management (linkage properties) and adaptive management (dynamic learning), with an emphasis on collaboration and social learning of heterogeneous actors and organizations across scales to address sustainability issues in specific locations and contexts. Mix of codified and informal agreements. Can have high up-front transaction costs due to necessary long-term investments of time and resources. Potential limits in dealing with	Folke et al. 2005; Hahn et al. 2006; Plummer & Armitage 2007; Armitage et al. 2009; Plummer 2009; Leys & Vanclay 2011

	rapidly emerging issues.	
Adaptive collaborative management	Collaborative process of generating, integrating, and critically appraising knowledge and interests of local communities, conservation authorities, and resource managers to develop policy and management approaches. Heavily focused on participatory methods and decision-making, social learning, and testing and re-evaluating approaches. Similar to adaptive co-management, but with a greater emphasis on social justice and usually not codified agreements. Can have high up-front transaction costs due to necessary long-term investments of time and resources.	Buck et al. 2001; Colfer 2005; Fisher et al. 2007; Kalibo & Medley 2007

Despite many benefits, key limitations are present within the adaptive governance framework. The application and outcomes are often argued to be context-specific and its ambitious cross-scale and multi-disciplinary nature can make for a seemingly nebulous approach (Brunner et al. 2005). Additionally, distinctions between adaptive governance and some of its applied institutional management tools are unclear (Plummer et al. 2013; Chaffin et al. 2014).

Proponents of adaptive governance and its connected management concepts view knowledge as an important component of environmental management and decision-making within SESs, seeking to combine conventional scientific and other forms of knowledge into applicable policies through open decision-making processes, with the ultimate goal of promoting common environmental interests that benefit society and the environment. This comes out of broader debates about the role of science and knowledge in environmental politics, with scholars pointing out the failure of environmental politics to connect global western scientific knowledge with local and indigenous knowledge (Bäckstrand 2008). A proposed remedy is increased public participation in scientific assessment processes, and thus providing a more explicit recognition of this merged global and local knowledge, or the "glocal level of knowledge production" (Bäckstrand 2008: 29). However, merely increasing participation still overlooks power imbalances between knowledge holders and perceived differences in knowledge legitimacy

11

(Nadasay 1999; Kofinas 2005; Fernandez-Gimenez et al. 2006).

Additional challenges to incorporating local and indigenous knowledge exist. Many studies focus on direct comparisons of western scientific knowledge and local and indigenous knowledge, viewing the latter as needing "validation" from the former or simply as different forms of data to be interpreted by "expert scientists" (Gilchrist et al. 2005; Gilchrist & Mallory 2007). Despite these challenges, knowledge integration and co-production research, which builds on decades of CBNRM and participatory action research scholarship, provides evidence for important outcomes of these inclusive processes, such as trust building, community empowerment, expansion of scientific knowledge, and enhancement of adaptive strategies.

Exploring specific mechanisms within the adaptive governance framework, through applied management concepts (e.g. adaptive management and adaptive co-management) in distinct study areas and at different scales can provide important insight into the utility of an adaptive governance framework for facilitating SESs ecological integrity and protecting local livelihoods. The aforementioned efficacy of local and traditional forms of knowledge and the context-specific nature of invasive species environmental impacts (Levine 2000; Pyšek et al. 2012) provides additional support for including a wide array of stakeholder knowledge and perceptions in invasive species assessments and more concerted efforts at community-based approaches to invasion management and ecosystem service conservation. This is important for SES scholarship as disturbances at one scale can easily impact another (Zurlini et al. 2013). Unique observational data from local and indigenous communities can shed light on broader landscape changes and vulnerabilities within SESs and provide insights into local adaptive practices for fostering their ecological integrity.

This is important as "...marginalized forms of knowledge may bring new meanings into environmental policy debates and hereby render nature governable in new ways" (Lövbrand 2013: 1).

Research Questions and Dissertation Objectives

My research questions include the following: 1) How does the process of knowledge integration and co-production combined with species distribution modeling (i.e. integrative geospatial modeling) look when conducted with resource-dependent indigenous communities in drastically different ecological, cultural, and political settings at different spatial and governance scales? 2) What benefits and drawbacks does this transdisciplinary methodology hold for applied management efforts within an adaptive governance framework? 3) What is the current state of knowledge integration and co-production research, regarding the necessary conditions for and potential outcomes of conducting this participatory research?

This work constitutes an applied research approach, as I am seeking to contribute understanding of a pressing problem and facilitate taking action, with research questions driven by the concerns of people but additionally informed by disciplinary theory (Patton 2002). My dissertation seeks to develop an integrative geospatial modeling tool for applied management of invasive species and provisioning ecosystem services at the local and landscape scale. Knowledge diversity is argued to be an important part of adaptive governance and critical for addressing complex issues of SESs. Within this framework, there is an assumption that adding more diverse forms of knowledge to applied management processes is inherently good and will produce better outcomes. Arguably, in the ecological world there are limited avenues for

thoroughly documenting and incorporating different forms of knowledge in a sophisticated and culturally appropriate manner, particularly in concert with advanced geospatial applications like species distribution modeling.

Participatory mapping and counter-mapping studies provide diverse methods for combining local and indigenous knowledge with geospatial analyses. Applications have ranged from coupling ethnographic methods with satellite imagery, orthorectified aerial imagery, topographic maps, and hand sketched maps to define the distribution and variation in cultural landscape assets, spatially relay and quantify community-defined ecosystem services, and understand land cover changes (Mapedza et al. 2003; Fagerholm & Kayhko 2009; Klain & Chan 2012), to combining local and indigenous knowledge with sketched maps, global positioning systems (GPS), and geographic information systems (GIS) software, to help tribes make claims to traditional territory and understand the distribution and yield patterns of subsistence areas (Poole 1995; Smith 2003; Willow 2013). Such work has proven critical for expanding the realm of conventional science and affording a higher level of ownership in the research process for local and indigenous communities involved. However, to my knowledge it has not employed the advanced applications of species distribution modeling. These participatory mapping methods and species distribution modeling could greatly enhance one another, by facilitating more meaningful stakeholder inclusion in modeling approaches and providing another layer of powerful geospatial analyses for participatory and counter mapping efforts when engaging critical sustainability and resource management issues that are important to local and indigenous communities.

Motivated by these questions revolving around knowledge and adaptive governance, my dissertation builds on local and traditional (i.e. indigenous) ecological knowledge, participatory

mapping, and species distribution modeling literatures to highlights the importance of coupling the adaptive governance mechanisms of knowledge integration and co-production with existing, powerful geospatial tools; an approach that has received limited attention to date. Furthermore, I focused my efforts on invasive species, which at times reveal the connectivity of an array of other detrimental disturbance drivers that threaten the ecological integrity of SESs and affect local livelihoods, including climate change and human development. Additionally, this research sought a more nuanced understanding of local observations and responses to changing environments by very distinct communities, to further highlight the multifaceted challenges and opportunities that are present to engaging in such transdisciplinary work at the community and landscape scales. This integrative geospatial modeling approach directly engages key features of transdisciplinary scholarship. Such research is problem-focused, spans disciplinary boundaries for holistic understanding of issues, and integration of knowledge through collaborative, mutual learning (Mattor et al. 2014).

Linked with my research questions, the specific objectives of this dissertation research are: 1) to catalogue local and indigenous knowledge and perceptions of invasive species in Alaska and northeastern Ethiopia, and use this knowledge to create invasive species risk assessment maps of the most pressing invaders defined by the community stakeholders, 2) to assess the vulnerability of important community-defined ecosystem services to the aforementioned invasive species, and 3) to analyze the policy and management implications of this collaborative transdisciplinary research framework.

Study Areas

I conducted vulnerability assessments of indigenous livelihoods to invasive species for the state of Alaska and the Afar region of Ethiopia (Figure 2). Both locations have distinct ecologies, with interconnected marine, subarctic, and tundra ecosystems in Alaska (Nowacki et al. 2002) and semi-arid and arid desert ecosystems in Afar (Getachew 2001). Although both study sites are states within their respective countries, they encompass drastically different spatial scales, with Alaska (approximately 172 million ha) at around 18 times the size of Afar (approximately 9.5 million ha). Alaska is characterized by hunter-gatherer societies and northeastern Ethiopia by pastoral societies, but in both cases these groups are increasingly restricted in their mobility and means to engage in subsistence practices, and moreover, both constitute marginalized communities within their respective countries (Getachew 2001; McNeeley 2009). With such important distinctions but also a shared common thread of large populations of indigenous peoples that are highly reliant on the landscape for their livelihoods, this work makes for a unique comparison of opportunities and challenges of conducting such integrative and transdisciplinary research in different contexts.
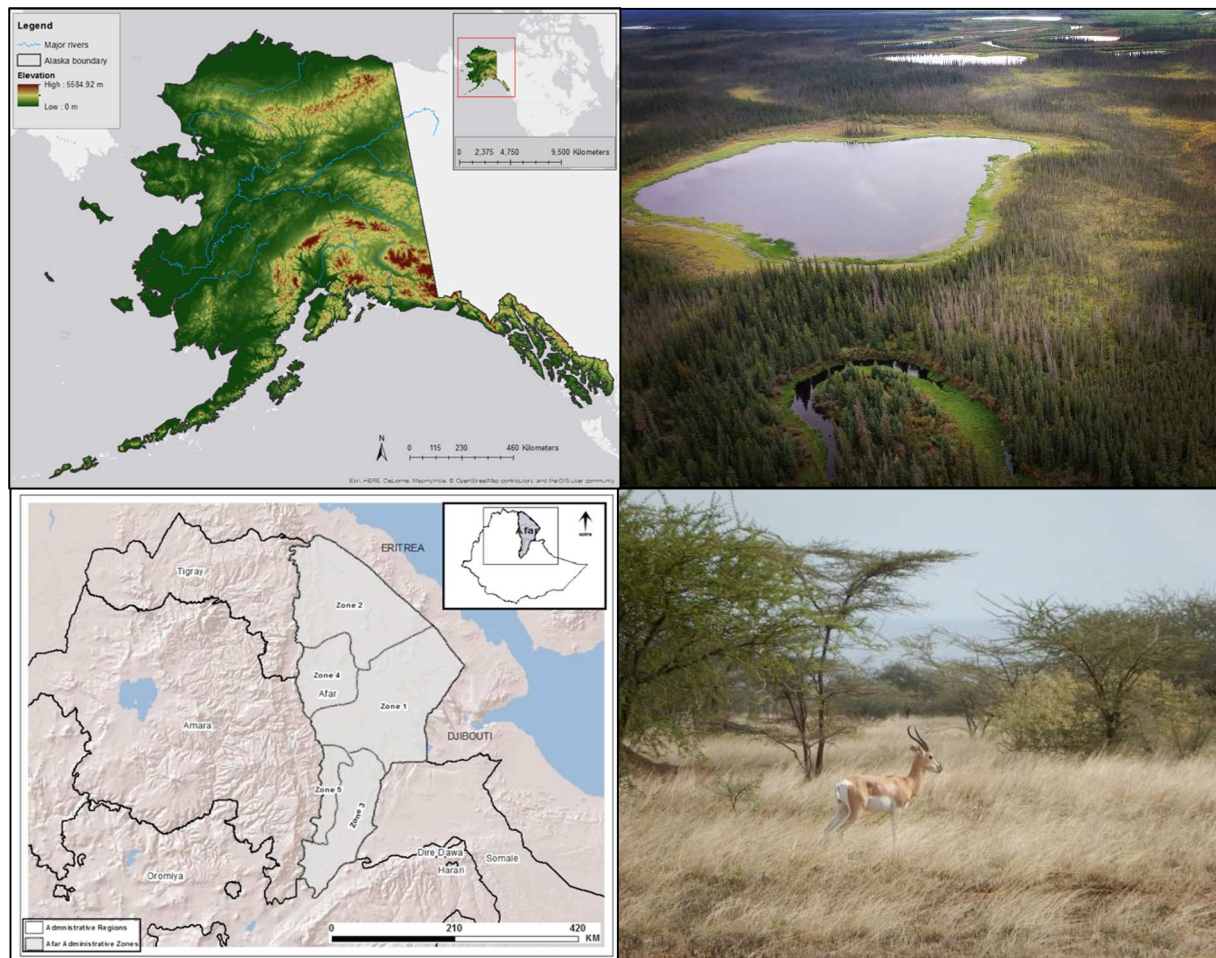
Figure 2. Dissertation research study areas: *Upper left (1)*: The state of Alaska (study region 1). *Upper right (2)*: Aerial shot of a lake complex representative of much of the subarctic habitat within Interior Alaska's Yukon Flats. *Lower left (3)*: The Afar region of northeastern Ethiopia (study region 2), divided by its five administrative zones. *Lower right (4)*: Soemmerring's gazelle *(Nanger soemmerringii)* in the semi-arid Aledeghi Plains of the Afar Region. Images courtesy of M. Luizza.

Methods and Goals

Ongoing work in Ethiopia has helped refine methods for documenting local and traditional ecological knowledge and revealed the importance of gender-inclusive data collection (Luizza et al. 2013). Ecological modeling techniques employed have been extensively used in other projects directed by my co-advisor Dr. Paul Evangelista and facilitated through the U.S. Geological Survey Fort Collins Science Center's Software for Assisted Habitat Modeling (SAHM; Morisette et al. 2013). Dr. Evangelista and colleague Tewodros Wakie facilitated my

access to local communities in Ethiopia based on their long-standing relationships and presence in the country. Dr. Evangelista's existing research provided an important avenue to connect with an array of resource managers in Alaska. Limited prior engagement with Native Alaskan tribes required extensive preliminary outreach with tribal councils and Alaska university researchers, in part aided by the Yukon River Intertribal Watershed Council. The necessity of these initial networking attempts ultimately limited the depth of indigenous knowledge collected in Alaska for this stage of my research.

Such bridging and boundary-spanning organizations and individuals can provide a measure of access and credibility with local communities when navigating these critical issues. Berkes (2009) notes the strong similarity of boundary-spanning and bridging organizations, which provide translation between science and policy spheres, with the latte having a broader scope. Such organizations "…provide a forum for the interaction of these different kinds of knowledge, and the coordination of other tasks that enable co-operation: accessing resources, bringing together different actors, building trust, resolving conflict, and networking" (Berkes 2009: 1692). For this study I view boundary-spanning and bridging organizations and individuals in a similar fashion, with each fostering the dissemination of knowledge and facilitating translation between science, policy and community spheres. This is important to note, as a number of challenges exist to gaining access and work with local and indigenous communities, especially the latter. Real and perceived perceptions of power and representation can fuel problematic "insider/outsider" dynamics among researchers and communities (Merriam et al. 2001). Furthermore, indigenous communities have often experienced "research fatigue", with academic scholars conducting numerous and sometimes overlapping studies with the same communities, and often producing limited tangible benefits for the participants (Clark 2008; Way

2013). This can pose major challenges to accessing and effectively engaging with local and indigenous communities. This is illustrated by a Native Alaska saying that states "researchers are like mosquitoes; they suck your blood and leave" (Cochran et al. 2008: 22).

My integrative geospatial modeling methodology (Figure 3) consists of a mixture of qualitative and quantitative data collection and is part of a larger collaboration between U.S. Geological Survey Fort Collins Science Center and Colorado State University's Natural Resource Ecology Laboratory. The stages, which are linked with my dissertation objectives are the following: 1) understand and catalogue the nuances of local and indigenous resource user perceptions of invasive species and provisioning ecosystem services, 2) model the suitable habitat of problematic invasive species across the landscapes of concern, 3) assess the vulnerability of important user-defined provisioning ecosystem services to invasive species, and 4) analyze the policy and management implications of this collaborative transdisciplinary research framework.
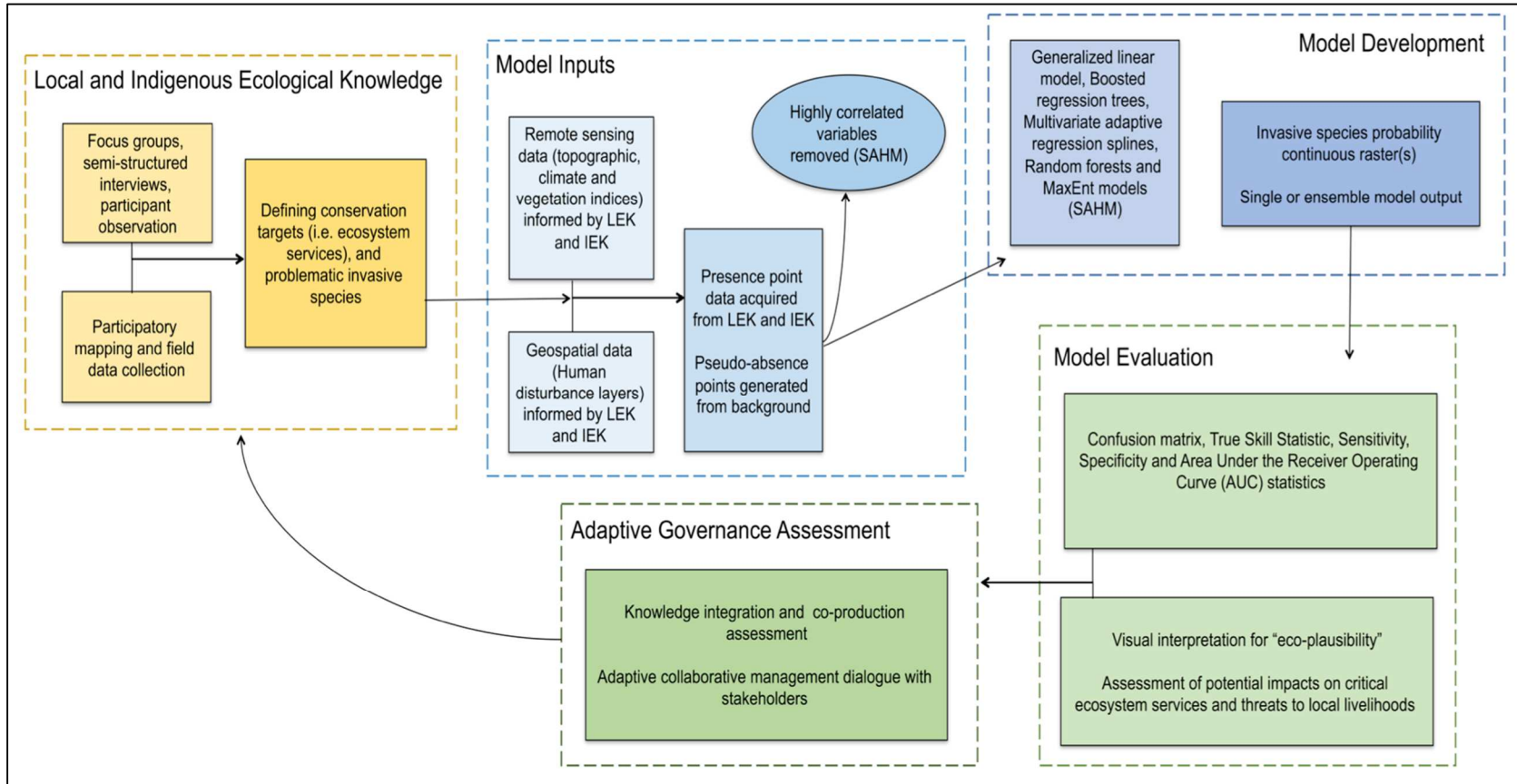
Figure 3. Integrative geospatial modeling methodology workflow. This multi-stage process includes cataloguing local and indigenous knowledge, used to define ecosystem service-providing species of interest and problematic invasive species (Stage 1). These data are used in concert with geospatial data including remotely sensed vegetation, topographic, climate and anthropogenic variables and species distribution modeling, to assess the threat of problematic invasive species to critical ecosystem services defined by local and indigenous communities (Stage 2). The vulnerability of important user-defined provisioning ecosystem services to invasive species is assessed (Stage 3). Invasion risk assessment maps are brought back to the communities to validate and calibrate and begin a dialogue about community-based conservation planning, and a concerted analysis is conducted on the implications this transdisciplinary approach holds for adaptive co-management and governance of invasive species and ecosystem services in Alaska and Ethiopia (Stage 4).

Each chapter provides an important engagement with knowledge integration and/or knowledge co-production and addresses a facet of the above integrative geospatial modeling workflow. Chapter one provides an application of the first three stages of integrative geospatial modeling in Alaska, with the integration of knowledge and co-definition of important ecosystem service conservation targets and concern around the interconnected threats of climate change and invasive species coming from Native Alaskan communities and federal and state land managers.

From this, I created current and future climate risk assessment maps to assess the vulnerability of Chinook salmon (*Oncorhynchus tshawytscha*) and whitefish species (*Coregonus nelsonii*) to invasive aquatic *Elodea* spp. Chapter two provides an application of the first three stages of integrative geospatial modeling in northeastern Ethiopia, with pastoral communities defining ecosystem service conservation targets and the interconnected threats of human development and invasive species. From this I created a current risk assessment map to assess the vulnerability of pastoral livelihoods to invasive rubber vine (*Cryptostegia grandiflora*). In this case, extensive participatory data collection efforts facilitated additional opportunities for shared learning during the knowledge integration process and the beginning stages of knowledge co-production. Chapter three reflects on the findings of applying integrative geospatial modeling in both locations and the opportunities and challenges encountered in each location for engaging in this type of transdisciplinary research. Through this reflection and based on current findings in the knowledge integration and co-production literature, it provides a preliminary assessment of stage four of integrative geospatial modeling, addressing the utility of this method for engaging adaptive governance mechanisms through applied management approaches in Alaska and Ethiopia, in addition to discussing the necessary next steps of enacting participatory validation and evaluation processes with project stakeholders and future research goals.

The ultimate goal of this work is to provide a useful tool for fostering collaboration between land management agencies, international aid organizations, and indigenous communities in Alaska and Ethiopia regarding adaptive and collaborative management of invasive species and ecosystem services. This research will contribute to the growing bodies of literature on adaptive governance, local and traditional ecological knowledge, indigenous livelihoods, collaborative conservation, species distribution modeling, and invasive species management. Species distribution modeling and invasion management literatures to date have afforded limited inclusion of indigenous and rural communities in their assessments, despite the National Invasive Species Council's 2008-2012 Management Plan having an important strategic goal of "Organizational Collaboration", which emphasizes collaboration not only between federal agencies but also tribal governments and private citizens (NISC 2008). Inclusion of indigenous knowledge and perceptions in invasive species science and management is arguably needed to more adequately address the report's other strategic goals of invasive species "Prevention", "Early Detection", "Rapid Response", "Control and Management", and "Restoration" (NISC 2008), and provide a better understanding of potential bridges and barriers for effective and collaborative adaptive management in different environmental, political, and cultural settings.

Moreover, this work overlaps with the broad vision and goals of international organizations working in Ethiopia and around the world, including the U.S. Agency of International Development (USAID) and Ethiopia CARE, both of which seek to reduce vulnerabilities and address insecurities that increase poverty and impact the resilience of local communities (CARE 2013; USAID 2014). Furthermore, this project contributes greatly towards the goals of the broader collaborative conservation community of increasing natural resource

sustainability and improving rural livelihoods, through a novel framework for addressing conservation efforts in rural regions with mounting anthropogenic pressures. Through my dissertation I hope to show the importance of combining local and indigenous ecological knowledge with advanced geospatial applications, to actively involve local communities in defining ecosystem service conservation targets and threatening invasive species, and provide another platform for sharing their important stories. There exists a need for increased stakeholder participation in ecosystem services and invasive species decision-making (White et al. 2008; Bremner & Park 2007; MA 2005), especially indigenous and rural communities, whose voices have been predominately left out of the conversation. More holistic approaches, as proposed by my integrative geospatial methodology, are critical if we are to attempt to balance environmental conservation and human livelihoods for more effective and adaptive governance in an increasingly connected and crowded world.

"Water is our life": Assessing impacts of invasive *Elodea* spp. on aquatic resources and native livelihoods in Alaska[2]

Alaska has one of the most rapidly changing climates anywhere on earth and is experiencing an accelerated rate of human disturbance. The combination of these factors increases the state's vulnerability to biological invasion, including non-native aquatic plants, which can have acute negative impacts on ecological integrity and subsistence practices. In this chapter, I assessed the threat posed by *Elodea* spp. (elodea) to aquatic resources and Native Alaskan subsistence livelihoods in the state. I created an elodea risk assessment using an ensemble of species distribution model algorithms developed with current observed climate data at a 2km spatial resolution. Models were applied to future climate (2040-2059) using five general circulation models best suited for Alaska. Based on Native Alaskan and local land manager insight and concern, I focused the vulnerability assessment on Chinook salmon (*Oncorhynchus tshawytscha*) and whitefish species (*Coregonus nelsonii*) spawning and rearing habitat. Model evaluations indicated that my results had moderate to strong predictability, with Area Under the Receiver Operating Curve (AUC) values of 0.88 (generalized linear model), 0.96 (MaxEnt) and 0.88 (multivariate adaptive regression splines) and classification accuracies of 82%, 90% and 85%, respectively. Current and future ensemble results revealed different levels of relative invasion risk across the state, based on the interaction of dominant subsistence practices and elodea climate suitability. This risk includes current high risk in the Athabascan region of Interior Alaska, which to date has no recorded observations of elodea, and future high risk in the Yup'ik region of western Alaska by midcentury. Results of this study suggest such integrative

modeling approaches can hold great utility for re-framing invasive species risk assessments and may provide a useful platform for facilitating the inclusion of Native Alaskan concerns in conservation planning and management efforts across the state.

INTRODUCTION:

Invasive species are one of the most pressing environmental, economic and cultural threats of the modern age. Biological invasions are noted to be among the most influential proximate causes of biodiversity loss worldwide, in addition to inflicting a range of detrimental impacts on local and national economies (IUCN 2000; White et al. 2008; Hejda et al. 2009). Concern over the establishment and spread of invasive species in Alaska is growing, with management efforts currently costing nearly $6 million each year (Schwörer et al. 2012; ANHP 2014). The state is also experiencing a rapid increase in anthropogenic disturbances including natural resource extraction and development of transportation infrastructure, coupled with acute climate change (Rupp & Springsteen 2009; Wilson et al. 2013). For instance, over the past 60 years, Alaska has warmed at a rate that is twice as fast as the rest of the country, with statewide average annual air temperature increasing by 3°F and noticeable inter-annual and regional variability (Stewart et al. 2013). These average annual temperatures are projected to rise by an additional 2°F to 4°F by 2050 (Markon et al. 2012). These interacting disturbances may exacerbate the problem of invasive species, as shifts in seasonality and temperature brought on by climate change and human dispersal are known to affect the spread of biological invasions across geographic scales (Mooney & Hobbs 2000; Bradley et al. 2012; Banks et al. 2015). This trajectory for Alaska is expected to increase the overall area of suitable establishment for a growing number of invaders (Jarnevich et al. 2014). These impacts may be especially

pronounced for Alaska's vast amount of freshwater aquatic habitat (Clark et al. 2010), as aquatic ecosystems (particularly freshwater) are estimated to be more prone to the effects of invasion than terrestrial ecosystems (Sala et al. 2000; Huotari & Korpelainen 2013). Combined, these factors pose major challenges for regional biosecurity, local livelihoods and overall ecological integrity.

Native Alaskan communities make up more than twenty distinct cultures across the state. Interactions of climate change and development already show negative impacts on hunting and harvesting efforts of Native Alaskan communities (McNeeley & Shulski 2011; Brinkman et al. 2014; Carothers et al. 2014). Subsistence practices (i.e. the customary and traditional uses of wild resources; Brinkman et al. 2014) are a major part of Native Alaskan livelihoods (Fall 2012), with subsistence fishing being highly important across the state for food security and cultural heritage (Fall et al. 2014). Such traditional use of resources is intimately intertwined with conservation and management, as many agencies in Alaska are charged with mixed management goals including biodiversity conservation, habitat preservation, recreation, and subsistence use. Achieving these mixed goals across such a large heterogeneous landscape can be facilitated to some degree by geospatial tools that have the ability to fill in certain data and knowledge gaps (Blaschke & Hay 2001; Pfeffer et al. 2013). Native Alaskan communities rely heavily on state and federal lands for an array of ecosystem services (i.e. the benefits that humans receive from natural systems and environments; Daily 1997). With approximately 90% of Alaska's land under state and federal authority (Mekbeb et al. 2009), holistic approaches to management that are adaptive and inclusive of local community concerns are greatly needed. Collaboration and social learning among scientific researchers, land managers, and local communities can benefit such applied management efforts (Berkes 2009, Armitage et al. 2011; Carothers et al. 2014).

However, the inter-connected issues of subsistence livelihoods and climate change-driven invasion vulnerabilities have not been adequately addressed in geospatial applications of risk assessments. This is troubling, because such work often plays a major role in conservation planning and resource management.

The utility of risk assessment procedures for addressing invasive species has grown in recent years (Buckley 2008; Lindgren 2012), including powerful geospatial applications like species distribution modeling techniques (Evangelista et al. 2008; Elith et al. 2010; Jarnevich et al. 2011). These approaches combine and quantify species location information with environmental data to predict a given species' distribution across a defined geographic space (Franklin 2009) and can allow for comparison and testing of various management approaches on the ground (Drew et al. 2011). Within species distribution modeling, the use of ensemble models is growing. This process combines the outputs of different individual models into a single map display, allowing areas of high model consensus to be delineated from those of low model consensus and thus potentially producing more robust predictions. This assessment is important due to the variability among commonly used correlative species distribution models, which are sensitive to the species occurrence data used and the specific mathematical algorithms employed (Araújo & New 2007; Jiménez-Valverde et al. 2008). The ensemble can highlight areas sensitive to choices made in the modeling process (such as model algorithm). Furthermore, ensemble models can be useful in instances where the species-environment interactions are not fully known, such as recently arrived species that have not spread to all suitable habitats (Stohlgren et al. 2010). Limited work has explored the application of ensemble modeling for invasion risk assessments or species climate suitability, although existing research provides promising results (Stohlgren et al. 2010; Ranjitkar et al. 2014).

Ensemble risk assessments can hold great utility for Alaska, as the state now faces the establishment of the first known submerged freshwater aquatic invasive plants within its borders, *Elodea* spp. (ADNR Personal correspondence 2014). Elodea is a genus of freshwater macrophytes commonly known as waterweeds. Of the seven *Elodea* sub-species, three (*E. canadensis* Michx., *E. densa,* and *E. nuttallii* (Planch.) H. St. John) are considered invasive to a number of continents including Africa, Asia, Australia, Europe, and North America (Huotari & Korpelainen 2013; Invasive Species Compendium 2014A). *Elodea canadensis* Michx. and *E. nuttallii* (herein referred to collectively as elodea) are the only two sub-species currently present in Alaska. Both are morphologically and phylogenetically close (Boiché et al. 2010) and like many other freshwater aquatic plants are highly plastic species (Di Nino et al. 2007), showing a broad distribution range, which is often only limited only by geographical barriers or acute changes in climate regions (Hussner 2012). The plant forms submerged, tangled masses and can persist in a wide range of trophic states, spanning nutrient-poor (oligo-mesotrophic) to nutrient-rich (highly eutrophic; Angelstein & Schubert 2008; Grudnik & Germ 2013). Although native to North America, elodea are not native to Alaska and are considered to be increasingly problematic species with invasive characteristics. First documented in southern Alaska in 1982, land managers did not take notice until 2010 when the plants began to rapidly establish in lakes and slow-moving streams around Anchorage, Fairbanks, Cordova, and the Kenai Peninsula (Fairbanks CWMA 2014). Elodea are believed to pose a major threat to interconnected wetland and riparian habitats found throughout Alaska; habitat for which many of the 234 tribes across the state are reliant for their livelihoods.Threats include degrading fish habitat, such as seasonal spawning grounds of Pacific salmon (*Oncorhynchus spp.*) and whitefish species (*Coregonus*

nelsonii) displacing native flora and fauna, impeding boat travel and safe float plane operation, and decreasing flow rates and increasing sedimentation of water bodies.

Research Questions & Project Goals

Land managers and local communities often have limited access to or training for techniques that assess the risk posed by invasive species. Therefore, determining the potential impact of problematic invaders to local subsistence livelihoods is important for holistic and adaptive conservation planning and management. To my knowledge, few studies have used ensemble modeling for risk assessments of aquatic invasive species, and none have explored the potential impacts of elodea on indigenous livelihoods in Alaska. Although the process of integrating diverse knowledge sources is a key social mechanism of the adaptive governance framework, few studies have coupled this process with advanced geospatial tools. Therefore, this research is driven by the following question: How does the process of knowledge integration combined with species distribution modeling inform our understanding of potential threats posed by invasive species to subsistence livelihoods? Linked with this question, the goals of this study included the following: 1) model the current and potential future climatic suitability for elodea for Alaska using an ensemble modeling technique, in concert with existing species occurrence records and climate data; 2) assess the vulnerability of particular fish subsistence practices to elodea invasion across the state based on six broad cultural/geographic regions; and 3) discuss the utility of this integrative modeling approach as a decision-support tool for adaptive and collaborative management efforts between Native Alaskan communities and land managers throughout Alaska.

METHODS

Study Area

I assessed vulnerability of indigenous livelihoods to elodea invasion in Alaska

(approximately 64° latitude and 150° longitude). Alaska is approximately 172 million hectares

of land and fresh
water, with elevation
ranging from sea
level at the Pacific
coast to over 6,000m
at Denali (Mt.
McKinley). The state
is home to diverse,
interconnected
marine, subarctic and
tundra ecosystems
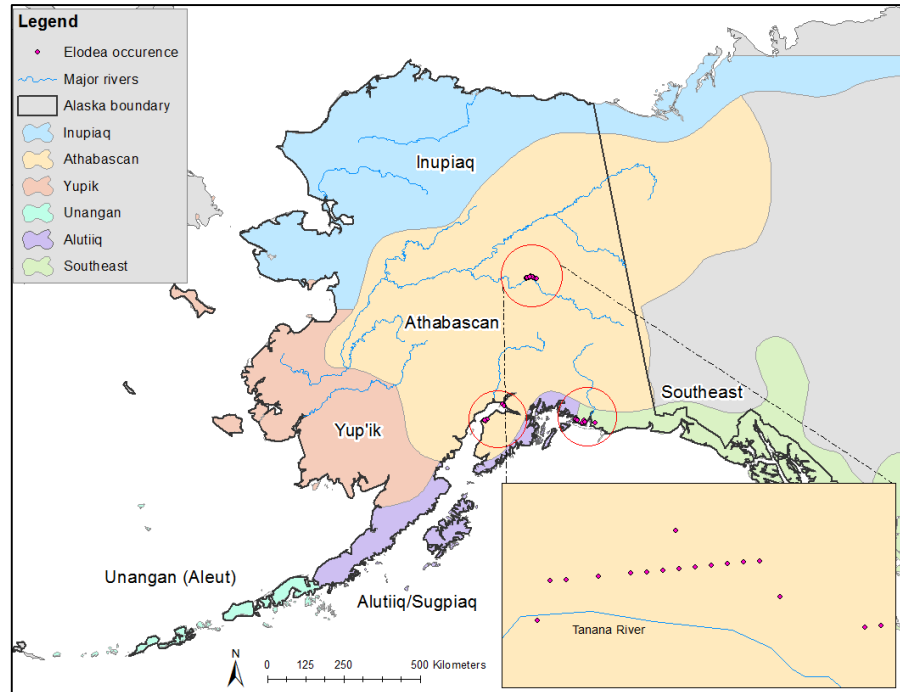
Figure 4. Study area of Alaska delineated by the six broad Native Alaskan cultures (adapted from Krauss et al. 2011) and Location of the 37 elodea occurrence points (denoted by red circles) used to develop the current climate ensemble model.

(Nowacki et al. 2002) that an array of plants, animals, and people rely on for their survival.

Native Alaskans comprise over twenty distinct cultures (Krauss et al. 2011), but for the purpose

of this study I have grouped them into six broad cultural domains, based on dominant language

and subsistence practices, including Inupiaq, Athabascan, Yup'ik, Unagan (Aleut),

Alutiiq/Sugpiaq, and Southeast tribes (Figure 4).

Project Impetus

Concerns of the threat of aquatic invasive species to local substance practices were

highlighted at the Yukon River Intertribal Watershed Council biennial summit in August 2013,

attended by co-advisor Dr. Paul

Evangelista and myself.

Participant observation and

informal discussions with Native

Alaskans and land managers at

the summit, in addition to follow

up visits with federal and state

land managers in Fairbanks and

Anchorage, AK assisted in

determining the conservation

targets of greatest interest (i.e.

Figure 5. Attendance at Yukon River Intertribal Watershed Council summit workshops, like this collaborative monitoring working group, provided important opportunities to hear the concerns of numerous tribal representatives and land management agencies across Alaska. Image courtesy of M. Luizza.

Chinook salmon and whitefish spawning and rearing habitat) and the invasive species of concern

(i.e. elodea). Attendance at the summit provided an important opportunity to interact with and

listen to the concerns of men and women from over 70 Alaska tribes and First Nations from

western Canada, in addition to an array of federal, state and provincial land management

agencies (Figure 5). Concerns over water and anadromous fish species were clearly shared by all

parties, as one Native Alaskan delegate emphasized during their opening remarks, "Water is our

life. It sustains us." Many summit delegates shared this sentiment, voicing additional concerns

for Chinook salmon and their aquatic habitat. Moreover, participants expressed growing

concerns about the connected issues of climate change, pollution, industrial development, and

invasive species, with a shared desire for alleviating ecological degradation.

Data Sources

Tribal representative and land management agency concerns were catalogued through a rapid appraisal approach (Beebee 1995), based on triangulation of ethnographic methods including participant observation and informal interviews (Marshall & Rossman 2011), and further supplemented by an extensive literature review of traditional ecological knowledge and subsistence practices across Alaska. The latter was done to corroborate data collected at the summit and fill in data gaps related to concerns of Native Alaskan groups not represented at the summit. The summit included tribes within the Yukon Watershed (predominately Athabascan but also including some tribes in the Inupiaq and Yup'ik regions), and thus did not include tribal representatives within the Unangan (Aleut), Alutiiq/Sugpiaq, and Southeast regions, or large extents of the Inupiaq and Yup'ik regions. Although an important caveat when interpreting the inclusivity and ability to capture concerns across the state, I argue this knowledge integration approach to be useful for expanding the scope of how agencies conduct risk assessments across a large landscape. Interview and observational data collection methods conducted at the summit were pre-approved by the Social, Behavioral, and Education Research Institutional Review Board (IRB) at Colorado State University (Protocol # 13-4436H).

I conducted rapid appraisal data collection in a flexible manner, including informal interviews during a 26-hour round-trip bus ride with Native Alaskan delegates and non-native attendees, from Fairbanks, AK to Mayo, Yukon Territory and back, and during meals and social activities with different tribal and agency stakeholders. These informal interactions provided a relaxed setting with unique opportunities to build rapport that would not have otherwise existed. For example, during our bus ride from Fairbanks, AK to Mayo, Yukon Territory, our bus was immobilized due to a flat tire. One of my Colorado team members (co-advisor Paul Evangelista)

and I changed the extremely large tire, as we otherwise would have been stranded most of the day waiting for a replacement bus. At the summit's opening plenary, a tribal delegate recognized our act of "heroism" and this became a light-hearted conversation starter initiated by tribal delegates when they encountered the "heroes" or "bus mechanics". Similarly, on the return bus ride, this level of comfort was expanded when my Colorado team members and other riders recruited me to serenade our bus driver with my travel guitar. This turned into an impromptu concert, culminating with a duet of a popular indie-folk song by the band "The Lumineers", by a female village chief from the Athabascan region and myself. These types of interactions seemingly afforded an increased level of comfort and may have facilitated added candor during the informal interviews, and absolutely made the research all the more memorable.

Additionally, I engaged in participant observation at a number of plenary sessions and smaller workshops at the summit. From these interactions, discoveries about the most pressing concerns and most important resources were catalogued in my field notebook. I conducted additional informal interviews with state and federal land managers over the next year following the summit. These activities resulted in feedback and data collection from approximately 30 Native Alaskan representatives and 8 key resource management individuals spanning U.S. Fish and Wildlife Service, Alaska Department of Natural Resources, and Alaska Department of Fish and Game.

Although this rapid appraisal approach conducted at an individual summit offers a limited snapshot of unfolding social life, it provided an important setting to hear an array of indigenous and land manager voices and engage important facets of ethnographic research, including a better understanding of how people feel in the context of their communities and as an outcome of the interaction of structure and agency through the practice of everyday life (O'Reilly 2012).

Field notes were thoroughly re-read to produce thematic memos to ascertain what patterns emerged within the notes. These were subsequently integrated with findings from the literature review (Marshall & Rossman 2011) to determine codes that represented the most pressing drivers of change stakeholders are concerned about and the most important ecosystem services. Pacific salmon (specifically Chinook) came out as the top item, linked with codes including "ecosystem services", "conservation", "biodiversity", "livelihoods", "identity", and "security". Particularly in the plenary sessions, the importance of protecting salmon habitat, mediating environmental and anthropogenic threats to their survival, and ensuring sustainable access to salmon for the various tribes was relayed.

For example, during the summit opening remarks, a Native Alaskan delegate from the interior Athabascan region noted the growing concern for salmon related to local economies and food security, stating, "We are hungry for fish too. King [Chinook] salmon was the life line on the Yukon [River], but kings have been in a fifteen year decline." This point was later added to during a lunch discussion, with another tribal delegate stating that this issue is not simply about harvesting salmon for economic gain and for food security. The problem is not about "'subsistence'. That's a legal term. It's livelihood; it's way of life; it's our identity". During a plenary session another tribal delegate implored the need for addressing the broader scope of this issue and acknowledging the interconnectedness of the land and water, saying, "We need to protect the watershed; not poison the water and plants. The spruce is our traditional medicine…the grass is our traditional medicine…the salmon is our life-line". These concerns were equally shared by land management agency representatives, but often framed along the lines of biodiversity preservation, subsistence access, and ecosystem health and resilience.

Whitefish was not as prevalent a topic in the interviews or participant observation activities, but the few times it was mentioned, this group of fish was noted to be another resource of great importance by both tribal and agency stakeholders. For instance, during a summit dinner, which consisted of whitefish, two tribal members relayed the importance of these fish as a food source that is often accessible throughout the year. This was further supported by land manager views and the background literature review, both of which relayed that where whitefish occurs, many sub-species are available year-round and act as an important staple for rural Native Alaskan communities as a consistent source of meat for people and their dogs (Andersen 2007; Brown et al. 2012). Informal member checking of the most important conservation target of concern was done through the informal interviews, by re-stating the major themes identified during the summit plenary sessions and workshops and soliciting clarification and additional feedback from tribal and land management stakeholders. This revealed consistent agreement with the field notes in regards to the importance of Chinook salmon and whitefish.

The supplementary literature review, to a great degree, corroborated the growing concerns of Native Alaskan community and land managers regarding Pacific salmon (particularly Chinook) and whitefish species, in addition to overlapping and distinct ways of relaying their importance, from biodiversity, keystone species protection, and subsistence framings common with many land managers (Pinkerton 1994; Adams et al. 2010; Fields & Reynolds 2011; Vercessi 2013), to access rights, food security, and cultural and spiritual identity framings common among many Native Alaskan stakeholders (Moncreiff & Klein 2003; Holen 2004; Langdon 2006; Carothers et al. 2014). However, it is important to note that these are not restrictive framings. Many tribal stakeholders equally engage and embrace the idea of biodiversity protection, which is often embedded in views cultural and spiritual identity related

to Pacific salmon and other species, and equally resource managers engage in alternative starting points to highlight the importance of both species.

Pressing drivers of change were more diffuse throughout the thematic memos in the notes. Linked with codes of "vulnerability", "disturbance", "threat", "decline" and "negative impacts", items ranged from climate change, oil and gas development, and non-native invasive species, to the overharvesting of salmon by other tribes, and exploitation of salmon through legal loopholes by international commercial fishing interests. With salmon and whitefish highlighted as provisioning ecosystem services of great importance to Native Alaskan and land management stakeholders, I deemed any drivers of change that specifically threatened them to be appropriate topics to explore in the modeling. Invasive elodea and climate change came out of extensive discussions with land management agency stakeholders, specifically U.S. Fish and Wildlife Service, as this freshwater aquatic plant is a problem of growing concern for land managers across the state. Elodea has seen recent expansion of its known range and potentially holds an array of cascading negative impacts for aquatic ecosystems and local livelihoods. With the added goal of helping re-frame agency risk assessments to better incorporate indigenous concerns, I decided to focus my integrative geospatial modeling approach on understanding the potential threat of elodea linked with climate change to Chinook salmon and whitefish subsistence.

I compiled elodea occurrence data from the joint survey efforts of project collaborators at Alaska Department of Natural Resources Division of Agriculture and Alaska Natural Heritage Program data portal (ADNR Personal correspondence 2014). From this survey database of lake and stream ArcGIS shapefiles, 37 occurrence points were created for use in the ensemble models. These points were located within three regions where elodea currently exists, including

the Kenai Peninsula and Cordova in the south-central part of the state (Alutiiq/Sugpiaq and

Athabascan cultural regions), and near Fairbanks (Athabascan cultural region) in the central part

of the state.

I acquired Chinook salmon and whitefish spawning and rearing site data from the Alaska

State Geo-spatial Data Clearing House (ASGDC 2014). This database includes spawning,

rearing, presence, and migration locations for all five species of Pacific salmon, whitefish, and a

number of other anadromous and non-anadromous fish species across Alaska, with annually

updated surveys spanning 1982 to 2014. I determined additional whitefish spawning locations

from Brown et al. (2012), as much less data exists for these species. Chinook salmon and

whitefish species data were extracted from the database and were then further reduced to only

spawning and rearing point locations within ArcGIS (v10.2). Each point's unique identification

code was then queried within an associated stream layer.

Predictor variables consisted of climate data created specifically for Alaska by the

University of Alaska Fairbanks International Arctic Research Center's Scenarios Network for

Alaska Planning (SNAP 2015). SNAP includes historical and projected climate downscaled from

Climate Research Unit data. SNAP bias corrects and downscales their data using the Delta

method, to detect spatial patterns of change from general circulation models (GCMs) historic

modeled climate and future modeled climate. I used future climate projections derived from the

5th coupled model comparison project (CMIP5), part of the Intergovernmental Panel on Climate

Change 5th assessment report (AR5; IPCC 2013). I selected five GCMs for the years 2040-2059

that performed best for Alaska based on actual climate data for the years 1958 – 2000 (Walsh et

al. 2008), and used the representative concentration pathway 4.5 emission scenario (RCP 4.5;

Table 3). The RCP 4.5 is a more conservative emission scenario where total radiative forcing is

stabilized shortly after 2100, without overshooting the long-run radiative forcing target level

(Thomson et al. 2011). I used only one RCP as climate change over the next few decades reflects

past emissions, resulting in little variation across the emission scenarios (Snover et al. 2013).

Table 3. List of the five best performing global circulation models for Alaska used in the future elodea habitat
suitability ensemble risk assessment.

GCM Name	Source Institution
CCSM4 RCP 4.5	National Center for Atmospheric Research
GFDL-CM3 RCP 4.5	NOAA Geophysical Fluid Dynamics Laboratory
GISS-E2-R RCP 4.5	NASA Goddard Institute for Space Studies
IPSL-CM5A-LR RCP 4.5	Institut Pierre-Simon Laplace
MRI-CGCM3 RCP 4.5	Meteorological Research Institute

I acquired qualitative and quantitative data on subsistence practices across the state from

literature reviews and the Alaska Department of Fish and Game Community Subsistence

Information System database (ADFG 2015). Villages were grouped by our study's six broad

cultural boundaries. Only villages with a majority Native Alaskan population and survey data

from 1990 and later were included in my analyses. I created a quantitative assessment of

subsistence harvests across major resource categories by averaging the estimated pounds

harvested across villages surveyed by Alaska Department of Fish and Game. These categories

included Pacific salmon, marine mammals, land mammals, whitefish, birds and eggs, and

berries. Although the total number of villages included varied by cultural region (e.g. N= 5 for

the Unangan (Aleut) region and N= 33 for the Yup'ik region), a visual assessment of village

locations across the state revealed an overall well-distributed sample for each cultural region.

However, these data may not be truly representative of harvest totals, as discrepancies may exist

between actual harvest totals and reported harvest totals.

Data Processing

All pre-processing and modeling procedures were conducted within the US Geological

Survey Software for Assisted Habitat Modeling (SAHM v1.2; Morisette et al. 2013). SAHM is

an open source modeling platform that expedites pre-processing and execution of habitat

suitability modeling. Using SAHM's *FieldDataAggregateAndWeight* module, I distributed

elodea presence points at a minimum distance of 2 km within stream layers with elodea

occurrences so only a single presence point existed within the cell size of the predictor variables.

I used SAHM's *BackgroundSurfaceGenerator* module to produce a Kernel Density Estimator

(KDE) probability surface with values between 0 and 100 using the 37 elodea presence locations

as inputs. I then produced 10,000 background points within SAHM using the KDE surface to

weight their placement. This method is useful to mimic bias found in presence data in

background points where an invasive species is spreading from introduction loci (Elith et al.

2010). This process smooths out the contribution of each occurrence point over the localized

sampling extent (Hernandez et al. 2006).

I calculated average precipitation and temperature for the most recent 20-year period

(1987 to 2006) and 2040 to 2059 from the SNAP data. For all climate data, I created 19

bioclimatic variables using average monthly temperature instead of minimum and maximum

temperature, as these data were not available in the R statistical software (v3.1.3) using the R

"dismo" package (for a full list of predictor variables considered see Appendix 1).

Modeling and Analyses

I trained the climate suitability model using existing elodea occurrence points and the

bioclimatic variables. I employed SAHM's *CovariateCorrelationAndSelection* module to

identify and avoid using redundant variables, removing one of any pair with a Spearman,

Pearson or Kendal correlation coefficient of |r| > 0.70, following the recommendation of Dormann et al. (2013; see Appendix 3 for final covariate correlation display). The initial set of variables assessed was based on my knowledge of the species ecology and included a number of terrestrial climate variables known to act as good proxies for aquatic invasive species (Kelly et al. 2014).

I developed the initial elodea climate suitability risk assessment with five species distribution model algorithms, including boosted regression trees (BRT; Elith et al. 2008), generalized linear model (GLM; Bolker et al. 2008), MaxEnt (Phillips 2006), multivariate adaptive regression splines (MARS; Friedman & Roosen 1995), and random forests (Breiman 2001). I ran the five models using a 10-fold cross validation approach, which is an effective method that utilizes all of the observations for training and testing the model (Refaeilzadeh et al. 2009). This approach involves partitioning the sampling data randomly into 10 equal sub-samples. One of the sub-samples is used as a model validation set, while the remaining 9 are used to train the model. This process is repeated 10 times (10 folds), with all 10 sub-samples used once as a validation data set. The results from the 10 folds are then averaged to produce a single estimation.

I used the multivariate environmental similarity surface (MESS) areas produced within SAHM for each of the current climate models and each of the five GCMs to identify locations outside the range of the environmental conditions used to generate each (Elith et al. 2010). An ensemble of the MESS outputs for both the current and future models was made to highlight where all models agreed on novel environmental conditions, and thus where we have less certainty about predictions.

Initial model runs revealed all five to have high statistical evaluation metrics, but evaluation of predictor variable response curves showed BRT and random forests models to be over-fit. Additionally a visual assessment of model outputs revealed both models predicted high habitat suitability above the Arctic Circle north of the Brooks Mountain Range, which was viewed as highly suspect and proved to be an area of model extrapolation when looking at the MESS maps for each. These algorithms were removed from further consideration leaving GLM, MaxEnt, and MARS for the final current elodea climate suitability ensemble.

I applied the GLM algorithm from the current ensemble to future modeled and downscaled climate data (2 km resolution) for 2040-2059 using the top five performing GCMs for Alaska. I chose GLM for the future climate suitability ensemble because it is the most simplistic regression-based model of the three algorithms utilized in the current ensemble and had the smoothest response curves, providing a broader and more comprehensive climate suitability assessment for elodea.

Model predictions for each of the three current climate model algorithms and five future GCMs were translated into binary classifications (0= low to no suitability, and 1= moderate to high suitability) using the default sensitivity equals specificity threshold rule setting in SAHM. Individual climate suitability model outputs were added together in ArcGIS raster calculator to produce a frequency histogram ensemble forecast (Araújo & New 2007), which shows the number of models (1-3 for the current ensemble and 1-5 for the future ensemble) forecasting the suitable climate for elodea at any point (i.e. pixel) across the state of Alaska.

I assessed model performance with a number of evaluation metrics provided in the SAHM model output, including the area under the receiver-operating characteristic curve (AUC), percent correctly classified, and sensitivity and specificity metrics. The AUC is a

threshold-independent metric that measures the ability of a model to discriminate a true occurrence point from an absence or background point. The AUC values range from 0 to 1. A value of less than 0.5 shows that model predictions were worse than random, a value of 0.5 no better than random, and a value of 1.0 indicating perfect discrimination (Peterson et al. 2011). Sensitivity (or true positive rate) and specificity (or true negative rate) metrics provide an estimate of the proportion of actual presence and background points from the test data being accurately predicted by the model, thus expressing the uncertainty associated with the final map predictions (Alatorre et al. 2011). Percent correctly classified reveals the percentage of test data correctly classified by the model (Talbert & Talbert 2012).

I determined relative invasion vulnerability risk by assessing the intersection of elodea climate suitability and dominant subsistence practices across the state. A combined annual Chinook salmon and whitefish harvest contribution of greater than or equal to 15 percent was deemed to hold moderate to high potential influence on subsistence livelihoods, resulting from a potentially significant reduction in total pounds harvested for subsequent caloric intake or economic exchange. This was used in concert with the elodea climate suitability ensembles to determine relative risk. For example, a region with less than 15 percent combined harvest of Chinook salmon and whitefish and low climate suitability predictions (i.e. 0-1 models predicting high suitability for the current ensemble and 0-2 for the future ensemble) would have low relative risk. A region with less than 15 percent combined harvest of Chinook salmon and whitefish but moderate-to-high elodea climate suitability (i.e. 2-3 models predicting high suitability for the current ensemble or 3-5 models for the future ensemble), or vice versa, would have moderate relative risk. A region with greater than or equal to 15 percent combined harvest of Chinook salmon and whitefish and high climate suitability predictions (i.e. all 3 models

predicting high suitability for the current ensemble and all 5 for the future ensemble) would have high relative risk. Additionally, Chinook and whitefish spawning and rearing streams were overlaid on the elodea ensemble models to visually assess the overlap of suitable elodea climate and critical spawning and rearing sites.

RESULTS:

Current Elodea Climate Suitability Ensemble

The current elodea climate suitability ensemble risk assessment performed well, with all three model algorithms employed producing overall high statistical evaluation metrics (Table 4), including the following moderate to high AUC values: GLM (AUC = 0.88), MaxEnt (AUC = 0.95), and MARS (AUC = 0.88). A mixture of temperature and precipitation variables drove the models. The most important variables (in order of importance) were mean temperature of the warmest quarter (BIO10) and mean temperature of the coldest quarter (BIO11) for GLM, and precipitation of the warmest quarter (BIO18), mean temperature of the warmest quarter (BIO10) and mean temperature of the coldest quarter (BIO11) for both MaxEnt and MARS (see Appendix 2 for all model response curves).

Table 4. Statistical evaluation metrics including area under the receiver-operating characteristic curve (AUC), percent correctly classified, sensitivity and specificity, averaged across cross-validation runs for all three species distribution model algorithms used in the elodea current climate suitability ensemble. The percent of Alaska having novel environmental conditions for each model algorithm is also included.

Algorithm	AUC (Train)	AUC (Test)	% Correctly Classified	Sensitivity	Specificity	Percent Novel
GLM	0.87	0.88	82	0.79	0.82	9.2
Maxent	0.96	0.96	90	0.86	0.91	9.7
MARS	0.92	0.88	85	0.74	0.85	9.7

The current ensemble revealed a range of climate suitability for elodea across Alaska with relatively high algorithm consensus (Figure 6). Fifteen percent of all the area predicted to have high climate suitability for elodea was agreed upon by all three model algorithms. This includes all three predicting high climate suitability across a large expanse of the Yukon Flats in the Athabascan region of the state's Interior, where elodea has not yet been recorded. Furthermore, additional suitable climate was predicted in the vicinity of existing elodea infestation sites in the interior city of Fairbanks (Athabascan region) and in the south-central region of the state in the Kenai Peninsula (Athabascan and Alutiiq/Sugpiaq regions) and Cordova (Southeast region).

I determined the Alutiiq/Sugpiaq region of Alaska (located in the south-central and south-western parts of the state) to have current low-to-moderate relative risk for elodea impacts on Chinook salmon and whitefish subsistence. Although having current elodea infestations and high suitability in the Kenai Peninsula, subsistence practices in the region are mostly based on other Pacific salmon sub-species, in addition to marine mammals, halibut (*Hippoglossus stenolepis*), mollusks and caribou (*Rangifer tarandus granti*) (see Appendix 4 for full list of subsistence resources by cultural/linguistic region).
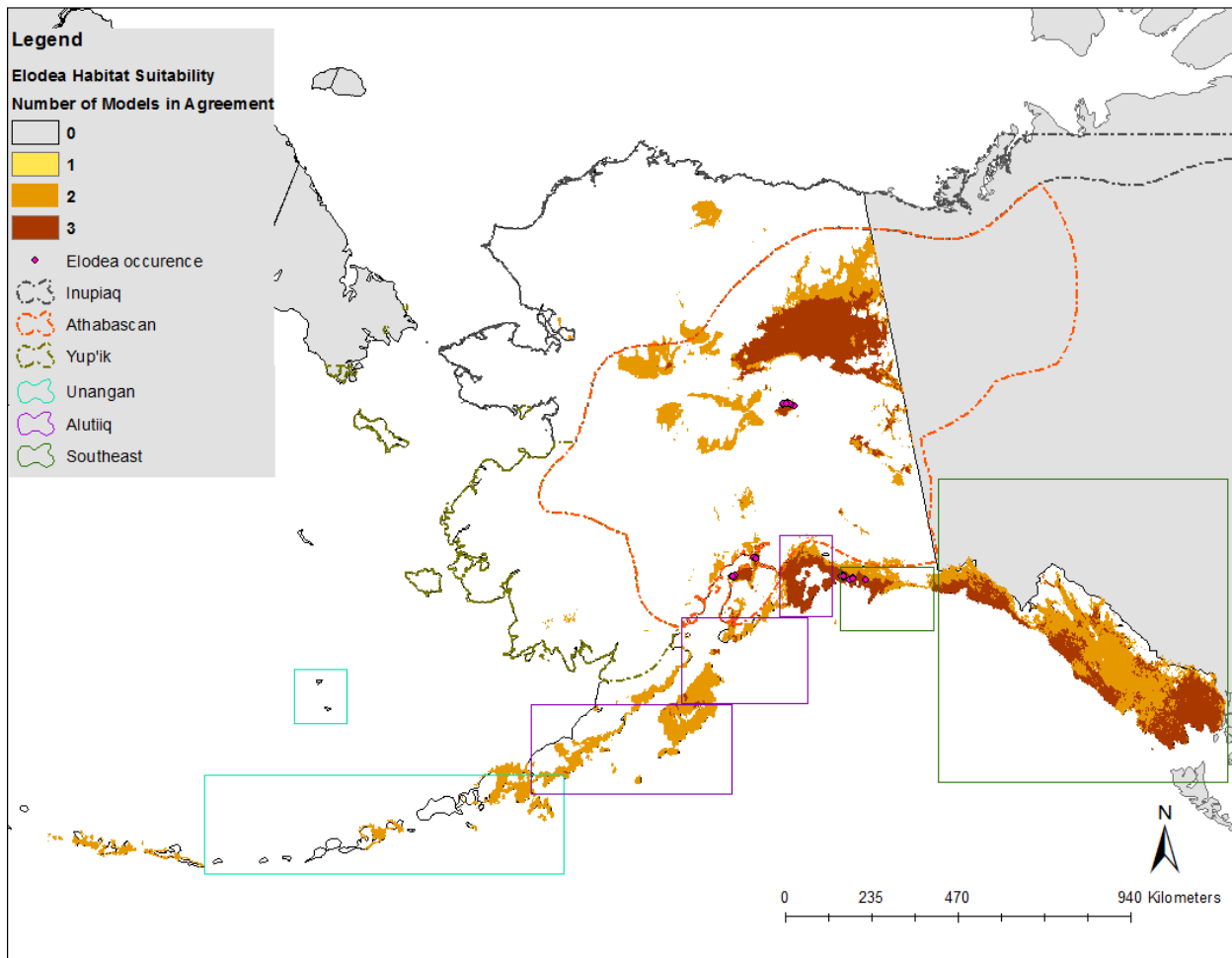
Figure 6. Current elodea risk ensemble showing the climate suitability of elodea across Alaska within the six major Native Alaskan cultural/linguistic groups. Areas in brown show locations where all three SDM algorithms agree on highly suitable climate for elodea. Areas in orange denote locations where only two models agree there is highly suitable habitat and areas in yellow show locations where only one model predicts highly suitable climate for elodea.

For this region, Chinook salmon makes up only 7%, with few recorded spawning or rearing sites. Sites are limited to Kodiak Island and the Alaskan Peninsula. Moreover, no whitefish spawning or rearing sites exist in this region. This level of relative vulnerability could dramatically increase if including or focusing explicitly on subsistence of other salmon sub-species, as some 78% of total annual harvest for this region comes from Pacific salmon, and these other species may share suitable habitat for spawning and rearing with elodea.

The Athabascan region of Alaska has current moderate-to-high relative risk for elodea impacts on Chinook salmon and whitefish subsistence. Although recorded Elodea infestations are only in the Kenai Peninsula section of this region, there is high climate suitability for elodea in a large expanse of the Yukon Flats (Figure 6b). Eleven percent of this predicted high climate suitable area was novel environment conditions, outside of those used to train the ensemble
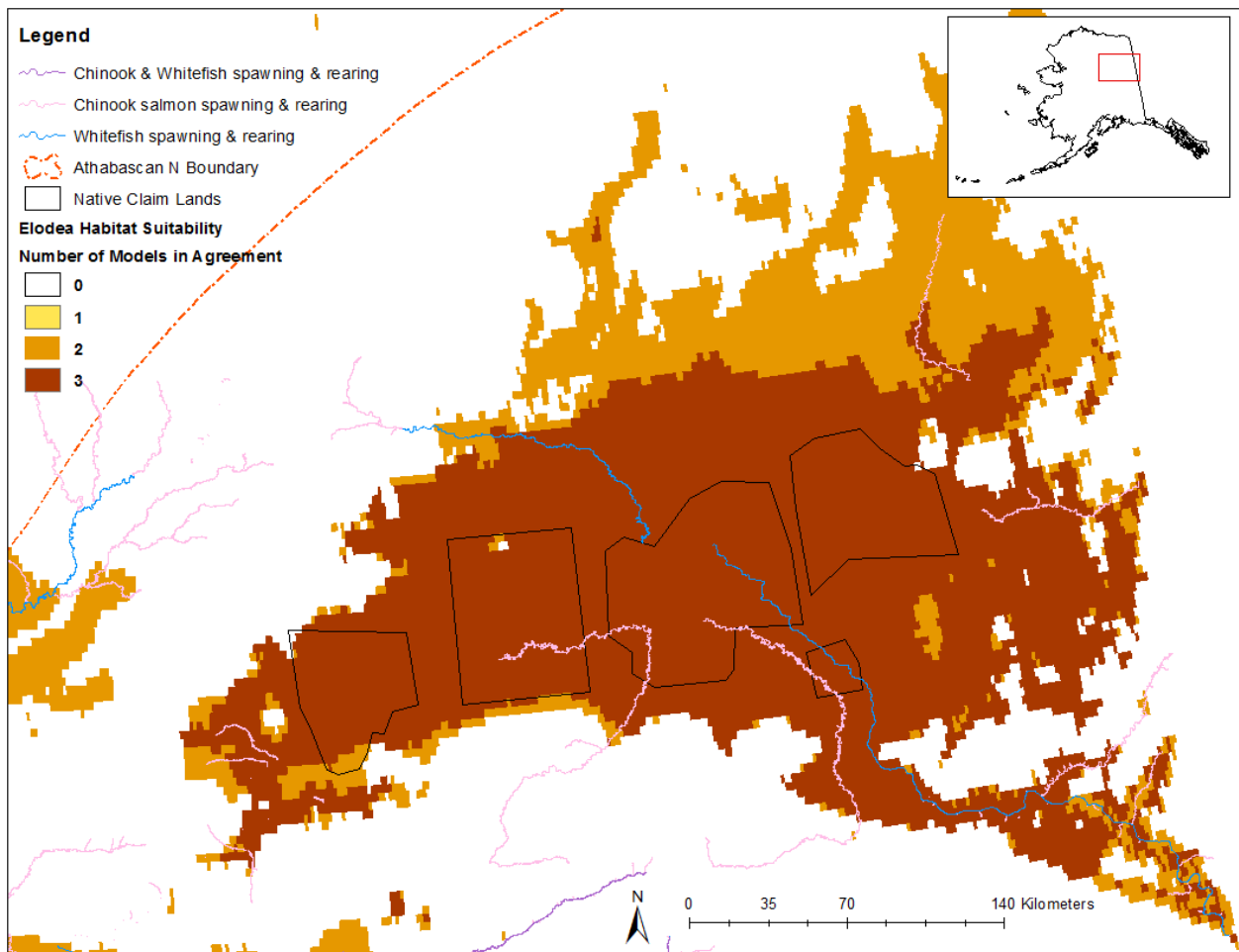
Figure 6b. The Yukon Flats within the Athabascan region. High current elodea climate suitability is denoted by brown areas and shows their relationship to recorded Chinook salmon and whitefish spawning and rearing sites. Village native claims lands within the Yukon Flats National Wildlife Refuge are highlighted by black borders.

model. This area of high elodea climate suitability includes a number of Chinook salmon and whitefish spawning and rearing sites that run within or adjacent to Koyukon and Gwich'in Athabascan native claims lands within the Yukon Flats National Wildlife Refuge.

This area additionally contains a major lake district and the confluence of a number of primary rivers that are connected by 40,000 streams, lakes, and wetlands, including the Yukon River, which flows westward through the Yup'ik region before emptying into the Bering Sea. Furthermore, in addition to having high dependence on moose (*Alces alces*) caribou and other Pacific salmon species, Chinook salmon and whitefish combined make up 24% of annual Athabascan subsistence harvest.

The Inupiaq region of Alaska has current low relative risk for elodea impacts on Chinook salmon and whitefish subsistence. Inupiaq subsistence practices are heavily focused on marine resources. Marine mammal and land mammal subsistence represent some 71% of total harvest for this region. Pacific salmon are relatively rare, with Chinook salmon making up 0% of the annual harvest. Although whitefish make up 11% of annual subsistence harvest, no GCMs predicted high climate suitability for elodea in this region.

The Southeast region of Alaska (consisting of tribes such as the Tlingit, Tsim shian, and Haida) has current low-to-moderate relative risk for elodea impacts on Chinook salmon and whitefish subsistence. Similar to the Alutiiq/Sugpiaq region, subsistence practices in this region are heavily based on other Pacific salmon sub-species, with Chinook salmon making up only 9% of annual harvest and whitefish making up 0% of the harvest. Regions of high climate suitability for elodea span the Southeast region, but few recorded Chinook salmon spawning and rearing sites exist. Like the Alutiiq/Sugpiaq region, this level of vulnerability could dramatically increase if including or focusing explicitly on subsistence of other salmon sub-species, as Pacific salmon constitutes approximately 54% of total annual harvest.

The Unangan region of Alaska has current low relative risk for elodea impacts on Chinook salmon and whitefish subsistence. Chinook salmon makes up only 4% of subsistence

harvest and whitefish 0% of the harvest, and no areas of high climate suitability for elodea exist in this region. Moreover, few recorded Chinook salmon spawning and rearing sites are present, and these are restricted to the upper part of the region on the Alaska Peninsula. Similar to the Southeast and Alutiiq/Sugpiaq regions, this level of vulnerability could dramatically increase if including or focusing explicitly on subsistence of other salmon sub-species, as some 52% of annual harvest is Pacific salmon.

I determined the Yup'ik region of Alaska to have current low relative risk for elodea impacts on Chinook salmon and whitefish subsistence. Although this region has some of the highest concentrations of recorded Chinook salmon spawning and rearing sites, and Chinook salmon and whitefish combined make up 26% of subsistence harvest, no areas of high climate suitability for elodea were predicted for the region.

My future ensemble revealed a larger portion of Alaska with climate conditions by midcentury matching that of currently occupied elodea sites across most of Alaska (Figure 7). All regions experienced increased climate risk except Inupiaq. Thirty percent of all the area predicted to have high climate suitability for elodea was agreed upon by all five GCMs. Potential future climate suitability for elodea in the Alutiiq/Sugpiaq region increased from low-to-moderate to moderate relative risk, as high climate suitability was predicted by all five GCMs across the entire Alutiiq/Sugpiaq region by 2040-2059. Future elodea climate suitability in the Athabascan region increased from moderate-to-high to high relative risk, as increased climate suitability for elodea was predicted by all five GCMs, including a near doubling of suitable climate habitat in the Interior and additional increased area around the Kenai Peninsula in the southern part of the region by 2040-2059. Future climate suitability in the Inupiaq region remained at low relative risk. Small, isolated pockets of high climate suitability were predicted.
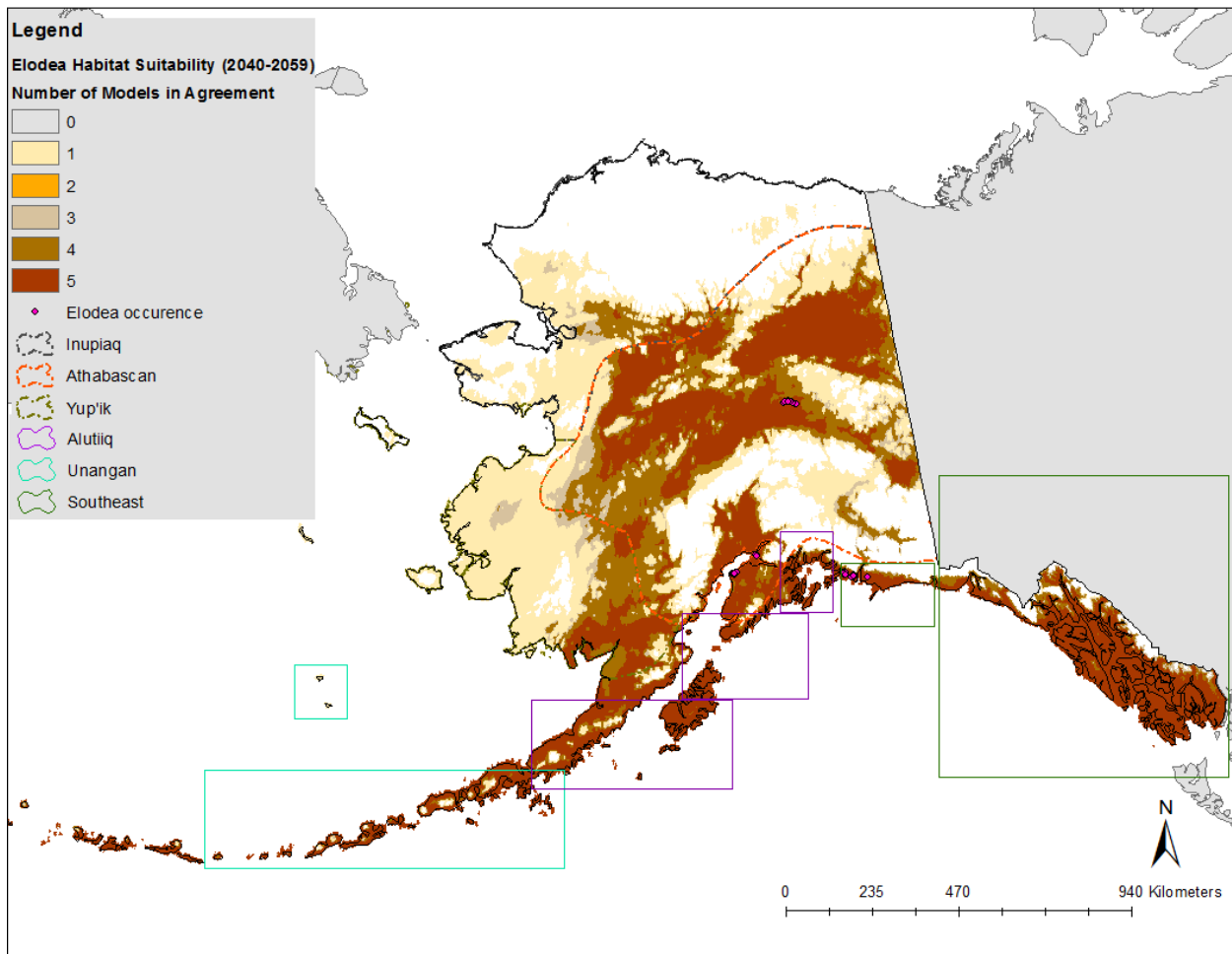
Figure 7. Future elodea risk ensemble (2040-2059) showing the areas with climate similar to that currently occupied by elodea across Alaska within the six major Native Alaskan cultural/linguistic groups. Values represent the number of future GCMs that agree on a location being climatically suitable.

Although they do not coincide with any recorded Chinook salmon or whitefish spawning and rearing sites, changes in future climate may shift this suitability too. For the Southeast region, future climate suitability for elodea remained at low-to-moderate relative risk. Although a moderate increase in climate suitability was predicted by all five GCMs across the region by 2040-2059, few recorded Chinook salmon spawning and rearing sites are present. Future climate suitability in the Unangan region increased from low, to low-to-moderate relative risk. A moderate increase in climate suitability for elodea was predicted by all five GCMs across the region by 2040-2059, but few recorded Chinook salmon spawning and rearing sites are present.

49

Future climate suitability in the Yup'ik region increased from low, to moderate-to-high relative

risk. A dramatic increase in climate suitability for elodea was predicted by all 5 GCMs across

southern stretches of the region by 2040-2059 and overlap with clusters of recorded Chinook

salmon spawning and rearing sites (Figure 7b).

A limited proportion of the landscape was classified as having novel environmental

conditions according to the ensemble of current and future climate suitability MESS map outputs

(Figure 8). For the current ensemble, 10 percent of the landscape was deemed novel by all three

model algorithms. These locations were restricted to the extreme northern extents of the state in

the Inupiaq region and southeastern extents of the Southeast region, in addition to small pockets

of novel environmental conditions in the Interior of the state in the Athabascan region. This

percentage slightly dropped for the future ensemble with 6 percent of the landscape categorized

as containing novel environmental conditions by all 5 GCMs. The locations of these novel areas

remained in the extreme northern and south-eastern extents of the state. Ensemble model

predictions in these locations have reduced certainty and thus should be interpreted with a level

of caution.
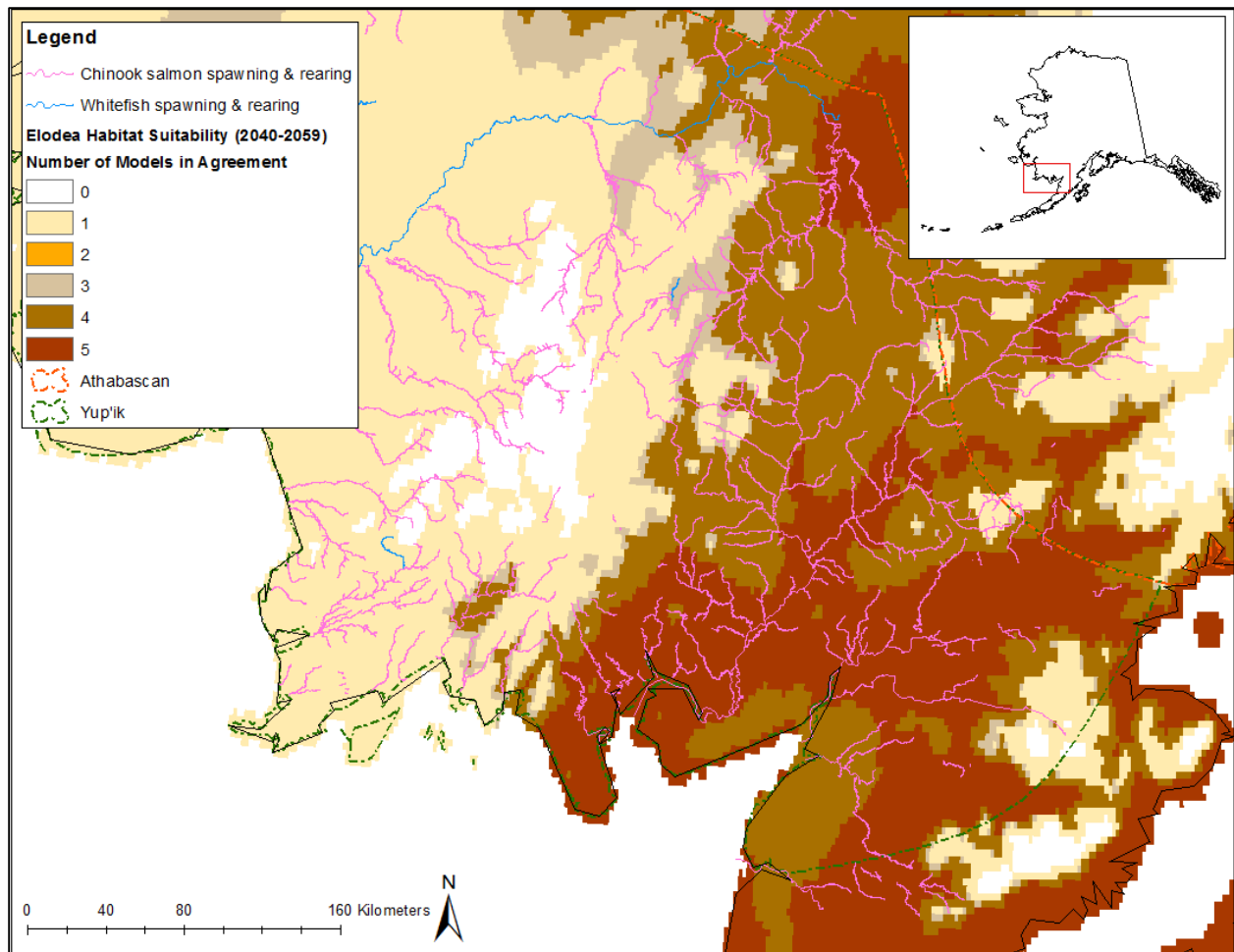
Figure 7b. Yup'ik region near Bristol Bay. High future elodea climate suitability is denoted by dark brown areas and shown to overlap with a number of Chinook salmon spawning and rearing sites.

DISCUSSION:

Integrative modeling approaches, like those found in this study can hold great utility for invasive

species risk assessments and may further facilitate adaptive and collaborative monitoring and

management efforts between indigenous communities and land managers across Alaska. The

process of talking with tribal and land management stakeholders seemed to reveal common

concerns related to water and anadromous fish species, but occasionally from distinct, albeit

potentially complimentary starting points (e.g. food security, economic security, and cultural

identity vs. biodiversity and keystone species protection and recreation interests). My efforts at

triangulating common concerns and important conservation targets among different stakeholders, combining diverse qualitative and quantitative datasets from these groups, and utilizing advanced geospatial applications provided an important opportunity for identifying regions across a vast landscape in need of targeted monitoring and surveying, which I argue should be collaborative and inclusive of Native Alaskan communities. Invasive species risk assessments are critical for state and federal land managers who require a spatially explicit

Figure 8. Ensemble outputs of the Multivariate Environmental Similarity Surface (MESS) maps produced in SAHM for both the current climate ensemble (above) and future climate ensemble (below). Areas in black show points where all models classify a location as having novel environmental conditions.

understanding of high priority areas, but such assessments that are inclusive of local community needs can further enhance effective collaborative monitoring and management.

A number of challenges exist to this integrative geospatial modeling work. Numerous obstacles were faced in regards to indigenous and local knowledge integration and presenting mapping results to stakeholders for participatory evaluation and discussion. When attempting to document Native Alaskan knowledge in a rapid appraisal manner, a more systematic qualitative data collection was initially sought, but I engaged in a less structured ethnographic data
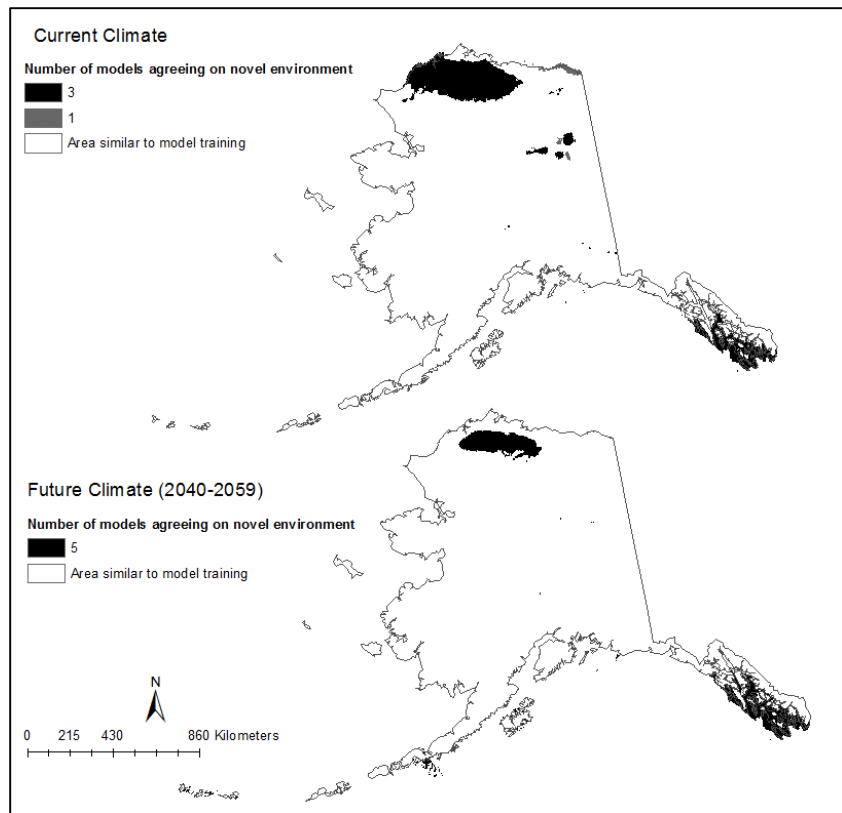
52

collection for two reasons: 1) initially a series of IRB-approved semi-structured survey and interview questions were prepared and set to be administered by our collaborating partners at the Yukon Intertribal Watershed Council, who have long-standing relationships with a number of the villages in attendance. The council canceled this activity the day of the scheduled interviews due to limited staff and scheduling conflicts. 2) With this being my first trip engaging face-to-face with Native Alaskan community members, I wanted to focus predominately on relationship building and gain an understanding shared concerns between Native Alaskan and land management agency stakeholders, while avoiding a stark researcher-subject approach. Thus, a lack of pre-existing trust and the loss of data collection support from our key boundary-spanning organization necessitated a major shift in approaches and limited the depth of qualitative data collection. Moreover, an additional IRB renewal was required over the following year. A subsequent attempt to connect with Native Alaskan communities through the watershed council under a new IRB proposal fell through with the resignation of key staff invested in our project coupled with high-turnover of tribal council staff they were working with. Finally, when seeking to present the maps to Native Alaskan stakeholders for their feedback, re-connecting with individuals from the summit turned out to be a difficult feat, as no names or contact information were recorded during the summit data collection. I made an additional attempt to bring preliminary maps to tribal communities in Interior Alaska, at a regional summit at Fort Yukon village. This meeting, facilitated through U.S. Fish and Wildlife Service, was canceled at the last minute due to inclement weather. Funding limitations did not allow me to return for the rescheduled summit the following month. Despite these issues, I have begun the process of sharing model outputs with and receiving feedback from land management stakeholders from U.S. Fish and Wildlife Service, Alaska Department of Natural Resources, and Alaska

Department of Fish and Game. On my scheduled trip to Alaska at the end of July 2015, I will share updated model outputs with these same agency stakeholders and will attempt to set up another meeting with some of the tribal councils in the Yukon Flats to begin a similar, iterative participatory validation process.

Sustained community involvement is critical for this integrative modeling approach, as the relative risk determined by our assessment of overlapping elodea climate suitability and subsistence patterns could dramatically change if taking into consideration other salmon sub-species. Across a majority of the cultural/linguistic groups, Pacific salmon was the largest subsistence category (see Appendix 4). The other four sub-species of salmon, including Chinook salmon and whitefish, may have a number of spawning and rearing habitat types that overlap with potential elodea habitat. This warrants further exploration, and can be driven by our ongoing discussions with stakeholders.

It is important to note that all of the spawning and rearing river and stream sites identified within our climate suitability map are not necessarily suitable habitat for elodea establishment. The diversity of spawning and rearing site characteristics for Chinook salmon and whitefish include some large, open rivers that are too deep and turbid for elodea. Yet, other locations characterized by slow moving, shallow water with gravel substrate are prime elodea habitat. Therefore, an important next step involves multi-scale modeling that can assist in refining habitat suitability predictions and incorporate important variables not captured in our broad-scale climate models. The state-level current and future predictions of potential elodea climate suitability provide an important, conservative baseline understanding of potential invasion patterns for this problematic species across Alaska. Such broad-scale modeling approaches are valuable in that they can relay factors that may limit a species' distribution over the long term

(Jarnevich et al. 2014). Local-scale modeling could incorporate anthropogenic drivers and more mechanistic limiting or driving factors that need to be captured with finer resolution models. For instance, water turbidity is considered to be a critical variable for elodea, with highly turbid waters limiting its establishment (Ellawala et al. 2011; Grudnik & Germ 2013). Recent flood mapping research has revealed the utility of the Normalized Difference Surface Water Index, derived from 30m resolution Landsat Thematic Mapper, to effectively capture turbidity in flood waters (Amarnath et al. 2014), and may prove equally effective in highlighting highly turbid waters in large rivers. Moreover, anthropogenic variables, which can act as an important proxy for introduction pathways and propagule pressure and disturbance (Simberloff 2009; Jarnevich et al. 2014), may further highlight areas in need of immediate monitoring and sampling, including variables like distance to roads and docks, as well as float plane accessible lakes.

I overlaid a float plane accessible lakes layer acquired from the Yukon Flats National Wildlife Refuge (USFWS, personal correspondence 2014) onto the Yukon Flats region of our ensemble model predictions, revealing a high overlap in highly suitable climate habitat and locations with added vulnerability from human dispersal (Figure 9). Incorporating these aforementioned variables into the modeling process would help refine predictions and likely capture some of the fast-paced drivers for spreading elodea. I excluded the float plane layer from my initial analyses due to its spatial restriction to the Yukon Flats. This would have required the creation a similar layer for the entire state, which was not feasible at the time, but is worth pursuing in concert with other land management agencies around the state in the future.
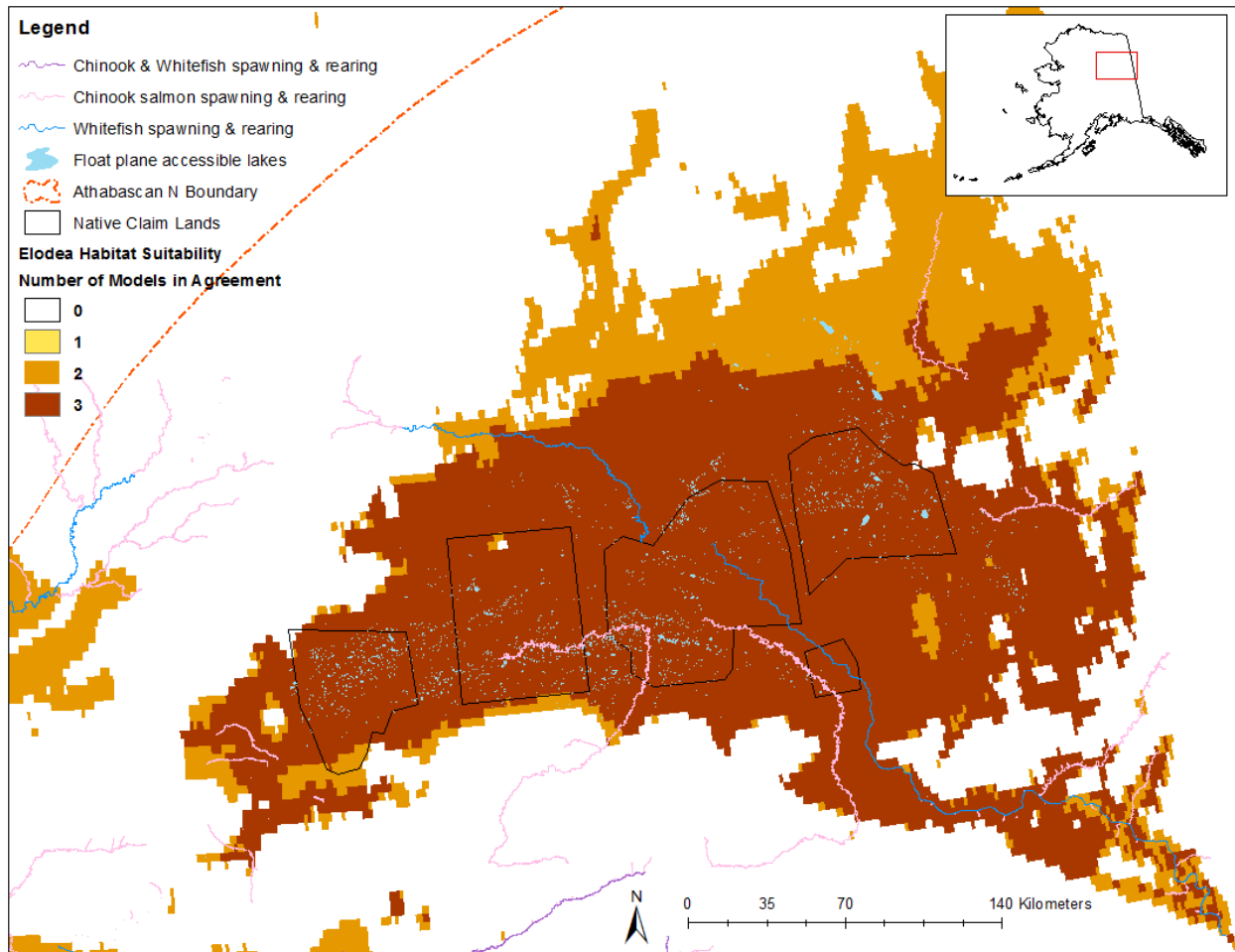
Figure 9. Yukon Flats within the Athabascan region. High current elodea climate suitability is denoted by brown areas and further shows the relationship of these areas to float plane accessible lakes and recorded Chinook salmon and whitefish spawning and rearing sites. Athabascan village native claims lands within the Yukon Flats National Wildlife Refuge are highlighted by black borders.

This process could enhance collaborative and adaptive monitoring and surveying efforts between

Native Alaskan communities and resource managers by relaying locations in the Yukon Flats

that have both suitable climate and float plane accessible lakes, and thus potentially heightened

risk to elodea establishment. Targeted surveying and monitoring could be enacted between

resource managers and villages, with new observational data being used to update the models. It

would also likely alleviate under- or over-prediction of elodea climate suitability that may be

occurring in certain locations, as illustrated by the model extrapolation highlighted by the

ensemble MESS maps. Under- or over- prediction in species distribution models can be attributed to the exclusion of a variable with high relative importance to the species of interest, or sampling bias inherent in species occurrence data (Phillips et al. 2009). Occurrence records for elodea in our models were clustered in three locations. A histogram of the SAHM covariate correlation (Appendix 3) reveals our BIO11 variable (mean temperature of the coldest quarter) to have a bimodal distribution pattern, which could be an artifact of sampling bias that is in part limiting current predictions in some locations, including the Yup'ik region in the western part of the state.

The potential negative cascading effects of elodea invasion warrant concerted monitoring and adaptive and collaborative management between local land managers and Native Alaskan communities. Elodea may pose direct negative impacts on local subsistence practices related to Chinook salmon and whitefish across Alaska. My current climate ensemble outputs revealed high suitability in the Yukon Flats of the Athabascan region and moderate-to-high future suitability in the Yup'ik region. This poses immediate concerns to Native Alaskan communities in the area and state and federal land managers. This includes the U.S. Fish and Wildlife Service Yukon Flats National Wildlife Refuge, which encompasses most of the current high suitability locations. Establishment in the lake and stream complexes around the Yukon River could have acute negative impacts, as numerous Athabascan and Yup'ik villages, in addition to three other U.S. Fish and Wildlife Refuges (Nowitna and Innoko in the Athabascan region and Yukon Delta in the Yup'ik region) are downstream of this high climate suitability region. With high potential for upstream elodea establishment occurring upstream of these areas in the Yukon Flats and Fairbanks areas of the Athabascan region, major flooding events, which frequently occur, could rapidly spread elodea. Invasive macrophytes including elodea in other locations have caused

significant shifts in lake productivity, species compositions and food web dynamics (Kelly & Hawes 2005). Even in Alaska's Chena Slough where elodea has established, it is believed to have displaced an entire population of arctic grayling (*Thymallus arcticus*; USFWS personal correspondence 2014). Although not a species that is heavily relied upon for subsistence, arctic grayling here use slower moving water with gravel substrate that is similarly utilized by Chinook salmon and whitefish in different regions of the state for spawning and rearing.

Moreover, different species of fish have different levels of affinity for aquatic plants. Depending on this affinity, establishment and spread of elodea could pose potentially important benefits or drawbacks for fish species and may additionally have mutualistic interactions with other problematic invaders. Mutualism between elodea and other invasive species has already been recorded. In Germany, the globally invasive crayfish (*Procambarus clarkii*) indirectly facilitates the dominance of invasive *E. nuttallii* in lakes by reducing native competitors (Chucholl 2013). Such a scenario could pose major negative impacts to local fisheries and their connected wetland and riparian ecosystems across Alaska. For instance, invasive northern pike (*Esox lucius*) may pose a growing threat if elodea establishes in the same locations. Considered an invasive species to south-central Alaska, northern pike have high affinity for aquatic plants throughout all life stages (Casselman & Lewis 1996), whereas salmon and trout species generally have low affinity for aquatic plants (Gettys et al. 2009). This could exacerbate detrimental impacts on salmon, as elodea may impede suitable spawning and rearing habitat in addition to benefitting the opportunistic northern pike that are known to heavily predate juvenile salmonids in their invaded range (Sepulveda et al. 2013). Although northern pike are native to other regions in the state, including the interior of the Athabascan region, predation facilitation and habitat

enhancements afforded by elodea could create a situation where northern pike become "native invaders" (Carey et al. 2012), leading to cascading negative effects on the interconnected habitats.

A number of new elodea occurrences were recorded by Alaska Department of Natural Resources for summer 2014 (ADNR personal correspondence 2015). Of the 25 new stream and lake infestations recorded, 24 were captured within the high suitability areas of our current climate ensemble. Many of these new locations were in close proximity to the occurrence records used to train the ensemble model, making a stronger case for incorporating dispersal variables like distance to current infested sites (Karatayev et al. 2015). One site in particular, Alexander Lake (the only new infestation site not captured by the current climate ensemble and located west of the Kenai Peninsula in the Athabascan region), is also struggling with invasive northern pike. Extensive mitigation efforts have been enacted to eradicate this invasive fish from the lake and its connected creek, which has experienced detrimental impacts on what used to be one of the most productive Chinook salmon sites (ADNR, personal correspondence 2015). Although preliminary, these initial findings warrant further research and reveal the robustness and adaptive nature of this integrative modeling process.

CONCLUSION:

Invasive elodea could pose a major challenge to natural resource managers in Alaska, as well as Native Alaskan communities that depend on the natural landscape for their livelihoods. These species may have equally detrimental impacts for indigenous livelihoods and cultural heritage that are centered on the land, water and wildlife. The goals of this study included modeling the current climate suitability of elodea across Alaska, which to date has not been done; predicting

how future climate conditions match these models; and predicting how elodea habitat suitability may spatially and temporally impact salmon and whitefish spawning and rearing habitat that local subsistence livelihoods rely on and land management agencies are charged with protecting. The current ensemble model had relatively high statistical evaluation metrics and revealed different levels of invasive elodea risk across the state of Alaska based on the interaction of dominant subsistence practices and elodea habitat suitability. This includes current high risk in the Athabascan region of Interior Alaska, which to date has no recorded sightings of elodea, and future high risk in the Yup'ik region of western Alaska by 2040-2059. My results suggest such an integrative modeling approaches can hold great utility for reframing how land management agencies do risk assessments, by incorporating concerns of local indigenous communities in the definition of conservation targets and threatening disturbance drivers; a process that can be further enhanced by concerted collaborative monitoring and engagement with Native Alaskan communities.

Integrating local pastoral knowledge, participatory mapping, and species distribution modeling for risk assessment of invasive rubber vine (*Cryptostegia grandiflora*) in Ethiopia's Afar region[3]

The threats posed by invasive plants span ecosystems and economies worldwide. Local knowledge of biological invasions has proven beneficial for invasive species research, but to date no work has integrated this knowledge with species distribution modeling for invasion risk assessments. In this chapter, I integrated pastoral knowledge with Maxent modeling to assess the suitable habitat and potential impacts of invasive *Cryptostegia grandiflora* Robx. Ex R.Br. (rubber vine) in Ethiopia's Afar region. I conducted focus groups with seven villages across the Amibara and Awash-Fentale districts. Pastoral knowledge revealed the growing threat of rubber vine, which to date has received limited attention in Ethiopia, and whose presence in Afar was previously unknown to my field research team. Rubber vine occurrence points were collected in the field with pastoralists and processed in Maxent with MODIS-derived vegetation indices, topographic data and anthropogenic variables. I tested model fit using a jackknife procedure and validated the final model with an independent occurrence dataset collected through participatory mapping activities with pastoralists. A multivariate environmental similarity surface analysis revealed areas with novel environmental conditions for future targeted surveys. Model performance was evaluated using area under the receiver-operating characteristic curve (AUC) and showed good fit across the jackknife models (average AUC = 0.80) and the final model (test AUC = 0.96). These results reveal the growing threat rubber vine poses to Afar, with suitable habitat extending downstream of its current known location in the middle Awash River basin.

---

[3] Research from this chapter is part of the following manuscript: Luizza, M.W., T. Wakie, P. Evangelista, and C. Jarnevich (Accepted). Integrating local pastoral knowledge, participatory mapping, and species distribution modeling for risk assessment of invasive rubber vine (*Cryptostegia grandiflora*) in Ethiopia's Afar region. *Ecology and Society*.

Pastoral knowledge provided important context for its rapid expansion due to acute changes in seasonality and habitat alteration, in addition to threats posed to numerous endemic tree species that provide critical ecosystem services to local communities. This work demonstrates the important benefits of integrating local pastoral knowledge with species distribution modeling for early detection and targeted surveying of recently established invasive species.

INTRODUCTION:

Invasive plants are one of the most serious threats to ecosystems and economies worldwide (IUCN 2000; Pimentel 2005; Vilà et al. 2010). These problematic non-native species are known to have negative impacts on biodiversity, ecosystem functioning, and an array of other natural processes and human activities (Vitousek 1990; Hejda et al. 2009). The increasing threat of invasive plants is fueled by a diverse set of fast- and slow-paced human disturbance drivers including climate change (Thuiller et al. 2007), habitat alteration and fragmentation (With 2004), intentional introductions (Mack & Erneberg 2002) and an increasingly globalized horticulture trade (Bradley et al. 2012). Vines (herbaceous and shrubby climbing plants) can prove especially problematic upon establishment in novel areas. This is due to their fast growth rates, which facilitate their ability to out-compete host vegetation by blocking access to light, ultimately reducing host survival and dramatically altering ecosystem structures. A number of vines are considered among the 100 worst global invasive alien species, including Hiptage (*Hiptage benghalensis*), kudzu (*Pueraria montana var. lobata*), and mile-a-minute-vine (*Mikania micrantha*) (Lowe et al. 2000), yet few studies have explored the interconnected threats invasive vines pose for sensitive arid ecosystems and local livelihoods.

Early detection of invasive plants, facilitated through mapping efforts, is critical for rapid response and effective monitoring strategies. The utility of risk assessment procedures for

addressing invasive plants has grown in recent years (Powell 2004; Lindgren 2012), including

powerful applications of species distribution modeling techniques (Evangelista et al. 2008;

Andrew & Ustin 2009; Evangelista et al. 2009; Stohlgren et al. 2010; Jarnevich et al. 2011).

These modeling techniques combine and quantify species occurrence location information with

environmental data to develop relationships to predict a given species' distribution across a

defined geographic space (Franklin 2009). Collaboration and data sharing in regards to invasive

species have improved, as evidenced by a number of regional and global species occurrence data

repositories (e.g. Global Biodiversity Information Facility, Global Invasive Species Information

Network, Invasive Species Compendium and National Institute of Invasive Species Science).

However, these species often do not have easily accessible -and perhaps even any available -data

until they become widespread problems at the national or global scales. Furthermore, field

surveys can be time- and cost-intensive, thus limiting early detection efforts. Ecological

knowledge of local communities can provide an important tool for early detection and

understanding of invasion impacts and the creation of initial risk assessment models for

subsequent targeted surveying and monitoring. This is critical, as such knowledge integration

may afford the necessary edge to address invasive species that have not fully established or

widely dispersed across the landscape. Despite a wide array of research noting the importance of

local ecological knowledge for resource management and conservation planning (Fernandez-

Gimenez et al. 2006; Ballard et al. 2008; Berkes & Berkes 2009; Gagnon & Berteaux 2009;

Luizza et al. 2013), and the growing call for broader inclusion of stakeholder knowledge and

perceptions in invasion research (Garcia-Llorente et al. 2008; Liu et al. 2011; Kapler et al. 2012),

consideration of local ecological knowledge within risk assessment studies, particularly species

distribution modeling research, is lacking. Moreover, perceptions of indigenous peoples are all

but absent from the conversation and few studies have explored the interactions between invasive species and ecosystem services that indigenous and rural communities rely on. This is important, as invaders can often have detrimental impacts on an array of services, posing major threats to local livelihoods (Pejchar & Mooney 2009; Urgenson et al. 2013).

Ethiopia's Afar region is facing the threat of multiple aggressive non-native plants including mesquite (*Prosopis juliflora*), whitetop weed (*Parthenium hysterophorous* L.), and the recently established rubber vine (*Cryptostegia grandiflora* Roxb. Ex R. Br.) (Yohannes et al. 2011). Rubber vine is a woody perennial vine of the Asclepiadaceae family that is native to Madagascar. Although not yet listed as an invasive alien species in Ethiopia (Invasive Species Compendium 2014B), it potentially poses a major threat to biodiversity and local pastoral livelihoods in Afar. It is an adaptive species that is stress tolerant and highly competitive in arid environments with limited water. The vine is known to rapidly capitalize on small amounts of moisture for germination, produce thousands of pappus seeds which can spread by wind or water, and develop a deep taproot (Grice 1996; Brown et al. 1998). Rubber vine is highly invasive in other semi-arid and arid landscapes where it has been introduced including Australia, Mexico, and the United States (Invasive Species Compendium 2014B). In Australia, where the species has been established since the late 19th century, it is noted to drastically alter ecosystems and fire regimes, promoting a shift from frequent grass-dominant surface fires to infrequent but more intense crown fires (Grice 1997; Grice et al. 2008). It can form dense mono-specific stands, especially in riparian areas (Kriticos et al. 2003) and tolerate a range of soil conditions including sodic and saline. In Mexico, rubber vine is known to outcompete native vegetation, altering important habitat for an array of vertebrate and invertebrate species (Rodríguez-Estrella et al. 2010). Although the origin of rubber vine introduction to Ethiopia is uncertain, it was introduced

intentionally in other locations as an ornamental plant (Kriticos et al. 2003; Rodríguez-Estrella et al. 2010) and grown during World War II as a natural rubber source (Agustus et al. 2000). Pastoralists in Afar tend to agree that the vine first appeared in the middle Awash River basin within the past 10 to 20 years, concurrent with increased frequency and magnitude of flooding events. To my knowledge no research exists that assesses the suitable habitat of rubber vine and its impacts on pastoral communities in Ethiopia, and few studies have explored the benefits of cataloguing pastoral knowledge in Afar for conservation planning and management[4]. This research is driven by the following question: How does the process of knowledge integration combined with species distribution modeling inform our understanding of potential threats posed by invasive species to pastoral livelihoods? Linked with this question, the goals of this study include the following: 1) integrate local pastoral knowledge and participatory mapping with species distribution modeling to map the suitable habitat of rubber vine in the Afar region, 2) catalogue pastoral knowledge and perceptions of rubber vine impacts on local livelihoods and the landscape, and 3) assess the utility of integrating local pastoral knowledge with species distribution modeling for invasion risk assessment studies.

MATERIALS & METHODS:

Study Site

The Afar region (Figure 10) is located in northeastern Ethiopia (between 8° 51' and 14° 34' N and between 39° 47' and 42° 24' E), and is one of the country's nine administrative states. This region covers an area of approximately 95,266 km² and is split into five administrative zones that are further sub-divided into 29 districts (*woredas*) and 355 *kebeles*, the smallest

---

4   Notable exceptions include Giday and Teklehaymanot (2013) and Tsegaye and colleagues (2010).

administrative unit in Ethiopia. The region is topographically diverse, with elevations ranging from 125m below sea level to 2,870m a.s.l. (Wakie et al. 2014), and is one of the hottest

habitable places on earth, with temperatures surpassing 50°C (122°F) and bimodal rainfall that is under 200mm annually across large extents of the landscape (Davies & Bennett 2007). This arid region holds a number of unique flora and fauna including endangered species such as the Abyssinian wild ass (*Equus africanus asinus*) and Grevy's zebra (*Equus grevyi*) (Kebede et

Figure 10. *Left:* Afar region divided by its five administrative zones. *Upper Right:* Afar region in relation to Ethiopia. *Lower Right:* Close up of the two districts (*woredas*) where we collected focus group and field data.

al. 2012 and 2014). Vegetation in the region is made up of grasses, forbs, shrubs and woody plants, well adapted to arid and semi-arid environments including *Acacia mellifera, A. nilotica, A. senegal*, *A. tortillis*, *Cadaba rotundfolia*, *Chrysopogon*, *Cymbopogon*, *Cynodon*, and *Dactyloctenium* species, *Dombera glabra*, *Salvadora persica*, and *Tamarix nilotica* (Tikssa et al. 2009; Bahru et al. 2012; Wakie et al. 2014). The earliest known direct predecessor of humans, *Ardipithecus ramidus* (4.4. million years old) and her slightly younger, but more famous pre-human sister, *Australopithecus afarensis* (3.2 million years old) were both discovered in this region that many Ethiopians describe as the place "where it all began" (Dalton 2006). Afar is home to approximately 1.5 million people of which the majority (nearly 80%) are pastoralist
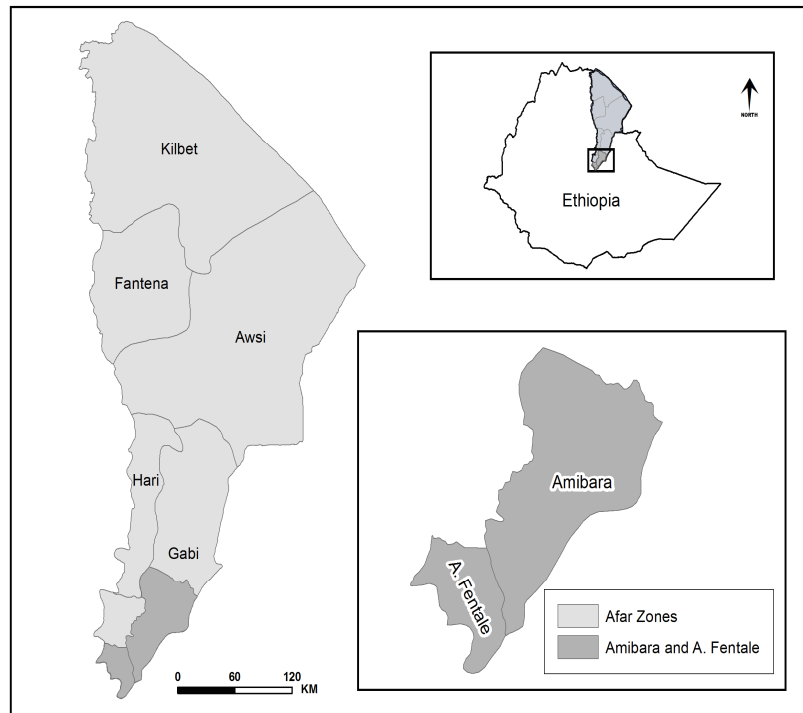
(Sonneveld et al. 2009), meaning they derive more than 50 percent of their income from livestock and livestock products (Rota & Sperandini 2009). Starting in the mid-1970s government sedentarisation policies and external appropriation of land have dramatically transformed pastoral practices in the region (Sonneveld et al. 2009; Tsegaye et al. 2013). Afar is also the dominant ethnic group (approximately 90%) and the main language spoken, which in addition to Somali and Oromo languages makes up the Lowland East-Cushitic language family (Getachew 2001).

Data Acquisition

My study design was pre-approved by the Social, Behavioral, and Education Research Institutional Review Board at Colorado State University (Protocol # 14-5049H). With the assistance of my colleague and research team member Tewodros Wakie, I collected field data, including rubber vine occurrence points and local pastoral knowledge in April and May 2014. We catalogued pastoral knowledge through semi-structured focus groups. This flexible approach allowed for the inclusion of different perspectives simultaneously (Morgan 1997) and provided a more relaxed and informal setting where unanticipated information could emerge (Huntington 1998). This proved fruitful, as a communal focus group setting facilitated the participation of some women, where otherwise they may not have been included. We deemed this gender-inclusive approach to be important, as women's ecological knowledge tends to be distinct from men's (Garibay-Orijel et al. 2012), yet often is overlooked in fields driven by knowledge documentation including ethnobiology and ethnobotany (Pfeiffer & Butz 2005; Luizza et al. 2013). Such distinctions in knowledge are in part driven by culturally defined roles and divisions of labor, which are present in Afar, with women being in charge of household sale activities and

67

the processing of dairy products (Getachew 2001; ESAP 2007), in addition to having different uses of local plants related to material culture (i.e. construction, traditional arts and handicrafts) (Bahru et al. 2012). In general, it is difficult to access Muslim women as study participants in Afar due to cultural taboos, especially when attempting individual interviews as a foreign, male researcher. Additionally, with greater restrictions on their time due to extended household duties, this informal group setting allowed women to bring their children and address domestic obligations such as food preparation, while still contributing to the research. Focus groups lasted approximately three hours and were conducted in the local Afar dialect and the national language Amharic with the assistance of Wakie, who is fluent in Amharic and English, and a local translator and research assistant who is fluent in Afar and Amharic and conversant in English. At the beginning of each focus group, a formal introduction was made, explaining the project objectives before receiving verbal consent by each participant.

Thirty-nine men and seven women participated in the focus groups across seven villages located within the Amibara and Awash-Fentale districts in Afar's southern Gabi Administrative Zone 3. We chose these sites because limited studies have been conducted in this region of Afar (Getachew 2001; Abule et al. 2005) and ongoing *P. juliflora* research led by members of our team greatly facilitated accessing the villages involved. The average size of the focus groups was seven people. Participants' ages ranged from 18 to 50 years, with over half (approximately 54%) being between the ages of 26 and 40. The average household size was nine people. The majority (nearly 70%) self-identified as pastoralists, predominately raising cattle, goats and sheep, in addition to some camels. The remaining fifteen individuals self-identified as agro-pastoralists, raising similar types of livestock, in addition to cultivating some crops including cotton and onions. In the interest of concision and the fact that pastoral activities still contribute to the

majority of the self-identified agro-pastoralists' income (over 50 percent), I subsequently refer to both groups collectively as pastoralists. Before conducting focus groups, we consulted the chairman of each village. In addition to being a local customary requirement, gaining the chairman's permission allowed for greater ease in locating and recruiting participants often spread out across a large geographic area. Focus group participants were recruited through a convenience sampling approach. I informed the village chairman at each of the seven village study sites about the project goals and they would designate one or two boys from the village to gather available men and women for participation in the focus groups.

Focus group responses were recorded with pen on printed interview guides for each of the seven villages. All attempts were made to capture verbatim responses of focus group participants and to anonymously distinguish individual responses when feasible. Focus group topics covered three broad areas: 1) Landscape-scale changes, which included questions such as: "Are there changes to nature which you have observed in your community during your lifetime, for example, changes in plants, water, soils, or wildlife?" 2) Seasonality, which included questions such as: "When do the rains come? Is it the same time every year?" 3) Plants and animals, which included questions such as: "Are there plants that you consider bad? Are any of these new to the region?" (See Appendix 5 for the full interview guide). Hand written notes were typed up on a personal laptop and entered into an observation frequency table (see Table 6) to assess the consensus and disagreement across villages related to different observations including changes in seasonality, ecosystem service-providing plants, and invasive species. Due to the fact that not all individual respondents could be anonymously identified in the focus group notes, observations were aggregated to the village level (i.e. maximum frequency value = 7).

A number of observations were subsequently used to define important variables for the rubber vine model, in addition to assessing the impacts of rubber vine on pastoral livelihoods.

Model Training Data

Through a series of open-ended questions, we interviewed pastoralists at each site about changes they have witnessed on the landscape and impacts of invasive plants on local livelihoods. The open-ended nature of the focus group interview questions revealed the growing presence of rubber vine, whose existence in the Afar region was previously unknown to our research team, and thus became the focus of subsequent data collection and analyses. We recorded 24 rubber vine observations with geographic coordinates (occurrence points) with a Garmin handheld GPS Navigator unit. This was achieved through a targeted sampling approach based on local knowledge. Pastoralists who participated in the focus group interviews and who had detailed knowledge of the landscape identified and guided our team to locations of invasive rubber vine in the field. I reduced the initial 24 points to 18 through the *FieldDataAggregateAndWeight* module located within the USGS Software for Assisted Habitat Modeling (SAHM v1.2; Morisette et al. 2013). This pre-processing module removed overlapping points within the same 250m-cell. We used SAHM's *BackgroundSurfaceGenerator* module to produce a surface with values between 0 and 100 using the 18 rubber vine locations as inputs, and created a Kernel Density Estimator (KDE) surface. I produced 10,000 background points within SAHM using this surface to weight their placement. This method is useful to bias background points to areas that have been sampled (Elith et al. 2010). This process helped to smooth out the contribution of each occurrence point over the localized sampling extent (Hernandez et al. 2006).

Model Validation Data

Following the focus group
interviews, we conducted participatory
mapping activities with the same
pastoralists (Figure 11) using mosaicked,
pan-sharpened (to 15m resolution) Landsat
8 satellite images from December 2013
that included the two districts with in our
study region (Table 5). We overlaid the
images with clear acetate paper and

Figure 11. Afar pastoralists identifying invasive plants with the assistance of Landsat 8 satellite imagery during participatory mapping activities. Image courtesy of M. Luizza.

participants used permanent markers to denote the locations of invasive plants and important

water resources across the landscape. We superimposed villages and towns on the high-

resolution imagery and clearly labeled them. These major landmarks helped participants to

rapidly familiarize/reorient themselves with the presented maps

Table 5. List of Landsat 8 cloudless scenes used in participatory mapping activities.

Available Cloudless Landsat 8 Scenes		
Path	Row	Scene Date
167	53	12/10/13
167	54	12/01/13
168	53	12/10/13

Environmental Variables

I chose environmental variables based on the most important ecological and

anthropogenic characteristics that might determine the distribution of rubber vine across the

study area. I acquired this knowledge of hydrologic and biophysical features and human-induced

disturbance drivers from a number of sources, including local pastoral knowledge, background

literature reviews and field observations. I derived a single vegetation index, Normalized

Difference Vegetation Index (NDVI; Tucker 1979) from the National Aeronautics and Space

Administration (NASA) Moderate Resolution Imaging Spectroradiometer (MODIS) satellite. I

acquired NDVI from the Land Processes Distributed Active Archive Center[5], with all pre-

processing steps, including re-projection, mosaicking and sub-setting conducted with the MODIS

Reprojection Tool[6]. I included August and November NDVI from 2012, to capture the two main

rainy seasons of the Afar region- *kerma*, which peaks in August, and *detrob*, which peaks in

November. These periods should highlight the green-up in the acacia trees, which rubber vine

often infests. Although the vine can bloom all year with sufficient moisture and grow on its own

in a shrub form, it tends to thrive in semi-shaded riparian areas, growing into the canopy of trees.

Although the spectral signature captured by NDVI may include *P. juliflora* in addition to acacia

species, rubber vine has been observed growing in concert with *P. juliflora* (Luizza, personal

observation), and therefore was deemed to pose limited issues for vegetation spectral signature

confusion.

I also included the following topographic variables: elevation, slope and compound

topographic index (CTI), all of which we obtained from the digital elevation model (DEM)

acquired from the Shuttle Radar Topography Mission[7]. The DEM product had a spatial

resolution of 90m. We derived slope and CTI from the DEM and resampled them in ArcGIS

v10.0 (ESRI 2011) to 250m spatial resolution using the nearest neighborhood algorithm to match

the resolution of the MODIS-derived NDVI predictors. Compound topographic index is a

calculation that uses slope and flow accumulation to identify drainage depressions and provides a

---

4   https://lpdaav.usgs.gov/data_access.
6   Https://lpdaac.usgs.gov/tools/modis_reprojection_tool.
7   http://srtm.usgs.gov/.

representation of soil wetness across a given landscape (Evans et al. 2014). I considered the following anthropogenic variables which may provide pathways of rubber vine introduction, thus acting as a proxy for propagule pressure and disturbance (Jarnevich et al. 2014): distance to roads, derived from a current roads geospatial layer for the Afar region, and distance to water, derived from a current rivers and streams geospatial layer for Afar. I acquired both layers from the Afar Pastoral Agriculture and Rural Development Bureau. My research team member Tewodros Wakie cross-referenced these data for accuracy with additional geospatial datasets and sources. This included overlaying the roads layer on the ESRI world 2D base map in ArcGIS 10.0, and cross-referencing the rivers and streams layers with an independent rivers and streams layer created with the ArcHydro 2.0 tool set within ArcGIS 10.0. Both visual validation procedures produced strong agreement between the different data sources. Additionally, I created a distance to settlements layer using 23 GPS locations of towns and villages we collected within the study area. I created distance layers for all three using the Euclidean distance calculation in ArcGIS 10.0 with a spatial resolution of 250m. This calculation measures the straight line distance of the centroid of each cell in a given raster to the centroid of a given source cell (Hirzel & Arlettaz 2003), which in the case of our study included all three of our anthropogenic variables.

I examined all pairwise combinations of predictors using a correlation matrix generated by SAHM's *CovariateCorrelationAndSelection* module (see Appendix 6 for full matrix). To identify and avoid using redundant variables, I removed one of any pair with a Spearman, Pearson or Kendal correlation of $|r| > 0.70$, following the recommendation of Dormann et al. (2013). For this study August and November NDVI were the only highly correlated variables.

73

August is part of the longer, primary rainy season *kerma*, and was therefore deemed to be a more robust predictor for the model, resulting in the removal of November NDVI from use in the final model runs.

Rubber Vine Modeling

I conducted all pre-processing and modeling procedures within SAHM, which is freely available and designed to expedite habitat suitability modeling procedures in addition to documenting a detailed workflow history of the different input data, pre- and post- processing steps and modeling options used (Morisette et al. 2013). Within SAHM we used the Maxent statistical software package version 3.3.3k to train the model (Phillips et al. 2004). This modeling approach is a general-purpose machine learning method that models species distributions from presence-only species occurrence records and has high accuracy in predicting plant distributions (Evangelista et al. 2009; Stohlgren et al. 2010; Elith et al. 2011), in addition to working well with small sample sizes (Pearson et al. 2007; Wisz 2008). 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 that is known and avoids all that is unknown (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 presence points) and provides a calculation of the percent contribution of the different environmental variables used in the model.

I used a jackknife validation approach to test overall model fitness due to the limited number of rubber vine occurrence points. Pearson et al. (2007) provide strong support for

Maxent's ability to produce robust model results with small species occurrence datasets (as small as 5). With such limited datasets, models are greatly influenced by exactly which observations are included. Using their novel jackknife, or "leave one out" procedure, we generated multiple models, equaling the total number of occurrence points to test overall model fitness. Each occurrence was removed from the data set and the model was built on the remaining points. I built 18 separate models for our study by setting the Maxent parameter 'Replicated run type' to 'cross-validation' and the parameter 'Replicates' to 18. The predictive performance was then assessed based on each model's ability to predict the single occurrence point excluded from the training data set. A final model trained with all 18 occurrence points was run after determining model fitness through the jack knife approach, and produced a continuous probability raster of predicted suitable rubber vine habitat across the Afar region.

Independent Modeling Validation and Novel Environment Identification

Independent validation data to evaluate the final model came from participatory mapping with the same focus group participants. Three villages noted rubber vine locations on the satellite image for the Amibara district. From this, I collected 52 rubber vine occurrence points. This set was later reduced to 50 validation points within SAHM's *FieldDataAggregateAndWeight* module. I digitized rubber vine occurrences from the participatory mapping activities by uploading the pan-sharpened and mosaicked Landsat 8 image into ArcGIS 10.0. I created point shapefiles for each of the three villages, based on a visual assessment of the acetate paper overlay on the satellite image. I created geo-referenced coordinates with the 'calculate geometry' function in ArcGIS 10.0 and combined these distinct sets of points to create a comprehensive participatory rubber vine validation data set. I projected all geospatial analyses in WGS 1984 UTM Zone 37 N, and ran all participatory mapping test data through SAHM's *ApplyModel*

75

module to validate the final rubber vine habitat suitability model. Additionally, I switched model occurrence datasets to explore the utility of training and testing the model with more stratified participatory field sampling data compared to the more clustered participatory mapping occurrence points. Model results were assessed based on the AUC. The area under the receiver-operating characteristic curve is a threshold-independent metric, with values ranging from 0 to 1 that measures the ability of a model to discriminate a true occurrence point from an absence or background point. An AUC value of less than 0.5 shows that model predictions were worse than random, a value of 0.5 no better than random, and a value of 1.0 indicating perfect discrimination (Peterson et al. 2011; Khanum et al. 2013).

One of the outputs of the Maxent model is a Multivariate Environmental Similarity Surface (MESS) map, which provides a measurement of the congruence of any given point to a set of reference points, with respect to the set of predictor variables used (Elith et al. 2011). This surface provides a visualization of where model predictions are extrapolating beyond the environmental conditions used to train the model (specifically for each point, the extent to which the most dissimilar variable is outside the training range), and thus denotes locations where model predictions are less certain due to novel conditions. In line with existing research on the utility of "iterative sampling design" (Stohlgren & Schnase 2006; Crall et al. 2013), where models based on field observations are used to guide additional field data collection and improvement of the overall model, I overlaid results from this study on the MESS map to provide additional model assessment and prioritize areas for future targeted surveying and monitoring efforts with pastoral communities.

RESULTS:

Impacts of Rubber Vine on Pastoral Livelihoods

High levels of agreement were found between men and women relating to knowledge and perceptions of rubber vine impacts and changes occurring across the landscape. In many instances, observations shared by one gender were corroborated and expanded upon by the other. Across all seven villages, focus group participants described combined pressures of extensive drought, reduced water flow from the Awash River due to large-scale government farms, and the influx of invasive species (Table 6). They clearly noted the connections between all three issues, with drought facilitating the establishment of invasive plants, and large-scale agriculture development disturbing the land and providing novel habitat for these invaders through extensive irrigation ditches. "The pastoralist way of life is changing", one respondent declared. "When native species were plentiful", the respondent added, "We used to have cold air and plenty of water. Now it is reversed; invasive plants, hot air and little water."

Table 6. Frequency table of pastoralist observations across the 7 village focus groups with illustrative quotes.

Observation	Illustrative quote(s)	Frequency (max n=7)
Decrease in rain and shift in timing of rainy seasons	"It is not as before. We are currently in *Segum* [one of the two primary rainy seasons] and there is no rain. The weather is always hot now." "There is less rain generally in recent years. The two main rainy seasons *kerma* and *segum* are all that is left…we believe this is connected to the loss of trees."	7
Increase in invasive plants linked with range degradation	"The rangeland is not the same as before. Exotic species are coming in and taking over. The grass and range is degraded…there is no grazing land by the village. Our life is like this now." "Native plant species have disappeared and now we have *weyane*, *halemero*, and *wola howla*."	7
Increase in predators due to invasive plants	"It [*halemero*] has vines that can bind and trap our livestock and they are attacked by wild animals like hyena…Lion are also moving into the *weyane* and *halemero* forests…	5

	Leopards and python are moving in closer as well due to the dense cover provided by *halemero* and *weyane*."	
Rubber vine spreads by water (facilitated by government farms)	"*Halemero* is found near the Awash River on both sides. It spreads by water…the drainage [irrigation ditch] from sugar cane development consumes a lot of water and much flows through. Some species grow on this new special habitat, like *halemero*...everything is called 'development' but really it is destruction. We have not seen the fruits of 'development'."	5
Rubber vine poisonous to livestock	"The grasses suitable for livestock no longer grow due to invasive plants. *Halemero* is poisonous and if cattle accidentally eat the leaves, they die."	3
Rubber vine kills native vegetation	"It [*halemero*] also suppresses important trees like *keselto* (*acacia nilotica*) and is present along the Awash River…*halemero* is poisonous and can kill other plants."	4
Decrease in native vegetation and wildlife	"The land is the same, but the resources are different; the weather is different. In the past we had cold winds, but now they are only hot. There is a shortage of water and a shortage of forage for our livestock…there used to be a number of useful grass species, but now they are all gone. Most native plants are gone." "The useful wildlife which grazes alongside our livestock is declining in numbers. Zebra used to be here and are now entirely gone, as well as hartebeest; all gone."	7
Increased travel to find livestock grazing and water	"There are major changes occurring. It used to be a clear landscape where we could see for long distances; we could see to the mountains. It was all grass and we could get grass very close to the village. Now, even after traveling long distances we don't get grass. There was a natural water area that has all dried up. We have to travel far to get water for our livestock."	4
Increased livestock ailments/mortality from lack of rain, invasive plants, and exotic diseases	"Our livestock numbers are dropping. The taste of milk has changed also because native plants are gone and the animals eat many *weyane* pods and *kebraba* [native weed]…it has other bad effects on the cattle, including tremors and even paralysis. The exotic species that are arriving from the river [Awash] are causing much of these changes, in addition to a lack of rain. Lack of rain is the biggest cause."	6
Increased conflict (with other clans and wildlife)	"We travel long distances to get grass. This leads to conflict with Somali clans, resulting in cattle theft and killings. Grazing is the biggest reason for conflict." "Wild animals and livestock now congregate at the small remaining native patches of forest and this leads to conflict…even baboons, who never attacked livestock before when native fruits were plentiful, are now attacking goats and sheep."	4
Loss of mobility	"There is no useful contribution from the government except for some agricultural advice from the Ministry of Agriculture.	

	The negative impacts of the government are widespread, including forced removal of our villages into compounds and the industrial sugar cane production… Flooding used to be useful as people could move to the hills during flooding and come back after and graze cattle on the new grass. Now we are settling here permanently and it is causing problems."	3

Acute changes to all four major rainy seasons were additionally noted, with each experiencing noticeable reductions in the volume and predictability of rainfall. These factors are believed by many pastoralists to be helping spread invasive plants. *Kerma*, the primary rainy season historically spanning four months from June to September, is now limited to the month of August. *Detrob*, the secondary rainy season, which in the recent past spanned October and November, now only occurs over a maximum span of five days. *Dedaa*, which historically spanned January and February, and *segum*, which occurred in April, have disappeared entirely. One respondent emphatically relayed that *dedaa* and *detrob* had already passed this year with no rain. This observation was met with agreeing nods and grunts of other pastoralists, with the same person somberly adding, "What is left are only the names of the seasons".

Although pastoralists described two other invasive plants as problematic, including the regionally prolific *Prosopis juliflora* (locally called *weyane*) and the nationally invasive *Parthenium hysterophorus* (*wola howla*), all participants noted *Cryptostegia grandiflora* (rubber vine; locally called *halemero*) to be the newest invasive plant to the region and of great concern. A majority of the villages (6 of the 7) relayed that rubber vine has noticeably increased in cover and habitat expansion in recent years (Figure 12). Participants noted that rubber vine grows in close proximity to the Awash River on both sides and first appeared in Afar in the upper and

middle Awash River during the communist Derg Regime (approximately 25 years ago). All respondents agreed that the vine is seed-propagated primarily through water, although it can also disperse its seeds by wind. Major flood events including those in 1998 were noted to assist in the establishment of the vine, but the increased frequency

Figure 12. Mature rubber vine (*C. grandiflora*) plant growing in shrub form (foreground). Other vines growing in tree canopies in the background, with the Awash River behind the vehicle. Image courtesy of M. Luizza.

and magnitude of these events in recent years has further exacerbated the situation. Respondents relayed that when the Awash River would historically flood, native grasses would sprout. In recent years when flooding occurs, grass does not grow, only rubber vine and *P. hysterophorus*. A number of respondents argued that this recent phenomenon is due in part to the massive influx of large-scale government owned sugar cane farms in the river valley. These huge monoculture industrial agriculture operations are water-intensive, requiring extensive irrigation ditch systems that follow the adjacent dirt roads. Many pastoralists believe these ditches are creating new habitat and seed dispersal systems for rubber vine, which is increasingly present in these recently disturbed areas (Luizza and Wakie field observations).

Respondents quickly expressed that rubber vine has a number of negative impacts. If livestock (especially cattle) unintentionally eat the leaves while browsing other species with which it is intermixed, they become sick and can die suddenly. Existing research on rubber vine confirms the vine to be poisonous, containing glycosides that have toxic effects on the cardiac

system if ingested (Cook et al. 1990; Mekonnen 1994). Although some people use the plant's milky latex sap as a livestock insecticide, applying it to bugs that are attached to cattle, it is not widely used, as a number of participants explained that it is also a skin irritant and will burn a person if any sap touches exposed skin. No other beneficial uses of rubber vine were noted, although Afar and Oromo people in and around Awash National Park (located in the upper Awash River basin to the south of our study region), have confirmed using rubber vine bark, branches and stems for house construction and tying material (Bahru et al. 2012). Additionally, like *P. juliflora*, rubber vine produces dense vegetation cover that poses a dual threat of restricting the mobility of livestock and providing cover for predators. Respondents noted that the vine can quickly bind and trap livestock, making them easy targets for hyena predation. The frequency of such attacks were noted to be on the rise, as the dense cover created by rubber vine and *P. juliflora* together has created shelter for a number of problematic wild animals such as lions, hyenas, leopards and snakes. A few pastoralists went on to state that snakes and leopards particularly take advantage of rubber vine habitat corridors.

Rubber vine kills native trees by growing up into their canopy, blocking their access to the sun and "choking them", in addition to inhibiting the establishment of grasses when growing in shrub-form. As one respondent exclaimed, "Where *halemero* grows, nothing else will!" The vine was said to have acute negative impacts on a number of native trees around the Awash River that are important to pastoral livelihoods. I catalogued eight endemic tree species that pastoralists identified as being threatened by rubber vine (alone or in concert with *P. juliflora*) and act as critical sources of firewood and charcoal (see Appendix 7 for a full list of local trees and their uses). The three most important species, locally called *keselto* (*Acacia nilotica*), *adado* (*Acacia senegal*) and *kilaito* (*Combretum aculeatum*), collectively provide nine distinct

ecosystem services including charcoal, construction, cosmetic, firewood, food, livestock fodder

and forage, wildlife forage, medicinal, and shade services. Respondents emphasized that the

most detrimental rubber vine impacts are seen with their most important firewood source *A.*

nilotica, which is present along the Awash River. One respondent noted that no *A. nilotica*

regeneration is occurring. "All we see are the remaining mature native trees; no new seedlings."

Moreover, other respondents stated that combined impacts of rubber vine and *P. juliflora* have

reduced important supplemental food sources. Pastoralists relayed that in the past there were an

array of wild edible fruits that have recently disappeared from the landscape and been replaced

with rubber vine and *P. juliflora*. One respondent added, "It even used to smell better with all the

different flowering, fruit-bearing plants. It is different now. Most of these edible fruits have

disappeared." The fruit-bearing *Cordia* spp. (locally called *mederto*) was stated to have been

most noticeably affected, with a drastic decline in cover and extent.

Rubber Vine Modeling

Local pastoral knowledge greatly facilitated modeling the suitable habitat of rubber vine

across the Afar region. The preliminary jackknife validation approach revealed overall good

model fit, with the average AUC value across the cross-validation subsets at 0.80 (Table 7).

Across all 18 cross-validation subsets, distance to water, August NDVI and distance to roads

were consistently in the top three predictors (see Appendix 8 for a full list of jackknife model

performance and variable contribution). The final training model, run with all 18 rubber vine

occurrence points, produced a training AUC value of 0.91 and high classification accuracy

(82%). The final model had strong discrimination with a test AUC of 0.96 and high classification

accuracy (93%). For both the train and test models, anthropogenic variables including distance to

water and distance to roads, in addition to August NDVI were the most influential model

predictors, explaining nearly 100% of the model predictions between the three variables (Figure

13). Upon switching the model occurrence datasets, model AUC values and correct classification

percentages remained high, but model predictions were restricted to areas with existing rubber

vine occurrence points, model predictor importance shifted to topographic and different

anthropogenic variables, and sensitivity (i.e. true positive rate) drastically decreased for the

validation model.

Table 7. Maxent statistical accuracy measurements with models produced using field collected training data and participatory mapping test data, and switched, using participatory mapping training data and field collected test data.

Rubber Vine Suitability (Field Collected Training Data)			
AUC	% Correctly Classified	Sensitivity	Specificity
0.909	81.9	0.823	0.819
Rubber Vine Suitability (PGIS Test Data)			
AUC	% Correctly Classified	Sensitivity	Specificity
0.959	92.90	0.918	0.929
Rubber Vine Suitability (PGIS Training Data)			
AUC	% Correctly Classified	Sensitivity	Specificity
0.986	93.85	0.939	0.938
Rubber Vine Suitability (Field Collected Test Data)			
AUC	% Correctly Classified	Sensitivity	Specificity
0.993	99.42	0.353	0.995
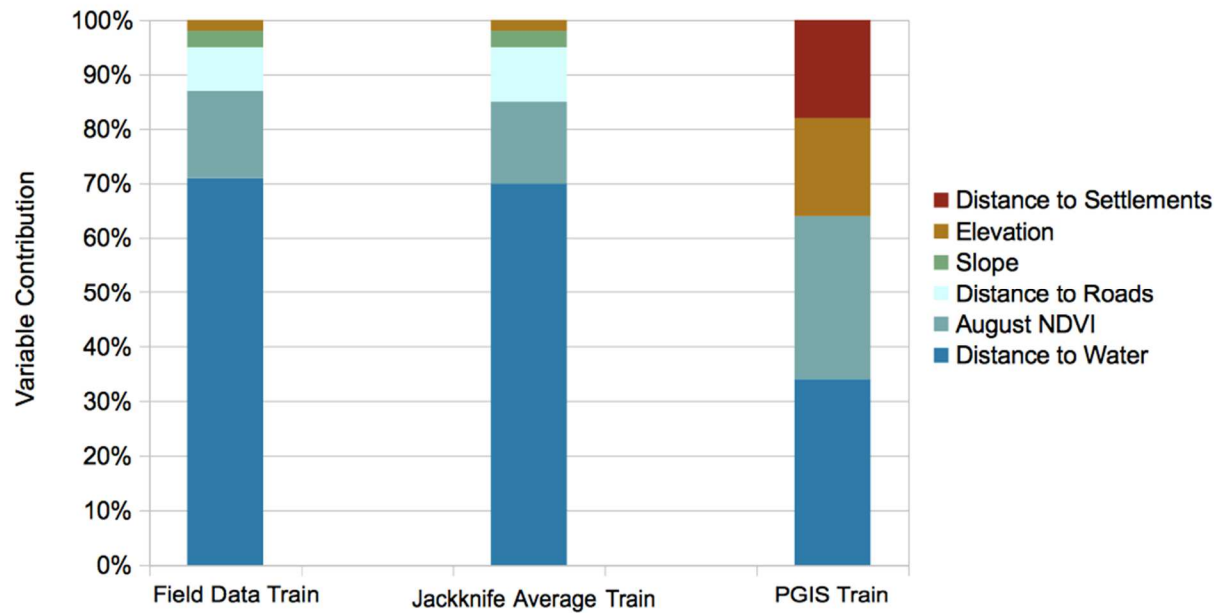
Figure 13. Relative contribution of each environmental predictor variable for the different training data. Higher percentage values indicate stronger influence on model response.
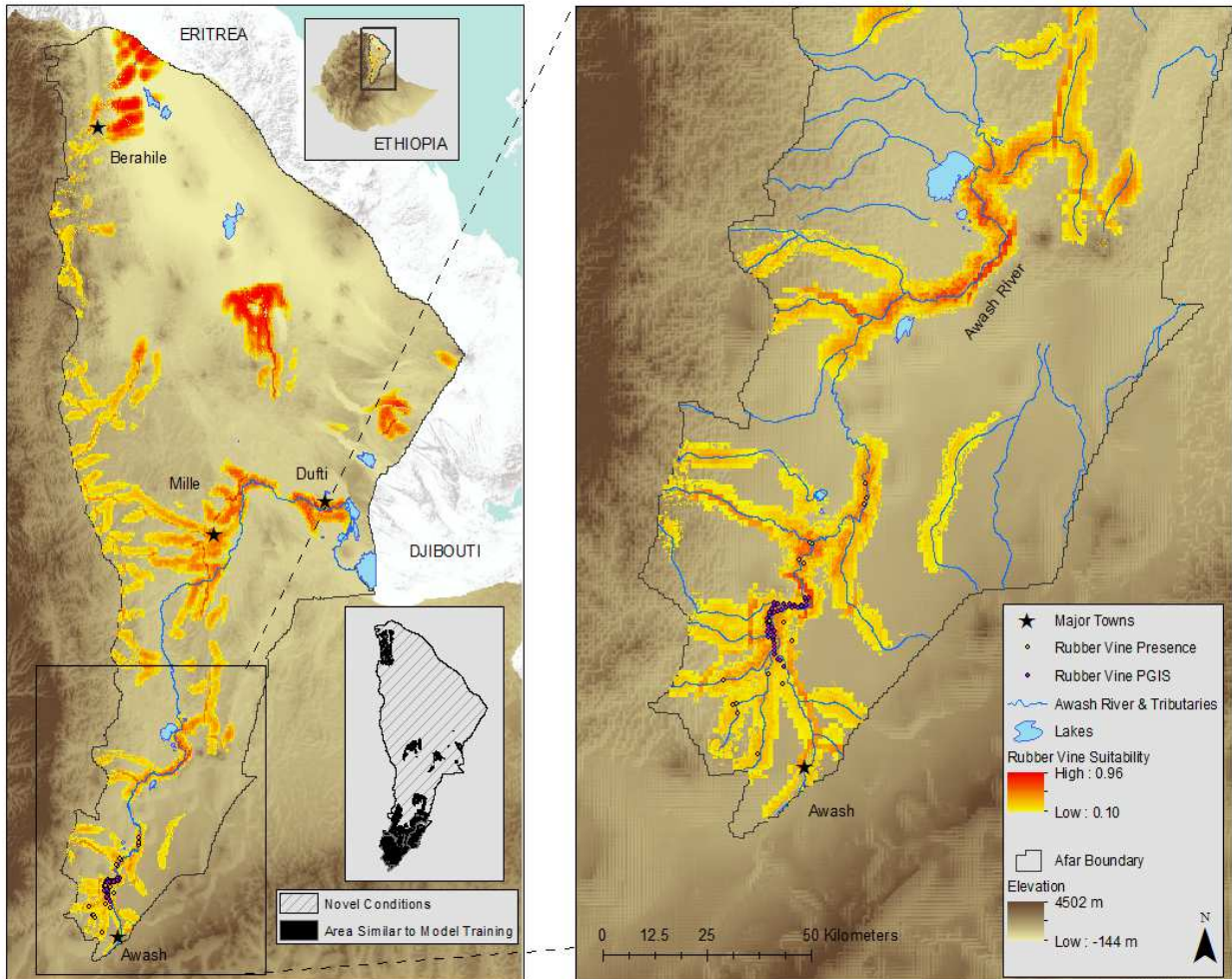
Figure 14. Rubber vine (*C. grandiflora*) habitat suitability across the Afar region of Ethiopia. Areas in red denote predictions of high habitat suitability. Hash marks signify locations with novel environmental characteristics.

The final distribution map shows the growing threat rubber vine poses for the Afar region (Figure 14). Overlaying the MESS map revealed 88 percent of the landscape to contain novel environmental characteristics outside of the range covered by the presence and background locations used to train the model (Figure 14; Elith et al. 2010). Hash marks signify locations with novel environmental characteristics in need of future targeted surveying.

DISCUSSION:

This research reveals the significant benefits gained by integrating local ecological knowledge with species distribution modeling for risk assessment studies. Model outputs were consistent with ecological knowledge of the species gained from pastoral communities, field observations and existing rubber vine studies, revealing high habitat suitability across much of the interconnected riparian areas of the Awash River basin. Rubber vine often favors riparian areas, climbing trees along river banks with consistent canopy openings (Kriticos et al. 2003; Yohannes et al. 2011), but the species can also be found as a sprawling shrub along gullies, creeks and disturbed areas like roadside ditches and waterholes where run-off water accumulates. Participatory data collection and mapping with pastoralists revealed the detailed and highly accurate knowledge of local community members in regards to rubber vine. Model training and test data sets were independent, but collected from the same pastoralists. All 24 locations noted to have rubber vine by pastoralists across the seven village study sites were verified as having rubber vine presence by our research team. Additionally, much agreement existed between the three villages that identified rubber vine occurrences during the participatory mapping activities, although none of the villages viewed the maps created at the other sites. This provides another level of evidence of the utility of local ecological knowledge.

Switching the model occurrence datasets resulted in additional high AUC values and correct classification percentages, but model predictions were noticeably restricted to areas with existing rubber vine occurrence points. Furthermore, model predictor importance shifted to topographic variables and different anthropogenic variables (i.e. elevation and distance to settlements), both of which had little to no influence in the other model runs. This is likely due to the close proximity of rubber vine occurrence points identified in the participatory mapping

activities to the respective villages of participating pastoralists. This spatial autocorrelation may account for the noticeable drop in the sensitivity value when applying the model trained on these data to the field collected occurrence points. Additionally, this may explain why elevation is a dominant driver for the model, based on the villages and participatory mapping points existing at much lower elevations compared to the field collected data which were much further out from the settlements. This process revealed the participatory mapping dataset to have noticeable sampling bias. The occurrence points were too spatially autocorrelated to train a model with, but provided a useful preliminary validation dataset and further highlights the importance of stratifying occurrence point sampling as much as possible, even within a participatory convenience sampling framework.

I overlaid the rubber vine habitat suitability map with the MESS map produced by Maxent to further assess relative confidence in the model output and determine locations for future targeted surveying attempts. The MESS output revealed locations with novel environmental conditions, e.g. conditions that rest outside the range covered by the presence and background locations used to develop the model (Figure 14; Elith et al. 2010). Crall et al. (2013) provide strong support for the use of an iterative sampling design facilitated by MESS map assessment, finding models trained on targeted sampling data to perform better than those generated from non-targeted sampling data. This study used such an approach, with the novel application of local pastoral knowledge as the targeted sampling training and test data sets. This added visual assessment is illustrative, as the southern Gabi zone where our field data were collected, has the highest average annual rainfall for the Afar region at approximately 510-1032mm (Sonneveld et al. 2010). Distinct environmental characteristics linked with average annual precipitation and elevation exist across the Afar region as one moves south to north, with

the landscape becoming increasingly arid, with greatly reduced rainfall and dramatically higher elevations. Our model effectively relayed rubber vine habitat suitability in relation to consistent environmental conditions linked with rivers and stream systems across the study area, with the addition of the MESS output highlighting where topographic, environmental, and anthropogenic characteristics are novel compared to the sampled region. These distinct environmental changes may act as a major limiting factor to rubber vine spread northward, but the species is noted to handle a diverse range of environmental conditions (McFadyen & Harvey 1990; Kriticos et al. 2003). I cannot say definitively that the predictions beyond the initial spatial extent north of the model occurrence points are robust, but these results show with great certainty the high suitability of rubber vine habitat immediately down-river of the collected occurrence points and the great potential for further expansion along the Awash River and its tributaries, thus providing an important early warning and monitoring tool for this recently established species and highlighting areas in need of additional field assessment.

Going into the focus group interviews our research team was well aware of the vulnerability of pastoral communities and the Afar landscape to *P. juliflora* and *P. hysterophorous*. These semi-structured interviews revealed the new and growing threat of rubber vine, which is currently not listed as an alien invasive species in Ethiopia, and receiving limited attention by local and regional government agencies and non-profit organizations working in the area. Early detection of invasive plants is critical, and often the best response time is during the early stages of establishment when the least is known about the species-environment interactions and overall invasion potential (Kriticos et al. 2003). Local knowledge can act as an important early warning system to understand a given species' current distribution, biology and impacts, and potentially provide a needed edge to more effectively mitigate and manage invasive species.

Early detection and understanding of invasive species' impacts is of the utmost importance and made especially clear when viewing well-established invasive plants in the region such as *P. juliflora*, which will likely never be fully eradicated. Similar to the current view of many in Ethiopia in regards to rubber vine, *P. juliflora* was treated with much ambivalence during its early stages of establishment, even upon showing invasive characteristics. *Prosopis juliflora* is now considered the worst invasive species in Afar and one of the most harmful invasive plants in Ethiopia, having numerous direct and indirect economic, ecological, and local livelihood impacts. Viewing the effects of rubber vine in Australia, where it has long been established relays the dire nature of addressing this problematic species. Rubber vine has been described as the single biggest threat to natural ecosystems in tropical Australia (McFadyen & Harvey 1990). Although the vine is not a weed of agricultural crops, it smothers and out-competes both wild and pasture grasses in Australia, in addition to invading and disrupting forest systems (Tomley 1995). The major economic impact from rubber vine invasion includes direct loss of pasture, with some infestations reducing the carrying capacity of livestock by up to 100%, coupled with riparian area invasions limiting livestock access to water. This has resulted in increased management costs estimated at USD $15 million per year to the northern Queensland beef industry alone (Anon 2001). This could prove disastrous for local Afar pastoralists who are heavily reliant on livestock. Pastoral livelihoods of the Afar have adapted to cope with uncertainty and the vulnerabilities associated with a harsh rangeland environment, but drought, collapse of livestock markets and disease are preeminent shocks to which they are especially at risk (Davies & Bennett 2007). Moreover, impacts could easily move beyond the local level, as seen with *P. juliflora* in Ethiopia and rubber vine in Australia, potentially reaching the regional and national level, as livestock are a major export commodity for Ethiopia (Catley et al. 2013).

Furthermore, political and cultural conflicts stemming from poorly designed development strategies beginning in the 1950s and the remnants of the Eritrean-Ethiopian War (1998-2000) have resulted in ongoing instability in the region. Afar pastoralists have already noted a lack of forage and fodder for their livestock and now need to travel further, resulting in increased conflicts with predators and Somali clans. Expansion of rubber vine could further exacerbate this already unstable situation. Pastoralists here depend on key riparian zones that provide important dry season and drought resources for herds, yet major drivers transforming riverine ecosystems threaten these assets, including dam construction, invasive species and irrigated plantation farming (Behnke & Kerven 2013; Oba 2013). Such disturbances to the Awash River are especially prevalent and long-standing, as the basin, which has merely five percent of Ethiopia's land area suitable for irrigation, has over one-third of its suitable land already irrigated, amounting to fifty percent of all land under irrigation in the entire country (Awulachew et al. 2007).

Furthermore, even when geospatial applications are inclusive they can foster social exclusion or have unintended consequences when not addressing things like accountability, empowerment, control, and use of knowledge (Pfeffer et al. 2013), as "stakeholder participation does not take place in a power vacuum: the empowerment of previously marginalized groups may have unexpected and potentially negative interactions with existing power structures" (Reed 2008: 2420). In this case of integrating pastoral knowledge to assess the risks posed by invasive rubber vine, local knowledge revealed certain patterns related to environmental and anthropogenic drivers, including large scale government farming potentially facilitating and rapidly increasing the rate of the plant's spread. Despite this, spatially relaying the heightened risk for rubber vine invasion in the Awash River basin could be used against pastoral

communities by existing power structures to further limit their access to this critical landscape. This unintended consequence is not unrealistic in light of recent land-grabs by the national government last year in the southern Oromo region (while we were conducting this study in Afar), resulting in the death of multiple student protesters at the hands of police[8], or, the long-standing history of a number of East African governments and western scientists pointing the finger of blame for rangeland degradation at pastoralists (Reid 2012), which has provided ill-informed justification for further disenfranchisement of these groups. Moreover, Ethiopia, under the communist Derg regime, had a common practice of forcibly relocating people that could pose civil opposition lasting into the early 1990s (Bussmann et al. 2011). This practice continues today under a democratically elected government, but described as "voluntary" relocation when resources are depleted in given area. However, a number of pastoralists in Afar noted forced relocation still occurs and our field team viewed a number of village sites that were noted to be forced sedentization settlements (Luizza, personal correspondence and field observations).

Challenges still exist for assessing and addressing rubber vine in the Afar region. Understanding the species' true ecological niche is difficult and the inclusion of additional environmental variables may be warranted in future modeling attempts. Rubber vine's native range is Madagascar, and this landscape poses certain challenges for fully understanding the vine's true habitat niche. For instance, the simple fact that Madagascar is an island quickly limits the species' dispersal capabilities. A few studies have explored rubber vine in its native range, finding its habitat to be characterized as dry tropical with highly pronounced summer rainfall (McFadyen & Harvey 1990), but Madagascar's small landmass and limited climatic variation, in addition to competition between it and its genetically similar sub-species *C. madagascariensis*

---

[8] Al Jazeera News (2014). Retrieved from: http://stream.aljazeera.com/story/201405021338-0023696.

may belie the true suitable climatic gradient that rubber vine can actually inhabit (Kriticos et al. 2003). This point is corroborated with observational evidence in the Afar region where rubber vine is found growing in very different habitat conditions, including as a singular shrub-like form in dry, sun-exposed dirt piles near recently disturbed agriculture fields, but also growing as extensive networks of vines, climbing up acacia trees in semi-shaded, cooler, wet, riparian areas. Therefore, model results should be interpreted with some caution, as Pearson and colleagues (2007) aptly stress that such assessments with limited occurrence data sets should be viewed as identifying regions with similar environmental conditions to where the species in question is known to occur, and not as predicting actual limits to the range of that species.

Necessary next steps include validation of the model outputs with pastoralists and conducting additional participatory, targeted surveying. Furthermore, having a female translator that speaks Afar and Amharic would likely better facilitate the recruitment of women for these future activities. Moreover, beginning a dialogue with local and regional government land managers and international aid organizations working in Afar around these study results will be an important step towards addressing rubber vine. This work further supports the idea that invasive species habitat suitability modeling should be an iterative process (Stohlgren & Schnase 2006; Crall et al. 2013), one that I argue should engage in collaboration and knowledge integration at all steps, beyond researchers and land managers, which is the current trend in species distribution modeling literature. Moreover, this work reveals the importance of working closely with and empowering local communities that have detailed knowledge of the landscapes they inhabit and newly established non-native species, to enhance and facilitate more effective and holistic risk assessment approaches including early detection and targeted surveying and monitoring efforts.

CONCLUSION:

Invasive plants have an array of detrimental impacts on ecosystems and rural livelihoods in arid and semi-arid regions around the world. Successful control of invasive species depends on early detection and rapid response, which I argue is best achieved through meaningful collaboration with local communities that live on the affected landscapes. This chapter demonstrated the utility of integrating local pastoral knowledge with species distribution modeling for invasion risk assessment studies, highlighting the growing threats posed by invasive rubber vine to the Afar region. The model was highly accurate, as evidenced by the assessment metrics, and highlights the growing risk rubber vine poses to the Afar region, with suitable habitat extending downstream of its current distribution in the middle Awash River basin. Local pastoral knowledge provided important context for its rapid expansion due to acute changes in seasonality and extensive habitat alteration, and described immediate threats posed to a number of native tree species that provide critical ecosystem services to local communities. To date, little attention has been paid to rubber vine in Ethiopia by government agencies, academic research institutions and non-profit organizations alike. Local pastoral knowledge thus acts as a critical early warning system that can enhance existing risk assessment approaches including early detection and targeted surveying of recently established invasive species.

The importance of knowledge integration and co-production mechanisms for adaptive governance: Reflections on integrative geospatial modeling as a tool for adaptive and collaborative management[9]

Adaptive governance has emerged as a flexible, multi-dimensional framework that addresses the management of social-ecological systems through multiple domains (i.e. ecological, social, political and economic). A number of social mechanisms have been identified as enhancing adaptive governance processes, including knowledge integration and knowledge co-production. Despite a growing number of studies that explore their application in local conservation and management efforts, synthesis of their major findings is limited, and no studies could be found that apply the same approach across distinct cases at different spatial and governance scales. In this chapter, I explore how my integrative geospatial modeling research, which incorporates knowledge integration and co-production with advanced geospatial applications at the landscape scale in Alaska and the local scale in Ethiopia, compares with the broader literature. I synthesize how research over the past twelve years has engaged each mechanism and reflect on my transdisciplinary research process while providing future research and management recommendations. Current scholarship reveals variability in how knowledge integration and knowledge co-production are engaged (i.e. as distinct concepts or interacting features), as well as limited incorporation with advanced geospatial applications. This growing body of work reveals important conditions for knowledge integration and co-production, including genuine power sharing, mutual respect for different knowledge forms, understanding power inequities and historical conflict, and co-definition of goals, in addition to potential outcomes such as trust building, community empowerment, expansion of scientific knowledge

---

[9] Research from this chapter is part of the following manuscript: Luizza, M.W., X, and A. Lovell (In Preparation). Seeking adaptive governance through knowledge integration and co-production: A review of trends and approaches. *Ecosphere*.

and enhancement of adaptive strategies. My integrative geospatial modeling work corroborates a number of these findings, including the potential enhancement of collaboration and adaptive strategies through goal and conservation target co-definition, the critical nature of trust building and providing a setting of mutual respect for different knowledge sources, and the ability of local and indigenous knowledge to expand the realm of conventional science. This work also raises additional questions regarding issues of scale, institutional connectivity, and the potential benefit of bridging and boundary-spanning organizations and individuals for facilitating more rapid knowledge integration and co-production processes. These findings imply that trandisciplinary approaches like integrative geospatial modeling can provide a useful and novel tool for understanding the complex and connected issues of local and landscape scale disturbance drivers, provisioning ecosystem services and subsistence livelihoods in regions with mounting anthropogenic pressures.

INTRODUCTION:

The inherent complexity of ecosystems necessitates holistic approaches to management and stewardship that go beyond compartmentalized disciplinary approaches (Savory 1988; Ostrom et al. 2007; Chapin III et al. 2009). Advancements across numerous disciplines, spanning the natural and social sciences continue to reveal that physical, ecological, and social processes cannot be viewed in isolation of one another, as they are highly inter-connected and constitute social-ecological systems (SESs). This requires a "humans-in-nature" outlook when addressing complex environmental issues across spatial and governance scales, as a range of biotic, abiotic, and institutional variables and processes are at play. Engaging a plurality of knowledge forms is increasingly argued to promote effective, collaborative, and adaptive governance outcomes. Yet,

traditionally marginalized groups including minorities, indigenous peoples and women tend to be at an added disadvantage in many "collaborative conservation" settings where cultural, institutional, and language barriers further confound a process already challenged by underlying and historically entrenched power disparities. Addressing these issues is critical to effective governance as "complex social dynamics, such as trust building and power relations, have often been underestimated and the view of social relationships simplified...Consequently, many attempts for ecosystem stewardship have failed" (Folke et al. 2005: 462).

Agenda 21, the action program coming out of the 1992 United Nations Conference on Environment and Development in Rio de Janiero, Brazil, emphasized the importance of incorporating traditional and scientific knowledge for sustainable development (UNED Agenda 21, Chapter 35.5). At the United Nations Environment Programme 2012 Conference on Sustainable Development in Nairobi, Kenya, these positions were reinforced with an updated agenda stressing the need to strengthen research and education programs aimed at "achieving a better understanding of indigenous people's knowledge and management experience related to the environment, and applying this to contemporary development challenges", and the further "enhancement of capacity-building for indigenous communities, based on the adaptation and exchange of traditional experience, knowledge and resource-management practices, to ensure their sustainable development" (UNEP Agenda 21, Chapter 26.3). Scientific research efforts have answered this call, with growing literature on the importance of local and traditional knowledge for effective management and adaptive governance (Berkes 2009; Leys & Vanclay 2011), and specifically how this knowledge can be used in concert with conventional science (Gratani et al. 2011; Bremer & Glavovic 2013).

Research Questions and Goals

This research is driven by the following question: Under what conditions do the social mechanisms of knowledge integration and co-production processes enhance adaptive governance? In this chapter, I first situate the discussion of knowledge integration and knowledge co-production within the broader literatures on SESs, adaptive governance, and local and traditional ecological knowledge studies; highlighting both processes as important social mechanisms of adaptive governance. I then relay how each are explored in existing case studies through a meta-synthesis spanning the last twelve years. I then reflect on the process of coupling knowledge integration and co-production with species distribution modeling (what I call integrative geospatial modeling) in Alaska and northeastern Ethiopia, relaying the opportunities and challenges faced with this transdisciplinary research in different contexts and providing recommendations for future work.

The Importance of Adaptive Governance for Social-Ecological Systems

Adaptive governance 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). This framework engages a wide array of cross-scale social and ecological interactions, to provide a vision for socially and ecologically desirable outcomes. Although sharing many features with other forms of environmental governance, what makes adaptive governance novel is a central focus on adaptation and learning. This is achieved through integrated vertical and horizontal processes (environmental and social), across nested formal and informal institutions and ecological boundaries. Such a unique

97

governance approach necessitates a deep understanding of a system's biotic, abiotic, and social processes. Additionally it requires integration of local and traditional management arrangements with more formalized practices of state regional and international institutions and markets. The idea of adaptive governance developed in concert with the concepts of SESs and resilience, resulting in the creation of a novel governance framework, argued to enhance the ecological integrity of coupled human and natural systems. Social-ecological systems are complex, adaptive systems (Berkes et al. 2003) comprised of dynamic and interacting processes. They are affected by an array of environmental and anthropogenic drivers of change, occurring across spatial, temporal, and institutional scales. Intimately linked with the concept of SES is resilience and ecological integrity, defined as 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 (Carpenter & Gunderson 2001; Folke et al. 2004). The ability to adapt to and shape change is central for ensuring the ecological integrity of SESs and thus addressing the drivers of change in a given system are of the utmost importance.

Although adaptive governance is inherently desirable, key limitations are present with the framework. The application and outcomes are often context-specific and its trans-disciplinary and integrative nature can make for a seemingly nebulous approach (Brunner et al. 2005). With such a wide array of ecological and social factors and processes and actors considered, isolating the most important mechanisms and generalizing broad research trends can become extremely difficult. Despite these limitations, this framework arguably provides benefits "...for determining better 'fit' between biophysical processes and the prevailing management approaches (Clark & Semmahasak 2013: 883), addressing the management of SESs through multiple domains, and providing the ability to better adapt to and prepare for current and future crises (Gunderson &

98

Light 2006). Adaptive governance includes pertinent, flexible mechanisms for understanding the innate uncertainty and stochasticity of SESs, and addressing the context-specific nature of many environmental issues. These mechanisms, engaged through applied management concepts such as adaptive management, co-management, adaptive co-management, and adaptive collaborative management, include: knowledge integration, knowledge co-production, adaptive learning, deliberation, experimentation, monitoring, and evaluation[10]. These social mechanisms are noted to support flexibility within institutions to better adapt to and address uncertainty and surprises associated with exogenous shocks to a given system, and thus promote the ecological integrity of SESs (Folke et al. 2005). In this study, I focus on the social mechanisms of knowledge integration and knowledge co-production. For this research I define knowledge integration as a multiple evidence-based approach that deal with the synthesis and validation of different knowledge systems, where different knowledge forms are viewed as distinct, yet complimentary and provide new insights to a given environmental problem. I define knowledge co-production as the collaborative process of generating new knowledge that brings a plurality of knowledge sources and types together to address a defined environmental issue, and engaging in collaborative and participatory processes at all stages of knowledge generation and a reciprocal transfer of knowledge, skills, and capacity. Although a number of scholars deal with each as distinct concepts, I view both as complimentary mechanisms, each engaging a facet of knowledge documentation and providing diverse opportunities for collaborative and participatory learning.

The genesis of knowledge integration and co-production can arguably be traced to a long line of applied and theoretical work on knowledge and participation in the social sciences. Reed

---

[10] Folke et al. (2005) and Brunner et al. (2005) provide useful syntheses of a number of important adaptive governance mechanisms.

(2008) aptly relays the connections between the growing popularity of stakeholder participation in natural resource management and the applied and theoretical work of participatory action research (Chambers 1983) and communicative action theory (Habermass 1987). Diverse knowledge is deemed important, but how different knowledge holders are engaged through participation is critical. Participation ideally should be inclusive and fair, representing the broad spectrum of relevant stakeholders and leveling the playing field of power between participants.

Within this arises an important distinction regarding forms of participation for stakeholders, which holds implications for how different forms of knowledge are engaged. "Normative participation" is noted to focus on process and the idea that participation in environmental decision-making is a democratic right, whereas "pragmatic participation" views participation and knowledge as tools for producing good decisions (Reed 2008). This aligns with Johnson's (2001) continuum of power-sharing in participatory research, where "functional participation", much like pragmatic participation, improves research through added knowledge and engagement of stakeholders but offers little involvement in decision-making, and "empowering participation", much like normative participation, involves a process of long-term local capacity building with equal power-sharing.

These framings have been incorporated into a great deal of community-based natural resource management studies. Reed's (2008) literature review of stakeholder participation in environmental management and Hage et al.'s (2010) assessment of the Stakeholder Participant Guidance for the Netherlands Environmental Assessment Agency find stakeholder participation to hold great potential for enhancing the quality of environmental decisions through consideration of diverse information inputs. However, citing Johnson's (2001) continuum, Arnold and Fernandez-Gimenez (2007) argue that despite the growing adoption of such

community-based and participatory approaches, "…there is still a lack of power-sharing in the research process, and the majority of self-identified participatory research projects utilize only functional participation" (Arnold & Fernandez-Gimenez 2007: 483). Much of this scholarship has focused on the local or community scale when engaging in these processes. Scaling up these participatory approaches can become a daunting task. Adopting many of the features, goals, and processes coming from these earlier works in the social sciences, adaptive governance has sought to engage participatory knowledge generation, application, and transmission through the multi-scalar realm of SESs and resilience. Arguably, knowledge integration tends to engage more in pragmatic participation, through efforts focused on synthesizing and validating distinct knowledge sources for added insights and enhanced understanding of an issue, whereas knowledge co-production, through concerted collaborative and participatory processes of knowledge generation, in addition to a focus on reciprocal transfer of knowledge, skills, and capacity, engages more directly with normative participation.

Power in Knowing: Knowledge Integration and Co-production; an Outgrowth of Traditional and Local Ecological Knowledge Research

Explosive growth has occurred in the realm of traditional (i.e. indigenous) ecological knowledge and local ecological knowledge studies over the past two decades. An array of scholars argue the inherent value of this different way of knowing the landscape and the importance of cataloguing and incorporating this knowledge with conventional western science. Examples demonstrate how both forms of 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

101

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). Such experiential and applied

knowledge of the environment holds utility for contemporary science, stemming from local

resource users' physical connection to place, and constituting a rich, deeply rooted "practical

environmentalism" (Pickering-Sherman et al. 2010).

Adaptive governance views knowledge as a critical component of environmental

governance within complex SESs. This purview comes out of broader debates about the role of

science and knowledge in environmental politics[11]. It seeks to integrate conventional scientific

and other forms of knowledge into applicable policies through open decision-making processes,

with the ultimate goal of promoting common environmental interests that benefit society and the

environment. Additionally, knowledge integration approaches have been proposed as useful

ways to leverage diverse forms of knowledge across scales and holding great potential for

incorporation with geospatial tools like remote sensing (Reed et al. 2011).

METHODS

For this chapter, I catalogued peer-reviewed scientific studies over the last twelve years,

which engage the adaptive governance mechanisms of knowledge integration and knowledge co-

production. I used a qualitative meta-synthesis analysis approach, which is defined as a "rigorous

study examining and interpreting the findings (as opposed to the raw data) of a number of

---

[11] Lövbrand (2013) offers an insightful overview of how the connections between science, politics, knowledge and power are conceptualized in global environmental politics literature. Two approaches to addressing science and knowledge are presented; a rationalist approach, where knowledge is engaged in a hierarchical and bureaucratic manner and a constructivist position, which explores the linkages of knowledge and power, and how that in turn informs environmental decision-making.

qualitative research studies, using qualitative methods" (Finfgeld 2003). This methodology has proven useful as an interpretive approach for synthesizing and producing new, integrated findings more substantive than those of the individual studies assessed (Thorne et al. 2004; Suich et al. 2010). However, this approach is limited by the quality of data and analysis in the studies included, and is further limited to studies that have already been conducted (Finfgeld 2003).

I accessed studies by searching key words "knowledge integration" and "knowledge co-production", in addition to related terms including "knowledge management", "knowledge exchange", and "knowledge transfer" within the Web of Science database. These searches were limited to academic journals filtered by the following topics: social sciences interdisciplinary, plant sciences, anthropology, remote sensing, water resources, environmental sciences, environmental studies, geology, ecology, forestry, sociology, political science, multidisciplinary sciences, and biodiversity conservation. This resulted in 2,611 articles. Additional snowball sampling of key articles discovered within this search followed. Paper titles and abstracts were reviewed to identify appropriate studies for inclusion in my subsequent analyses. Articles considered were limited to electronically available manuscripts that explicitly engaged in the application or evaluation of knowledge integration and/or knowledge co-production for environmental management, conservation and/or sustainable development issues, resulting in 45 studies.

A number of articles that were included did not explicitly use the terms "knowledge integration" or "knowledge co-production" but used related concepts like "knowledge co-creation", "knowledge generation and exchange", and "social learning", with definitions that overlapped with my interpretation of knowledge integration and co-production. Some of these studies consisted of multiple cases, such as Pohl et al. (2010) who examined the role of

researchers in knowledge co-production within sustainability projects in Kenya, Switzerland, Bolivia and Nepal, and Raymond et al. (2010) who evaluate local ecological knowledge integration for environmental management in the United Kingdom, Solomon Islands, and Australia. For each of the 45 examples, study location(s), stakeholders, research methods, key findings and mechanism(s) explored were catalogued (Table 8 provides select examples. For full list of cases see Appendix 9). I conducted the same assessment for my two dissertation case studies in Alaska and Ethiopia (Table 9) and compared the context and key findings of my work with the broader literature, in an effort to relate my integrative geospatial modeling approaches to the existing theory and application of the adaptive governance mechanisms of knowledge integration and co-production for adaptive and collaborative management.

RESULTS

Knowledge Integration and Co-production Over the Past Twelve Years

Applied efforts of knowledge integration and knowledge co-production exist across local resource management, sustainable development, and conservation planning contexts. Studies spanned 29 peer-reviewed journals, the majority of which were in *Ecology and Society* (9 studies), followed by *Journal of Environmental Management* (4 studies). The remaining were found across a mixture of social and natural science-focused journals including *Current Anthropology*, *Ecological Applications*, *Society and Natural Resources*, *Human Ecology*, and *Landscape and Urban Planning*. Furthermore, the majority of studies (76%) were published in the last five years. A number of articles engaged in documentation of local and traditional ecological knowledge and facilitated participatory outlets for research framing, data collection, and data analysis and reporting. Most dealt with the concepts of knowledge integration and co-

104

production separately, with only six explicitly discussing them as connected mechanisms. For example, Pohl et al. (2010) argues knowledge integration to be an important piece of the broader knowledge co-production process, with sustainability researchers acting as a critical boundary-spanning organization for knowledge co-production between scientific and non-scientific communities.

Table 8. Overview of the geographic location, stakeholder arrangement, research methods and key findings of a sample of the 45 knowledge integration and knowledge co-production case studies assessed (see Appendix 8 for full list). TEK= traditional ecological knowledge, LEK= local ecological knowledge, IK= indigenous knowledge, and NGO= non-governmental organization.

Study Location	Mechanism(s)	Stakeholders	Methods	Findings	Citation
United States	Evaluation of **knowledge integration** (LEK and conventional science) for a sustainable agriculture monitoring team	Farmers, university and agency researchers, and non-profit staff	Interviews, field notes, and content analysis	Knowledge integration provided opportunity for empowerment through sharing of LEK and valuing of alternative knowledge systems by scientific researchers. Trust building between stakeholders a key result of process. Major challenges still existed throughout process linked with distinct worldviews and epistemologies between scientific researchers and farmers.	Nerbonne et al. (2003)
Russia	**Knowledge integration** (TEK) of village elders into community definitions of sustainability	Local communities and research scientists	Focus groups, interviews, and surveys	TEK integration of elder community members was shown to bolster local sustainability definitions and goals, as well as enhance inter-generational knowledge transfer between community elders and youth.	Crate (2006)
United States	Evaluation of **knowledge integration** (TEK and conventional science) for applied co-management research	Research scientists, land managers and Native Alaskan hunters	Interviews, participant observation, document analysis and workshops	Various roles of TEK integration. Strong dissemination of integrated research findings. Genuine power sharing promoted successful integration. Inclusion of TEK in all phases of research and long-term relationship building afforded multiple opportunities for informal interactions between stakeholders (enhanced trust-building and transparency). Some conflicts between different observations of conventional science and TEK. Potential for co-option of knowledge still exists based on underlying power imbalances.	Fernandez-Gimenez et al. (2006)
Philippines	**Knowledge integration** (LEK and conventional science) for flood risk assessment and	Community members, local and municipal government, regional NGO, research	Participatory mapping	Participatory mapping facilitated the broad understanding of geo-referenced data and the incorporation of LEK and scientific knowledge about vulnerability through collaborative learning. Foundation of trust	Cadag & Gaillard (2012)

	disaster risk reduction planning	scientists			and communication key for engaging a wide array of stakeholders. Process empowered the most marginalized people by providing access to scientific knowledge and legitimizing their LEK.	
Ethiopia	Traditional ecological knowledge documentation and **integration** for fire management plan development	Local pastoralists and research scientists	Interviews, field observations, and landscape level vegetation age structure analysis	TEK of pastoralists revealed high level of understanding regarding fire behavior and effects. Observations and vegetation analyses corroborated sustainable nature of traditional burning practices that is based on community needs of increasing grazing value, controlling a toxic caterpillar, and reducing predator attacks, but also provides important firebreaks and diverse vegetation mosaic. TEK could inform sanctioned government management fire planning.	Johansson et al. (2012)
Arctic Observing Summit (multiple Arctic communities)	Evaluation of **knowledge co-production** (TEK and conventional science) for community-based monitoring	Indigenous communities, resource managers, and scientific researchers	Literature review and observations at 2013 Arctic Observing Summit	The state of community-based monitoring in the Arctic shows processes focused on community needs and interests where TEK and science produce fine-grained local-scale data, readily accessible to communities and decision-makers. Need for connecting efforts, as they are often undocumented and disconnected among wider networks.	Johnson et al. (2015)
South Africa	**Knowledge integration** (LEK) and comparison with remotely sensed and field data to assess rangeland conditions and assist in remote rangeland monitoring	Livestock farmers, research scientists	Remote sensing, statistical variance analysis, photo elicitation and participatory field evaluations	Local knowledge explained significant differences in field sampled vegetation classes. Remote sensing correlated poorly to field-measured vegetation classes to do spectral noise and high iron oxide content of soil, revealing LEK to be highly useful for monitoring efforts.	Kong et al. (2015)

Table 9. Overview of the geographic location, stakeholder arrangement, research methods and key findings of my two research cases.

Study Location	Mechanism(s)	Stakeholders	Methods	Findings	Citation
Alaska	**Knowledge integration** (TEK and LEK) for risk assessment of stakeholder-defined provisioning ecosystem services to invasive species under current and future climate conditions	Native Alaskan tribal representatives, federal and state land managers, research scientists	Integrative geospatial modeling: Species distribution modeling, participant observation, informal interviews	Knowledge integration provided an important rapid appraisal opportunity for the co-definition of critical conservation targets and threatening disturbance drives between LEK of land management agencies and TEK of Native Alaskan tribal representatives. Diverse land manager LEK facilitated access to an array of spatial data sets incorporated into analyses.	Luizza et al. (In Review)
Ethiopia	**Knowledge integration** and **knowledge co-production** (LEK) for risk of stakeholder-defined provisioning ecosystem services to invasive species	Afar pastoralists and research scientists	Integrative geospatial modeling: Species distribution modeling, participant observation, focus group interviews, participatory data collection, participatory mapping	Pastoral knowledge revealed a new invasive species in the region, unknown to research scientist stakeholders and receiving little attention from government agencies and NGOs. Participatory approaches of knowledge co-production empowered communities and provided setting of mutual respect for different knowledge sources, facilitating shared learning and trust building. Much congruence between local ecological knowledge and conventional scientific observations, with the former expanding scientific understanding of the invasive species in question.	Luizza et al. (Accepted)

Other scholars echo this sentiment, noting knowledge integration to be an important and necessary precursor step to knowledge co-production (Armitage et al. 2011; Dale & Armitage 2011; Gratani et al. 2011; Trimble & Berkes 2013; Jackson et al. 2014). I catalogued studies based on their geographic location (Global North versus Global South), if they were evaluations or applications of knowledge integration and/or co-production processes, if they involved a codified co-management agreement between stakeholders, if they involved indigenous communities, and if they utilized geospatial applications (Figure 14). Of the 45 studies examined, the majority (30 examples) occurred in the Global North (i.e. the United States, Australia, Canada, Europe, and Russia), with far fewer cases occurring in the Global South (i.e. Africa, Asia or South America). Additionally more studies involved evaluation of

Figure 14. Distribution of meta-synthesis cases according to their geographic location in either the Global North or South, if they were an evaluation or application of knowledge integration and/or co-production processes, if they were a codified co-management agreement or not, if they involved indigenous stakeholders or not, and if they employed geospatial applications or not. A majority of cases occurred in the Global North, with a vast majority being non-codified co-management agreements, and very few cases using geospatial applications.

knowledge integration and/or co-production processes (27 examples), with researchers employing a range of qualitative methods to assess the utility and impacts of these approaches, compared to application of knowledge integration and/or co-production processes (18 examples).
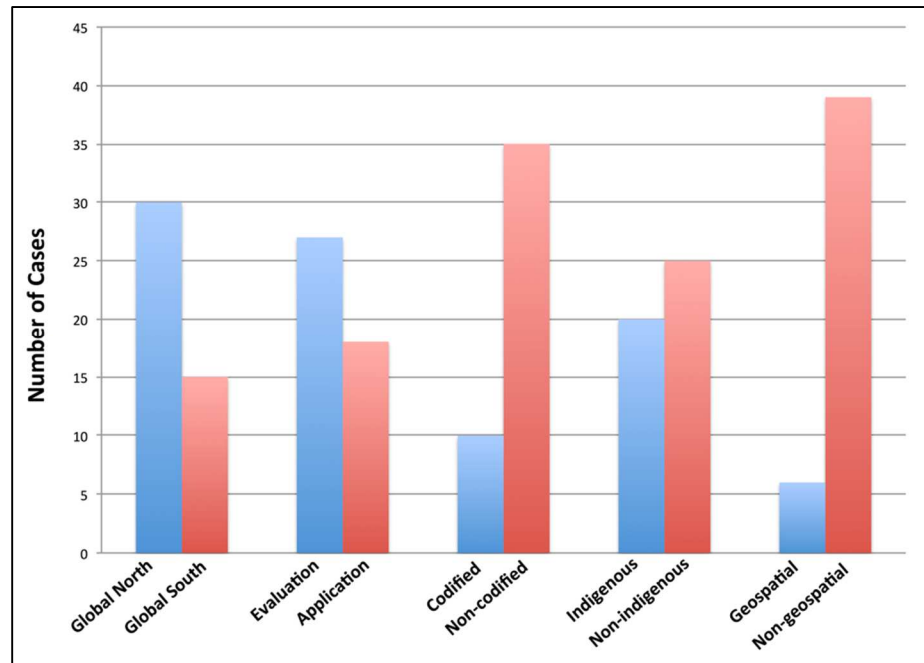
109

A more even split was found between studies that involved indigenous stakeholders (20 examples) and those that did not (25 examples). A vast majority of studies were non-codified management arrangements (35 examples), with the remaining being codified co-management agreements between a state and a resource-dependent community (usually a land management agency and an indigenous community). Finally, very few studies (6 examples) utilized geospatial applications such as remote sensing imagery and analyses, geographic information system software, global positioning systems, and spatial modeling. From this growing body of work, knowledge integration and co-production prove to be important social mechanisms for moving towards effective, collaborative and adaptive resource management, development and conservation planning. A number of key findings come out of these studies including necessary conditions for effective knowledge integration and co-production and important potential outcomes, some of which overlap. Important conditions include genuine power sharing, mutual respect and equal standing for different knowledge forms, a moderate level of trust between stakeholders, understanding of institutionalized power inequities and historical conflict, and co-definition of goals and issues of concern in an iterative manner. Important potential outcomes include community empowerment, expansion of scientific knowledge, facilitating future collaboration and co-management, increasing bonds of trust and open communication and enhancing adaptive strategies.

Power sharing, Trust Building and Respect for Diverse Knowledge Forms

Genuine power sharing, mutual respect for different knowledge forms and recognizing the equal standing of distinct ways of knowing the landscape proved especially important in evaluations of effective knowledge integration and co-production processes. Fernandez-Gimenez

110

et al. (2006) highlight the inclusion of traditional ecological knowledge of Native Alaskan hunters throughout all phases of co-management research coupled with long-term relationship building, afforded multiple opportunities for informal interactions between stakeholders. This fostered a greater level of transparency and in turn enhanced trust building between indigenous community members, scientific researchers and land managers. Cadag and Gaillard's (2012) work on knowledge integration for flood risk assessments and disaster planning in the Philippines showed strong foundations of trust and open communication to be critical for conducting participatory mapping activities with a wide array of stakeholders ranging from local community members and government officials, to regional non-governmental organization staff and research scientists. Other studies support these findings, with long-term relationships built on trust and frequent communication being important for knowledge integration among diverse indigenous and non-indigenous stakeholders (Trimble & Berkes 2013; Weiss et al. 2013; Schneider & Rist 2014), and even facilitating the redistribution of power through an array of knowledge sources (Ballard et al. 2008).

Limited levels of trust between stakeholders can pose major challenges to engaging in effective knowledge integration or knowledge co-production, and this can be exacerbated when there is limited acknowledgement or understanding of institutionalized power inequities and historical conflict, or when different forms of knowledge are not afforded the same level of respect. For example, when evaluating water management processes in the Netherlands, Edelenbos et al. (2011) discovered inherent challenges for engaging knowledge co-production, particularly between local citizens and policy-makers and bureaucrats. Great resistance to incorporating citizen knowledge in decision-making by policy-makers was apparent, but was not the case with knowledge co-production between policy-makers and bureaucrats due to

institutionalized relationships. A lack of respect for different knowledge forms led to less inclusive decision-making and skepticism as to the legitimacy of policy decisions among community stakeholders. Similarly, when evaluating the knowledge co-production process for co-management of a national park in Colombia, Ungar & Strand (2012) discovered no evidence of co-produced knowledge informing management decisions. Great distrust existed between many of the stakeholders including scientific researchers, park staff and indigenous Tikuna community members. In an attempt to respond to crises and long-term social-ecological dynamics, park managers engaged in a process of multi-scale social network maintenance and mobilization at the expense of open deliberation and collective knowledge creation. Arguably such management decisions further exacerbated existing distrust between stakeholders based on long-standing power imbalances.

Community Empowerment

The process of knowledge integration and/or knowledge co-production can often result in a level of community empowerment, especially for marginalized stakeholder groups (Gratani et al. 2011; Jackson et al. 2014). For example, Shaffer (2014) provides an evaluation of knowledge co-production among U.S. and Tanzanian researchers and local communities for local scale climate change monitoring in Tanzania. They find not only a high degree of congruence between traditional ecological knowledge and conventional scientific observations, but empowerment of communities to explore local climate adaptation and policy-making, fostered through extensive participatory data collection. Moreover, these locally driven approaches of analyzing scientific observations in light of community traditional knowledge further enhanced trust building and facilitated sharing of information between districts. Alexander et al. (2011) further reveal the

potential for empowering communities by integrating indigenous observations of climate change with global climate assessment data. Climate narratives encompassing a number of indigenous Arctic communities were documented and collated with peer-reviewed scientific studies. These narratives were overlaid on a geographic information systems map of climate change impact studies spanning 1970 to 2004. This process revealed both data sources to complement one another, provided a needed human dimension to the existing climate change research, and more importantly provided a voice to resource dependent communities, whose knowledge has largely been excluded from global climate assessment reports. Nerbonne et al.'s (2003) evaluation of local farmer knowledge integration with conventional science in Minnesota lends additional evidence to the potential of community empowerment coming out of knowledge integration. Farmers noted that the process of sharing their knowledge of the landscape and farming practices and seeing it embraced by researchers was personally validating and provided a greater level of trust between the different stakeholder groups.

Knowledge Congruence and Expanding the Realm of Scientific Knowledge

A number of studies reveal knowledge integration and co-production to expand the realm of scientific knowledge by providing important new insights and filling in gaps in conventional scientific observations (Gagnon & Berteaux 2009; Alexander et al. 2011). Moreover, when engaging indigenous knowledge, many studies find high levels of knowledge congruence between indigenous and conventional western scientific knowledge (Jackson et al. 2014; Shaffer 2014). Kong et al. (2015) provide an application of local ecological knowledge integration and comparison with remote sensing and field data, to assess rangeland conditions and assist in remote rangeland monitoring in South Africa. Local knowledge of livestock farmers explained

significant differences in field sampled vegetation class data, collected through participatory field evaluations. Interestingly, remote sensing correlated poorly to field-measured vegetation classes due to spectral noise and high iron oxide content of soil. This validation process revealed local ecological knowledge to be highly useful and more accurate for ongoing monitoring efforts. Beaudreau and Levin (2014) further these ideas with a synthesis of ecological knowledge of local fishers and divers in the northwestern U.S. over a 70-year period. Despite some variation in knowledge based of age group and information environments (i.e. the nature of how, when and where individuals acquired ecological information), local ecological knowledge proved to be a valuable source for detailed ecological information on abundance of and environmental changes to over 20 marine species, with the authors arguing that inclusion of diverse knowledge sources can overcome some issues of "shifting baseline syndrome" due to lack of long-term ecological data. This problem if not addressed may lead to misconceptions about the ecological integrity of a given system. This enhancement of conventional science is further seen with Johansson et al.'s (2012) study in the Bale Mountains of Ethiopia, where traditional pastoral knowledge was documented and integrated with conventional science for fire management planning. They found pastoralists to have high levels of understanding regarding fire behavior and effects, with scientific field observations and vegetation analyses corroborating the sustainable nature of their traditional burning practices, which could greatly enhance existing government management fire planning.

Enhancing Collaboration and Adaptive Strategies

Knowledge integration and co-production are noted by a number of studies to facilitate future collaboration and co-management arrangements, and potentially enhance adaptive

strategies. This is noted to occur through the combination of increased bonds of trust and open communication, and the co-definition of goals and issues of concern in an iterative manner (Hahn et al. 2006; Alexander et al. 2011; Trimble & Berkes 2013; Weiss et al. 2013). Butler et al. (2012) provide an evaluation of traditional ecological knowledge integration in Australia for fisheries co-management between Melanesian local fishers and fishery managers. They reveal the importance of co-defined cultural keystone species that provide significant ecosystem services for communities and international conservation interests for stimulating cross-cultural resource adaptive governance and potential local co-management efforts. Gret-Reganmey et al. (2013) and Schneider & Rist (2014) make similar discoveries in distinct knowledge integration and co-production studies in Switzerland- mapping forest-based ecosystem services and fostering transdisciplinary water governance respectively. In both cases deliberative dialogue, learning and trust building were facilitated by the iterative process of bringing knowledge back at multiple cycles to diverse stakeholders ranging from community members and recreation managers to scientific researchers and environmental economists. Hagemeier-Klose et al. (2014) further support these findings with their work on knowledge integration for climate scenario planning in Germany. Scenario planning processes facilitated social learning and collaboration through a platform of diverse knowledge integration and exchange processes among research scientists and agency representatives that were argued to hold great potential for enhancing adaptive capacity.

MY DISSERTATION RESEARCH

This growing body of literature reveals potentially important and connected conditions for and outcomes of knowledge integration and co-production. Much of this work is focused on the evaluation of knowledge integration and co-production processes based on stakeholder feedback and other qualitative analyses. My dissertation cases are the application of a novel,

115

transdisciplinary knowledge integration and co-production approach for risk assessment mapping in distinct ecological and cultural settings spanning different spatial and governance scales. Limited work explores the application of knowledge integration and co-production with advanced geospatial tools. Select studies relay the great potential this type of work holds, through the use of spatially explicit GIS-based Bayesian Networks, process-based modeling, global positioning systems, and remote sensing data (Alexander et al. 2011; Cadag & Gaillard 2012; Gret-Reganmey et al. 2013; Perkins et al. 2013; Herrmann et al. 2014; Kong et al. 2015). Despite this, no other studies could be found that utilize advanced geospatial applications, specifically powerful species distribution modeling algorithms. This is arguably a critical gap, as maps play a major role in conservation and natural resource management planning and policy-making. Both study sites constitute historic anthropogenic systems, where the landscape is shaped by and shapes the inhabitants (Fernandez-Gimenez & Estaque 2012). Hunting, harvesting, and herding practices for these groups are essential for sustaining livelihoods (Getachew 2001; McNeeley 2009), making them especially vulnerable to the interaction of slow and fast disturbance drives like changing climate and invasive species.

Similar to Armitage et al. (2011) and others, I view the concepts of knowledge integration and knowledge co-production as linked mechanisms, both facilitating collaborative and participatory approaches to environmental problem solving and fostering holistic and adaptive approaches to resource management and conservation planning. Although, I contend that knowledge integration processes engage in pragmatic participation, whereas knowledge co-production engages more directly with normative participation. In both examples, the integration of traditional and local ecological knowledge was done to assess the vulnerability of community-defined provisioning ecosystem services to invasive species deemed most problematic by these

stakeholders. In the case of northeastern Ethiopia, the added engagement of knowledge co-production occurred through a number of in-depth, participatory processes. Each case corroborates a number of aforementioned findings from the broader knowledge integration and co-production literature, but also raise additional questions worth further consideration and exploration.

Integrative Geospatial Modeling in Alaska

My Alaska case provides a unique approach to knowledge integration at a larger spatial and governance scale (i.e. the entire state of Alaska). A majority of existing studies focus on a local landscape or community scale for their research. This is important in facilitating in-depth understanding of different and potentially diverse stakeholder knowledge forms, but affords limited understanding of the potential for wider application of knowledge integration and co-production across larger spatial scales with more diverse ecological, social, cultural, and political contexts. Alexander et al. (2011) act as one example of a broader application of knowledge integration. Their documentation and subsequent collating of indigenous knowledge of numerous indigenous representatives of Arctic communities spanning Asia, Europe and North America, with peer-reviewed scientific studies on climate change revealed a high degree of congruence between these distinct forms of observational data. Additionally, indigenous knowledge filled in conventional science gaps by providing important missing information on climate patterns in remote regions with few climate instrument records. This reveals the potential utility of such approaches at a broader spatial and governance scale, but is still heavily focused on validation of indigenous knowledge compared to western scientific knowledge.

My Alaska chapter provides an example of knowledge integration for co-defining conservation targets and disturbance drivers of concern and re-framing how they are assessed in light of local subsistence livelihoods. Observational data and informal interviews with Native Alaskan tribal representatives and federal and state land managers at the Yukon Intertribal Watershed Council Biennial Summit (2012), afforded a detailed understanding of important conservation targets and disturbance drivers of concern. This resulted in my selection of Pacific salmon and whitefish as critical conservation targets and invasive elodea and climate change as threatening disturbance drivers based on my analysis of stakeholder input. These data, in addition to extensive spatial data sets from land management agency stakeholders were used in concert with species distribution modeling algorithms to map the vulnerability of important provisioning ecosystem services to a threatening invasive species. Although stakeholders concerns often came from different framings (e.g. food security and cultural identity, biodiversity and keystone species protection and commercial and sport fishing concerns), integrating these different stakeholder perceptions revealed the shared view of important conservation targets including Chinook salmon (*Oncorhynchus tshawytscha*) and whitefish species (*Coregonus nelsonii*), and the growing concern of Alaska's first submerged freshwater aquatic invasive plant *Elodea* spp.

This corroborates existing studies that argue for the potential enhancement of collaboration and adaptive strategies through an iterative process of goal and conservation target co-definition (Butler et al. 2012; Trimble & Berkes 2013; Weiss et al. 2013). In my Alaska case, the flexible transdisciplinary nature of integrative geospatial modeling shows great potential as a robust tool for spatially understanding critical provisioning ecosystem services that can vary for different stakeholder groups, and further offer an iterative approach for updating models and

118

engaging stakeholders. This may foster social and institutional learning through reflection on management goals and model outputs and provide avenues for adjusting applied management strategies. Hahn et al. (2006) similarly show flexibility and reflexivity to enhance social learning and subsequent applied collaborative wetlands management efforts in Sweden, in addition to assisting with conflict resolution among diverse stakeholders. Knowledge integration provided an important rapid appraisal opportunity for the co-definition of critical conservation targets and threatening disturbance drives between local ecological knowledge of land management agencies and traditional ecological knowledge of Native Alaskan tribal representatives. Limitations to the knowledge integration process exist though, as the tribal summit did not include Native Alaskan representatives from a number of locations including Inupiaq, Southeast, Alutiiq/Sugpiaq and Unangan regions. This information gap was supplemented with literature reviews and a detailed subsistence harvest data analysis for each region.

This case does not provide evidence of true community empowerment, as knowledge integration was focused more on pragmatic participation, with Native Alaskan knowledge providing important insights but not involving shared decision-making or extensive collaborative engagement. This highlights inherent challenges of attempting knowledge integration or co-production research at broad spatial and governance scales, as the number of knowledge sources can exponentially increase, thus limiting the depth of information documented or participatory processes engaged. This could change with a continued iterative process of bringing back maps to community stakeholders for validation and open dialogue about collaborative and adaptive management strategies. This further supports the idea that such knowledge engagement processes are long-term investments when seeking adaptive governance outcomes (Fisher et al. 2007; Armitage et al. 2009).

119

The iterative process in this research was focused more heavily on sustained interaction with federal and state land management agency stakeholders, in part due to established relationships, but also because my work in this instance sought to provide a rapid appraisal approach that leveraged diverse knowledge and data sources to assist in re-framing agency risk assessment mapping efforts to include a more holistic understanding of the potential impacts of invasive species on local subsistence livelihoods. Therefore, this case did not engage in or reveal instances of power sharing related to the overall research design and execution or subsequent decision-making, as Native Alaskan knowledge integration was limited to documentation and more pragmatic participation to expand the issue scope of resource managers when engaging in applied management. This further supports existing arguments of the critical nature of trust building (Fernandez-Gimenez et al. 2006; Weiss et al. 2013; Schneider & Rist 2014) and the long-term process of knowledge integration and co-production (Armitage et al. 2011; Dale & Armitage 2011). For this case, I feel rapport was established and important initial foundations of trust building were laid with certain tribal delegates, but overall trust building and the creation of social capital, which is "the glue for adaptive capacity and collaboration" (Olsson et al. 2004) was neutral. This further highlights the need for sustained and repeated interactions with indigenous community and resource management stakeholders. I hope my continued attempts to engage in this process (often self-funded) despite multiple instances of projects falling through, relays to the stakeholders I am collaborating with some measure of my commitment to this process, and to the people and landscapes this work seeks to support.

Integrative Geospatial Modeling in Ethiopia

My Ethiopia case provides an example of local ecological knowledge integration and knowledge co-production, coupled with similar species distribution modeling algorithms to map

the vulnerability of important provisioning ecosystem services to threatening invasive species at the local scale. This work in the Afar region of northeastern Ethiopia supports a number of broad findings in the existing literature including the importance of respect for different forms of knowledge enhancing participatory data collection and project design, the critical nature of trust building, and the ability of local and traditional ecological knowledge to expand the realm of conventional scientific knowledge. With the assistance of my Ethiopian research colleagues, I documented indigenous pastoral knowledge about changes witnessed on the landscape, important provisioning ecosystem services and threats to pastoral livelihoods.

Pastoral knowledge from focus group interviews revealed a new invasive species in the region- rubber vine (*Cryptostegia grandiflora*), which was unknown to our research team and has received little attention from government agencies and non-governmental organizations. Knowledge co-production came out of extensive knowledge integration efforts, including participatory field data collection and participatory mapping efforts. A setting of mutual respect for different knowledge sources facilitated shared learning and seemingly a measure of trust building. A number of studies from the broader literature stress the importance of this. For example, Hartley and Robertson's (2008) evaluation of local fisher knowledge integration with conventional science in the United States revealed a high level of agreement among fishers and scientists as to the importance of knowledge integration for applied management, but that few thought it possible due to long-standing mistrust and lack of communication between these distinct stakeholders. However, Hearne and Powell (2014) found knowledge integration of diverse stakeholders for water management in the Philippines, facilitated through extensive participatory networks, fostered high levels of bonding social capital and trust building.

In Afar, focus group participants quickly realized they were in charge of where the discussion went and that our team was genuinely interested in helping them address their concerns. Approaching the interviews as informal discussions in a social setting, with women attending to household duties, children running around, and participants and researchers participating in the cultural custom of chewing khat leaves (*Catha edulis*), seemingly opened doors to discuss contentious political issues, discuss culturally meaningful medicinal plants, and brainstorm treatment approaches to mitigate rubber vine. Prior long-standing relationship building conducted by my Ethiopian colleagues further enhanced the process of shared learning and trust building. This supports findings of Fernandez-Gimenez et al. (2006), who through an evaluation of knowledge integration in Alaska reveal that the inclusion of traditional ecological knowledge throughout all phases of the research coupled with long-term relationship building, fostered a greater level of transparency and in turn enhanced trust building between Native Alaskan community members, scientific researchers and land managers.

Much congruence was found between pastoral knowledge and conventional scientific observations of invasive rubber vine. Pastoral knowledge provided a deeper understanding of the plant's ecology and biology, where it exists on the landscape, and the threats it poses to arid ecosystems and local livelihoods. This corroborates a number of knowledge integration and co-production studies that espouse the ability of local and traditional ecological knowledge to expand the realm of conventional science by providing important new insights and filling in gaps in scientific observations. Gagnon & Berteaux's (2009) evaluation of traditional ecological knowledge integration with western science for understanding arctic fox (*Vulpes lagopus*) and greater snow goose (*Chen caerulescens atlantica*) ecology, revealed great complementarity between the two forms of knowledge across spatial and temporal scales and further facilitated in

122

the generation of new insights and new hypotheses. Jackson's (2014) evaluation of knowledge integration of indigenous landowners in Australia for improved water planning and management revealed similar knowledge congruence and the enhancement of scientific knowledge of fish species, but also provided opportunities for indigenous landowners to share stories about fish, including their cultural significance. Moreover, other studies highlight the benefits of knowledge integration and co-production for expanding the realm of science and management, revealing important connections between landscapes and local livelihoods for enhanced biodiversity protection (Kalibo & Medley 2007), increasing scientific understanding of local fire behavior linked with the sustainable burning practices of local communities (Johansson et al. 2012), and the potential for improving management through wider cultural consensus analyses with indigenous communities (Carothers et al. 2014). This was equally the case working with Afar pastoralists, who relayed detailed information about the impacts of invasive rubber vine coupled with agricultural development and climate change on important plants and animals that provide an array of provisioning ecosystem services.

A level of power-sharing occurred in Afar regarding research execution, with pastoralists in the driver's seat when it came to the process of sharing knowledge, identifying threats to their livelihoods, and engaging in participatory data collection. Ballard et al. (2008) note the important outcome of redistribution of power through diverse knowledge sources while evaluating community forestry monitoring efforts in the United States. However, limited examples of true community empowerment regarding decision-making occurred in this case, as government and international aid agency stakeholders still tend to hold the majority of this authority and few of these stakeholders were involved in this project. As noted with the Alaska case, this could

change with a continued iterative process of bringing back maps to community stakeholders for validation and open dialogue about collaborative and adaptive management strategies.

CHALLENGES TO KNOWLEDGE INTEGRATION AND CO-PRODUCTION

Both cases of integrative geospatial modeling in Alaska and northeastern Ethiopia support a number of findings in the broader knowledge integration and co-production literature. This includes the potential enhancement of collaboration and adaptive strategies through an iterative process of goal and conservation target co-definition, the critical nature of trust building and providing a setting of mutual respect for different knowledge sources, and the ability of local and indigenous knowledge to expand the realm of conventional science by providing important new insights and filling in gaps in scientific observations, but this work also raises additional important questions. For instance, the issue of scale is a focal topic across a range of disciplines, including questions regarding what spatial or governance scale a problem should be addressed, or how changes in temporal scale may affect data inference (Danielsen et al. 2010; Zia et al. 2011; Geijzendorffer et al. 2015). Within the knowledge integration and co-production literature, few studies discuss issues of scale in great depth, although there is great need for improving knowledge management, dissemination, and integration at the national and international scales (Chasek et al. 2011). Gagnon and Berteaux (2009) do argue that determining the scales of the observations that form both traditional ecological and conventional scientific knowledge are critical when attempting to integrate the two. Understanding differences in spatial and temporal scales of observations can provide opportunities to expand knowledge, fill in existing data gaps, and stimulate new questions, but may also pose challenges when different knowledge sources disagree, potentially raising issues related to knowledge credibility and latent power inequities.

124

The importance of institutional connectivity is another less discussed topic in much of the knowledge integration and co-production literature. Clark & Slocombe (2011) offer an important example of institutional connectivity proving to be highly important for facilitating knowledge integration. Their evaluation of traditional ecological knowledge integration with conventional science for adaptive co-management of grizzly bear-human conflict in Canada revealed noticeably different outcomes for seemingly similar cases. The successful case of knowledge integration was attributed to strong vertical and horizontal integration of institutions, which provided cross scale institutional networks for transferring knowledge. This line of inquiry warrants further research, as different institutional arrangements may promote or hinder successful knowledge integration and co-production. In the case of my Alaska research, a seemingly moderate level of cross-institutional networks exist between tribal, federal, and state stakeholders, strengthened by long standing relationships of key land managers with Native Alaskan communities. In the Afar region of northeastern Ethiopia this type of horizontal and vertical institutional integration is nearly non-existent. This raises another issue in regards to adaptive strategies. A number of studies note that the process of knowledge integration and co-production may lead to more adaptive measures, facilitated through a diversity of knowledge sources. Despite a vast majority of the examples explored being evaluations of knowledge integration and co-production cases, few relay if actual shifts in adaptive strategies occur. This arguably requires longer-term investments in monitoring these processes to identify such changes.

Another area of research receiving limited attention in the broader literature is the potential benefit of bridging and boundary-spanning organizations and individuals for enhancing knowledge integration and co-production processes. These individual and organizational actors

enable cooperation among distinct stakeholder groups ad foster the dissemination and translation of knowledge between science, policy, and community spheres. This is achieved through coordination of important tasks such as accessing resources, bringing together different actors, building trust, resolving conflict, and networking (Berkes 2009). Other research supports the idea of boundary-spanning and bridging organizations and individuals supporting environmental governance and adaptive management efforts (Olsson et al. 2004; Sternlieb et al. 2013), but only one study assessed in my meta-synthesis explicitly referenced either form of organization or individual.

Pohl et al. (2010) evaluated knowledge integration processes in cases spanning Kenya, Switzerland, Bolivia, and Nepal, finding sustainability researchers to act as an important boundary-spanning organization for knowledge co-production between scientific and non-scientific communities. Moreover these researchers took on different roles as "reflective scientist" (facilitating common understanding and incorporating local knowledge), "intermediary" (bridging different stakeholder concerns and approaches around common issue) and "facilitator of a joint learning process" (reconciling different worldviews). Arguably this typology proved somewhat true in both my Alaska and Ethiopia cases. My role in Alaska constituted to some degree, an "intermediary" researcher, bridging state and federal land management agency and Native Alaskan community concerns about anadromous fish species and connecting it to the issue of invasive aquatic plants, climate change, and cascading impacts on subsistence livelihoods. In Ethiopia, my role was much more of a "reflective scientist" working across multiple villages to gain common understanding of issues faced and changes witnessed by pastoralists, and incorporating their knowledge into my risk assessment of invasive plants. In both examples other bridging and boundary-spanning organizations and individuals

facilitated me in conducting more rapid knowledge integration and co-production processes. This, coupled with participatory methods that fostered knowledge co-production, produced a greater level of investment in the research by pastoralists in northeastern Ethiopia, but due to a lack of institutional connectivity, there were limited opportunities for interaction and limited investment from agencies and aid organizations in this research. In Alaska, bridging and boundary-spanning organizations and individuals provided the setting for interacting with a number of Native Alaskan and federal and state agency stakeholders. Knowledge integration at a broader landscape scale limited engagement with Native Alaskan communities. Iterative engagement was noticeably limited to federal and state agency stakeholders, but stronger institutional connectivity may provide better outlets and avenues for continued knowledge integration, co-production, and dissemination in the future. In these cases, organizations like the Yukon River Intertribal Watershed Council, trusted land managers in Alaska, and American and Ethiopian colleagues with an established presence in the Afar region of Ethiopia, provided a level of built-in trust and legitimacy by affiliating themselves with my research. Knowledge integration and co-production are noted by a number of scholars to be long-term commitments (Armitage et al. 2011; Dale & Armitage 2011; Weiss et al. 2013), often with the process involving knowledge integration leading to more holistic and participatory knowledge co-production (Armitage et al. 2011; Dale & Armitage 2011). This long-term approach can avoid simple extractive knowledge documentation devoid of meaningful participation, but critical boundary-spanning and bridging organizations and people may provide an avenue for more rapid application of knowledge integration and co-production processes. However, in both cases, difficulties in sustaining repeated interactions with rural communities, due to funding, logistical, and technological barriers were present.

The next steps in this research include bringing back the risk assessment maps produced through my integrative geospatial modeling approach for participatory evaluation and assessment. Furthermore, follow up interviews with all stakeholder groups about the utility of this transdisciplinary process will be conducted, in addition to continuing open discussions about conservation planning and invasive species management in both locations.[12] This is a critical part of the iterative goal definition and project re-framing process that other knowledge integration and co-production studies highlight. This is an important step in my integrative geospatial modeling approach that will directly evaluate the utilization of knowledge integration and co-production for collaborative and adaptive management of ecosystem services and invasive species within an adaptive governance framework. This stage will likely reveal additional opportunities and barriers to effective knowledge integration and co-production related to distinct worldviews and power relations among different stakeholder groups. Treating knowledge integration and co-production as deliberative, iterative processes is argued to be important for effective management (Gret-Reganmey et al. 2013; Schneider & Rist 2014). However, this raises another challenge in terms of finding resources and availability to engage both mechanisms in an iterative manner. Setting the stage for knowledge integration and co-production requires long-term commitments and great expenditure of time and resources (Armitage et al. 2011; Dale & Armitage 2011); something that is true for collaborative conservation work more generally speaking.

Understanding the opportunities and challenges present for this type of integrative work is important for adaptive and collaborative resource management. Even with seemingly

---

[12]   I will be conducting follow-up work in July 2015 with tribal, state and federal Alaska project stakeholders, and am in the process of organizing similar follow-up work with pastoral, non-governmental organization and regional government stakeholders in northeastern Ethiopia for November or December 2015.

successful cases of knowledge integration and co-production, understanding and attempting to address power imbalances is critical, as traditionally marginalized stakeholders, including minorities and indigenous communities may still be under-represented in these processes (Ballard et al. 2008), and great potential still exists for knowledge co-option based on underlying power imbalances (Fernandez-Gimenez et al. 2006) and long-standing distrust between different stakeholder groups (Ungar & Strand 2012). For Alaska and the Afar region of Ethiopia this is important for facilitating meaningful stakeholder engagement and power sharing in applied management efforts. Alaska's Native Claims Settlement Act of 1971 has had acute impacts on Native Alaskan subsistence practices through the abolishment of both aboriginal title to the land and hunting and fishing rights (McNeeley 2009). This puts tribes at an added disadvantage when engaging the often conflicting political, economic, social and biological objectives of an array of management and use interests, especially revolving around fisheries management (Moncrieff & Klein 2003). In the Afar region of Ethiopia, indigenous groups are at an even greater disadvantage, with concerted efforts by the national government starting in the 1950s to sedentize and restrict customary rights to access resources by mobile pastoral peoples, followed by the Land Reform of 1975, which did not recognize any of the Afar's land rights (Getachew 2001). This has led to displacement, added poverty, and overall increased marginalization of the Afar people and other pastoralists across the country. Moreover, to this day the government still moves people when land is deemed degraded (Bussmann et al. 2011), and talking with local Afar communities revealed that forced sedentization processes still continue in the region (Luizza personal correspondence). This can pose major challenges to effectively applying knowledge integration and co-production processes within the existing resource management institutional

129

structures. Therefore, finding overlap between external (i.e. land management agency, non-governmental organizations) and internal (i.e. local community) motivation is important.

REFLECTIONS

We face immense and connected environmental and social challenges today that require flexibility and holistic understanding of the abiotic, biotic, and socio-cultural processes. Distinct worldviews and observations associated with diverse forms of knowledge can provide nuanced and detailed understanding of a landscape and holds the potential to greatly enhance our understanding of ecological changes and implications for local adaptation. Thus, knowledge integration and co-production are increasing recognized as important adaptive governance mechanisms for effective, collaborative, and adaptive management efforts. Exploring this literature over the past decade reveals a number of important findings: 1) Knowledge integration and knowledge co-production processes receive little attention within the applied realm of advanced geospatial applications. 2) A number of important conditions exist for engaging in effective knowledge integration and co-production, including genuine power sharing, mutual respect and equal standing for different knowledge forms, understanding of institutionalized power inequities and historical conflict, and co-definition of goals. 3) Knowledge integration and co-production can lead to a number of outcomes such as trust building, community empowerment, expansion of scientific knowledge, and enhancement of adaptive strategies.

My integrative geospatial modeling work in Alaska and Ethiopia supports a number of these findings, including the potential enhancement of collaboration and adaptive strategies through goal and conservation target co-definition, the critical nature of trust building and providing a setting of mutual respect for different knowledge sources, and the ability of local and

indigenous knowledge to expand the realm of conventional science. This work also raises additional questions regarding issues of scale, institutional connectivity, and the potential benefit of bridging and boundary- spanning organizations and individuals for facilitating more rapid knowledge integration and co-production processes. Moreover, existing power disparities cannot be overlooked when engaging in this process. Even when approaches are inclusive and collaborative they can foster social exclusion. For example, similar "participatory spatial knowledge management tools", which are common in urban planning and development, often do not adequately account for things like accountability, empowerment, control, and use of knowledge, thus detracting from their ultimate goals and beneficial features (Pfeffer et al. 2013). If geospatial products of knowledge integration and co-production processes are co-opted by illegitimate power sources, these tools could be used against already marginalized and disenfranchised stakeholders. This is especially concerning in developing countries that are still entrenched in neo-patrimonial political systems, which are often mired in a context of social unrest and political upheaval, and greatly depend on self-enrichment from natural resources to uphold tenuous political allegiances (Médard 2002).

When local and indigenous knowledge integration and knowledge co-production are viewed as a mechanism for sharing concepts and applying practices for management of natural resources, rather than data to be extracted, collected, and repackaged within an existing, conventional scientific framework, great potential for increased community engagement, empowerment, and effective action on the ground can occur. These processes hold great utility for leveling the playing field for stakeholders, promoting access to and dissemination of important knowledge relevant to decision-making, and fostering a deeper understanding of social-ecological systems.

Conclusions: Moving forward with integrative geospatial modeling

This research demonstrates the utility of integrative geospatial modeling as a valuable transdisciplinary tool for addressing conservation efforts in rural regions with mounting anthropogenic pressures. Limited work explores the application of knowledge integration and co-production with advanced geospatial tools. This is arguably a critical gap, as maps play a major role in resource management and conservation planning and policy-making. Species distribution models in particular have become a primary tool for ecological inference, which greatly informs and influences this type of decision-making (Guillera-Arroita et al. 2015), yet the importance of local and indigenous knowledge has been undervalued and more often than not entirely ignored.

My dissertation approach applied the adaptive governance mechanisms of knowledge integration and co-production in concert with species distribution modeling in distinct ecological and cultural settings that span different spatial and governance scales. The ultimate goal of this work was to develop a novel transdisciplinary tool for fostering more holistic, collaborative, and adaptive management processes and outcomes with indigenous groups and land managers regarding important stakeholder-defined ecosystem services and problematic invasive species. From this work, the interconnected nature of knowledge integration and co-production was revealed, with each engaging a facet of knowledge documentation and providing diverse opportunities for collaborative and participatory learning. Moreover, knowledge integration and co-production and species distribution modeling proved complimentary, with each distinct disciplinary approach enhancing the other. In line with the views of Armitage et al. (2011) and others, I found knowledge integration to be an important mechanism in its own light, but also a

critical initial process that can lead to deeper, more collaborative, and increasingly participatory knowledge co-production processes.

Each chapter speaks to the importance of local and indigenous knowledge for enhancing adaptive and collaborative management approaches. In chapter one, my work in Alaska showed knowledge integration to provide an important rapid appraisal opportunity for the co-definition of critical conservation targets and interacting disturbance drivers of invasive species and climate change between local ecological knowledge of land managers and traditional ecological knowledge of Native Alaskan tribal representatives. This provided an important opportunity to re-frame management approaches to risk assessment mapping, informed by local community needs and concerns. Bridging and boundary-spanning organizations and individuals such as the Yukon River Intertribal Watershed Council and key U.S. Fish and Wildlife Service staff were critical for providing access and an added level of legitimacy to the rapid appraisal process of my integrative geospatial modeling methods. Conducting this work at a broader landscape spatial and governance scale (i.e. the entire state of Alaska) posed some inherent challenges to knowledge integration and moving towards knowledge co-production, specifically in regards to feasibility of engaging a much wider and necessary range of stakeholder knowledge sources, thus requiring greater time and resource investments.

In chapter two, local pastoral knowledge integration in the Afar region of northeastern Ethiopia revealed a new invasive species (rubber vine) in the region, unknown to research scientist stakeholders and receiving little attention from government agencies and non-governmental organizations. Extensive participatory methods including participatory mapping and field data collection, coupled with knowledge integration efforts such as focus groups and interviews, started the process knowledge co-production, which empowered communities and

provided setting of mutual respect for different knowledge sources, facilitating shared learning and a level of trust building. From this, great congruence between pastoral knowledge and conventional scientific observations were found, with the former expanding scientific understanding of the biology, ecology, and impacts of invasive rubber vine. Similar to the Alaska case, key bridging and boundary-spanning individuals including American and Ethiopian colleagues with an established presence in the Afar region were critical for providing access and an added level of legitimacy to the rapid appraisal process of my integrative geospatial modeling methods. Limited institutional connectivity and capacity, and a high level of contention and animosity between pastoral communities and local, regional, and national government entities may pose great barriers to enacting collaborative and adaptive management strategies in practice. Engaging these stakeholders while understanding and acknowledging the contentious historical, political, and cultural backdrop in which these groups reside will be a necessary next step as I move forward with this work.

In chapter three, I provided a synthesis of the growing body of work on knowledge integration and co-production as important social mechanisms of adaptive governance, revealing a number of necessary conditions for effective knowledge integration and co-production processes and important potential outcomes. These conditions include genuine power sharing, mutual respect and equal standing for different knowledge forms, a moderate level of trust between stakeholders, understanding of institutionalized power inequities and historical conflict, and co-definition of goals and issues of concern in an iterative manner. Important potential outcomes include community empowerment, expansion of scientific knowledge, facilitating future collaboration and co-management, increasing bonds of trust and open communication and enhancing adaptive strategies. My research in Alaska and northeastern Ethiopia, corroborates a

number of broader findings, including the potential enhancement of collaboration and adaptive strategies through goal and conservation target co-definition, the critical nature of trust building and providing a setting of mutual respect for different knowledge sources, and the ability of local and indigenous knowledge to expand the realm of conventional science. This work also raises additional questions for further inquiry along the lines of scale, institutional connectivity, measuring the enhancement of adaptive strategies, and especially the role of bridging and boundary-spanning organizations and individuals, as they provided in both of my cases a level of trust and legitimacy with stakeholders, which proved necessary for facilitating more rapid knowledge integration and co-production processes. In addition to this work being facilitated by bridging and boundary-spanning organizations and individuals, my role as a bridging and boundary-spanning researcher was made equally apparent. As Pohl et al. (2010) discover in their multiple case study evaluation of knowledge co-production processes, researchers often take on distinct roles as boundary-spanning organizations between scientific and non-scientific communities. In both of my cases this seemingly proved true as I began the process of engaging as a "reflective scientist", facilitating common understanding and incorporating local knowledge and as an "intermediary", bridging different stakeholder concerns and approaches around a common issue. Moreover, the use of maps, whether for participatory mapping activities or evaluation of initial results, provided an equally important platform for engaging in shared learning and deliberation. Often ecological modeling approaches are seen as strictly an ecological tool. The application of my integrative geospatial modeling method in both cases lends evidence to the great potential for not only engaging different knowledge sources and providing an enhanced platform for the voices of resource-dependent communities to be better heard, but also in bridging social and natural science approaches. These models can act as a

135

boundary-spanning object to bring social and natural scientists together for transdisciplinary collaboration and potentially even cross-disciplinary knowledge co-production. The resulting maps can act as a "boundary object"; providing a shared space between diverse groups in a decision-making context and structured to accommodate diverse informational needs of the stakeholders (Star 2010; Mattor et al. 2014).

It is important to note that my research activities tended to include only one major stakeholder group (i.e. local pastoral community members, federal and state land managers). Future steps of engaging in more concerted participatory evaluation of the risk assessment maps will need to include all major stakeholder groups. In the future, I hope to enact a process of participatory knowledge exchange related to the risk assessment maps created through this dissertation. This would involve an iterative process of meeting with distinct stakeholder groups individually (e.g. tribal, resource management, pastoral, non-governmental organization) and then as full stakeholder groups, multiple times. This process would entail critically appraising the risk assessment maps and providing a deliberative platform to raise other concerns. Discussion about specific threatened regions would also include the use of free list documentation, which is a structured interviewing technique to elicit systematic data about a cultural domain (Weller & Romney 1988; Quinlan 2005). This would be used to further refine our understanding of important ecosystem services and threatening disturbance drivers for all stakeholders involved and help determine the cultural salience of specific items listed. We would subsequently conduct participatory field surveys of specific locations determined to be high priority validation sites, to update the models with new invasive species presence or absence data, but also document narrative site descriptions by different stakeholders and begin planning sustained collaborative monitoring and management efforts.

Despite the growth in this area of research, a limited number of studies discuss the process of applying knowledge integration and co-production and even less utilize these mechanisms in concert with advanced geospatial applications. I argue that incorporating the adaptive governance mechanisms of knowledge integration and co-production with the advanced geospatial application of species distribution modeling, provides a robust toolset for moving towards effective, collaborative, and adaptive resource management and conservation planning, and provides a methodological avenue that begins to bridge science-policy and social-natural science disciplinary boundaries.

Top-down, discipline-specific approaches tend to fail at adequately addressing the complexity of ecosystems or the needs of resource-dependent communities that are directly tied to them. Non-native invasive species are a critical global issue and proved to be a useful focal point for my integrative geospatial modeling cases. In each instance they showed the connectivity of diverse and detrimental disturbance drivers that negatively impact SESs, by undermining ecosystem integrity and holding equally detrimental impacts for indigenous livelihoods and cultural heritage that are centered on the land, water, and wildlife. An important caveat exists with this line of thought though; for this to be truly effective it requires consensus across stakeholder groups about the ill effects of a given invasive species, which may not always be possible, and something academic researchers, land management, community and other stakeholders should be aware of. Non-native species labeled as "invasive" by one stakeholder group may hold important benefits for another, as revealed by a number of studies (Foster & Sandberg 2004; Garcia-Llorente et al. 2008; Marshall et al. 2011; Shackleton et al. 2011; Belnap et al. 2012). If there is a level of consensus in regards to the negative impacts of an invasive species of concern, that issue may provide a much easier focal point that all stakeholders can

137

collaborate around and for which local and indigenous communities may be more inclined to share their knowledge about openly, thus facilitating knowledge integration and co-production processes. This dovetails with a main point by Gagnon and Berteaux (2009). Looking at indigenous knowledge
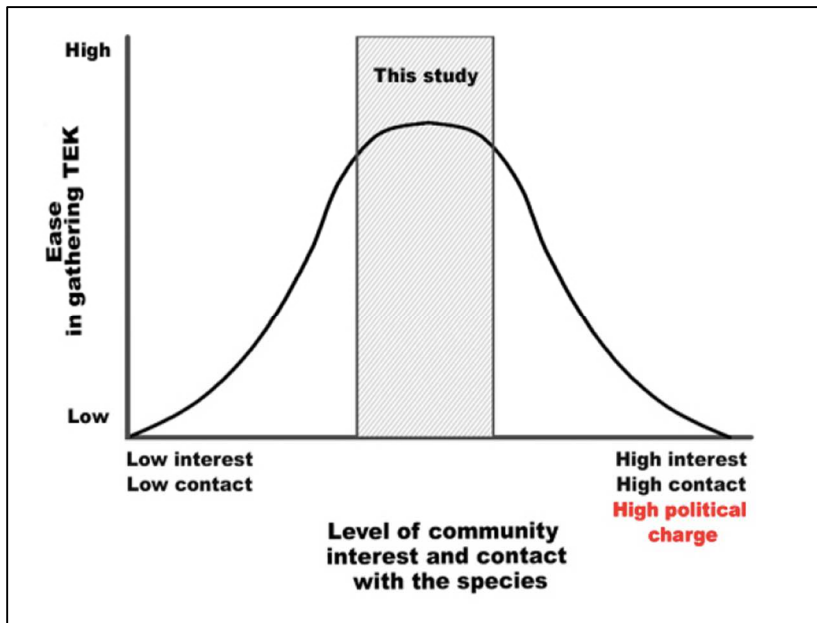

Figure 15. Conceptual graph of the ease of collecting and integrating TEK, based on level of interest and contact a community has with a given species and the level of political charge associated with it. Courtesy of Gagnon and Berteaux (2009).

integration of arctic fox and greater snow goose with conventional science in Canadian Arctic, they argue that the level of a local community's interest in and contact with a given species, in addition to the level of political charge associated with it, influences the ease with which it is possible to gather traditional ecological knowledge about that species of interest (Figure 15). They note that when a community has little interest in or contact with a species, traditional ecological knowledge is low and cannot be effectively gathered (left side of curve). When community has high interest in a species and issues surrounding it are politically charged, traditional ecological knowledge collection can become difficult to collect without bias (right side of curve). An ideal context rests in the middle of graph, where species are visible and engaged with but do not insight strong reactions. Arguably this can transfers with invasive species and even habitat types or distinct ecosystem services. For example, when working with pastoralists in my Ethiopia case, community members were happy to share detailed knowledge

about rubber vine and relay as many locations of the plant as possible. Consensus among villages about the detrimental nature of the plant was present, in addition to a high level of interest and contact with it, in addition to it not being a controversial political issue, in part because the government is not aware of the level of establishment. While simultaneously mapping water resources with the same villages and using the same maps, pastoralists would at first only reveal locations of government-drilled wells. Further questioning about naturally occurring springs and wetlands was met with some discussion among community members, and then brief descriptions about general locations of important water features and the map identification of a few prominent water features easily distinguished on the satellite imagery. It became clear that sharing sensitive information about the exact location and distribution of artisanal springs and small seasonal wetland locations that their livestock depend on during drought was not something they were willing to openly share, at least not based on our brief interactions. These important habitat types are of high interest and high contact with communities, but great political charge exists around traditional rights to access water and government appropriation of those resources.

In the case of rubber vine in Ethiopia, great consensus exists within the local pastoral communities about the negative effects of the plant. It is likely that non-governmental organization and Ethiopian government institutions would share this sentiment towards rubber vine, but limited interaction with these stakeholders due to weak horizontal and vertical connectivity of institutions leaves this to conjecture, and an important next line of inquiry in this integrative geospatial modeling process. In the case of elodea in Alaska, consensus around the problematic nature of this plant was shared by state and federal land managers, but Native Alaskan community consensus is still unclear at this time. Native Alaskan tribal representatives noted concern for invasive species, but elodea's existing occurrence sites are limited in

geographic scope and therefore not a species that a great number of community members are aware of. Determining this will require more extensive documentation of different Native Alaskan communities' awareness and perceptions of elodea. The ability to achieve this understanding was especially limited by the broad geographic and governance scale of the project and constitutes another important next step for this work.

Such integrative modeling approaches can hold great utility for re-framing how invasion risk assessments and conservation planning is conducted, to more actively address indigenous stakeholder concerns and increase the salience of these mapping efforts for resource-dependent communities. However, these methods still hold the potential to further alienate and disenfranchise local and indigenous stakeholders and should not be understated. When knowledge and stakeholder engagement are mentioned in the broader environmental modeling literature, it tends to be limited in scope or in some instances mere "lip service" paid to popularized buzz words (Voinov & Bosquet 2010: 1268). Yet, even when geospatial applications are inclusive they can foster social exclusion when not addressing things like accountability, empowerment, control, and use of knowledge (Pfeffer et al. 2013). If communities lack the technical skills to conduct and interpret these modeling approaches and are furthermore not using the map outputs, this detracts from some of the key benefits of this work including mobilizing communities for advocacy, environmental education, and self-determination. If academic researchers and resource managers are solely holding the reigns of producing, interpreting, disseminating, and taking action based on these map outputs, "…then the project of integration actually serves to concentrate power in administrative centers, rather than in the hands of aboriginal people" (Nadasdy 1999: 1).

Native Alaskan and Ethiopian pastoral communities are at an added disadvantage with a legacy of disenfranchisement at the hands of governments, land managers, and scientific researchers alike, linked with a string of legal acts that have usurped their rights to the land, water, and wildlife. Addressing these power disparities in part rests with researchers and managers relinquishing absolute control over decision-making and research approaches, as truly participatory work cannot treat communities as "passive beneficiaries" (Mulrennan et al. 2012).

The idea of knowledge in adaptive governance is much more complicated than often shown in the literature and should be critically appraised and problematized. Simply checking a box that additional knowledge sources were considered does not address underlying issues of power, and "as such, any attempt to consciously catalyze AG [adaptive governance] or create windows of opportunity for governance transitions through intervention should be preceded by an explicit analysis of relevant power and politics that may be precipitating environmental and social injustices stemming from the marginalization of minority cultures, religions, worldviews, and environmental ethics" (Chaffin et al. 2014: 63). This is something a growing number of scholars, advocates, communities, and resource managers are attempting to address and therefore it is critical to continue exploring the use of inclusive and novel tools that seek to bring marginalized communities into the problem-definition fold at the beginning of the process and provide multiple opportunities for different forms of knowledge to inform, add to, and critique the process and outputs.

The inherent complexity of SESs requires flexibility in managing for ecological integrity and moving beyond overly simplistic and discipline distinct management approaches. Decision-making in regards to vulnerability and adaptation is place-based and context-specific, requiring the inclusion of local ways of knowing and understanding, which entails the engagement of

141

numerous often competing interests and goals (McNeeley 2009). Environmental impacts of invasive species are equally place-based and context specific (Levine 2000; Pyšek et al. 2012). With a strikingly limited assessment of the interactions between invasive species and ecosystem services that indigenous and rural communities rely on for their livelihoods, novel, transdisciplinary approaches that afford a more nuanced and holistic understanding of coupled SESs are needed. To address vulnerability we need to understand what is happening in a given location, including the internal and external stressors, the ability to adapt, and the priorities and needs of the stakeholders directly affected.

Diverse knowledge framings provide an important understanding of these dimensions, because within the adaptive governance framework, managing for ecological integrity and social resilience "...is about bringing together old knowledge, from diverse sources, into new perspectives for practice...to develop the social capacity to respond to environmental feedback and change" (Folke et al. 2005: 445). Different approaches to participation and stakeholder engagement may contribute greatly to adaptive management (Stringer et al. 2006), and I contend that engaging in both normative participation approaches, such as knowledge co-production, or pragmatic participation approaches, such as knowledge integration can facilitate important arenas for marginalized voices to be heard and enhance adaptive and collaborative management efforts.

Collaboration facilitated by knowledge integration and co-production is critical between diverse indigenous, academic, and management stakeholders. Local and indigenous communities bring insights into their own environment, and unique understandings of their own social and spatial systems, including what things are most important and what has typically worked in the past. Outside researchers can provide understanding of relevant disciplines and other technical

and functional skills. Integrative geospatial modeling can act as a useful and accessible tool for adaptive and collaborative management of ecosystem services and invasive species within an adaptive governance framework. As a researcher engaged in integrative geospatial modeling, I can act as a bridging and boundary-spanning individual, but one that is driven by local and indigenous community concerns and further enhanced by other bridging and boundary-spanning organizations and individuals to achieve these results. Triangulating common concerns and important conservation targets among different stakeholders, combining diverse qualitative and quantitative datasets from these groups, and utilizing advanced geospatial applications provided an important opportunity for identifying regions across a vast landscape in need of targeted monitoring and surveying, which I argue should be collaborative and inclusive of local and indigenous communities if we are to effectively address the growing environmental and social challenges we face on this planet.

References

Abule, E., H.A. Snyman, and G.N. Smit (2005). Comparisons of pastoralists perceptions about rangeland resource utilisation in the Middle Awash Valley of Ethiopia. *Journal of Environmental Management* 75: 21-35.

Adams, L.G., S.D. Farley, C.A. Stricker, D.J. Demma, G.H. Roffler, D.C. Miller, and R.O. Rye (2010). Are inland wolf-ungulate systems influenced by Pacific salmon? *Ecological Applications* 20(1): 251-262.

[ADFG] Alaska Department of Fish and Game (2015). Community Subsistence Information System. Retrieved from: http://www.adfg.alaska.gov/sb/CSIS/. Accessed December 01, 2014.

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

Adger W.N., and P.M. Kelly (1999). Social Vulnerability to Climate Change and the Architecture of Entitlements. *Mitigation and Adaptation Strategies for Global Change* 4: 253-266.

[ADNR] Alaska Department of Natural Resources (2014). Division of Agriculture Plant Materials Center. Personal correspondence. Agustus, G.D.P.S., M. Jayabalan, and G.J. Seiler (2000). *Cryptostegia grandiflora* – A potential multi-use crop. *Industrial Crops and Products* 11: 59-62.

Alatorre, L.C., R. Sánchez-Andrés, S. Cirujano, S. Beguerí, and S. Sánchez-Carillo (2011). Identification of mangrove areas by remote sensing: The ROC curve technique applied to the northwestern Mexico coastal zone using Landsat imagery. *Remote Sensing* 3: 1568-1583.

Alexander, C., N. Bynum, E. Johnson, U. King, T. Mustonen, P. Neofotis, N. Oettlė, C. Rosenzweig, C. Sakakibara, V. Shadrin, M. Vicarelli, J. Waterhouse, and B. Weeks (2011). Linking indigenous and scientific knowledge of climate change. *BioScience* 61(6): 477-484.

Amarnath, G. (2014). An algorithm for rapid flood inundation mapping from optical data using a reflectance differencing technique. *Journal of Flood Risk Management* 7(3): 239-250.

Andersen, D.B. (2007). Local and traditional knowledge of whitefish in the upper Koyukuk River Drainage, Alaska. Research North, Final Report for FIS Project 04-269. Funded by the U.S. Fish and Wildlife Service, Fisheries Resource Monitoring Program, Anchorage.

Andrew, M.E., and S.L. Ustin (2009). Habitat suitability modelling of an invasive plant with advanced remote sensing data. *Diversity and Distributions* 15: 627-640.

Angelstein, S. and H. Schubert (2008). Elodea nuttallii: Uptake, translocation and release of phosphorus. *Aquatic Biology* 3: 209-216.

[ANHP] Alaska Natural Heritage Program (2014). Alaska's Most (Un)Wanted Invaders. Retrieved from: http://aknhp.uaa.alaska.edu/botany/akepic/alaskas-most-wanted-invasive-species/.

Anon. 2001. Weeds of National Significance: the Rubbervine (*Cryptostegia grandiflora*) Strategic Plans. Launceston, Tasmania, Australia: National Weeds Strategy Executive Committee.

Araújo, M.B. and M. New (2007). Ensemble forecasting of species distributions. *TRENDS in Ecology and Evolution* 22(1): 42-47.

Armitage, D.R., R. Plummer, F. Berkes, R.I. Arthur, A.T. Charles, I.J. Davidson-Hunt, A.P. Diduck, N.P. Doubleday, D.S. Johnson, M. Marschcke, P. McConney, E.W. Pinkerton, and E.K. Wollenberg (2009). Adaptive co-management for social-ecological complexity. *Frontiers in Ecology and the Environment* 7(2): 95-102.

Armitage, D., F. Berkes, A. Dale, E. Kocho-Schellenberg, and E. Patton (2011). Co-management and the co-production of knowledge: Learning to adapt in Canada's Arctic. *Global Environmental Change* 21: 995-1004.

Arnold, J.S., and M. Fernandez-Gimenez (2007). Building social capital through participatory research: An analysis of collaboration on Tohono O'odham tribal rangelands in Arizona. *Society and Natural Resources: An International Journal* 20(6): 481-495.

[ASGDC] Alaska State Geo-spatial Data Clearinghouse (2014). Retrieved from: http://www.asgdc.state.ak.us. Accessed November 10, 2014.

Awulachew, S.B., A.D. Yilma, M. Loulseged, W. Loiskandl, M. Ayana, and T. Alamirew (2007). Water Resources and Irrigation Development in Ethiopia. International Water Management Institute, Working Paper 123, Colombo, Sri Lanka.

Bäckstrand, K. (2008). Civic science for sustainability: Reframing the role of experts, policy-makers and citizens in environmental governance. *Global Environmental Politics* 3(4): 24-41.

Bahru, T., Z. Asfaw, and S. Demissew (2012). Indigenous knowledge of plant species of material culture (construction, traditional arts and handicrafts) used by the Afar and Oromo nations in and around the Awash National Park, Ethiopia. *Global Journal of Human Social Science Geography and Environmental Geosciences* 12(11): 1-23.

Ballard, H.L., M.E. Fernandez-Gimenez, and V.E. Sturtevant (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.

Banks, N.C., D.R. Paini, K.L. Bayliss, and M. Hodda (2015). The role of global trade and transport network topology in the human-mediated dispersal of alien species. *Ecology Letters* 18: 188-199.

Barbera, G. (1995). History, economic and agricultural importance. In Barbera, G., Inglese, P., and Pimienta, Z. (eds.) Agroecology, Cultivation and Uses of Cactus Pear. FAO Plant Production Paper No. 132. FAO (Food and Agriculture Organization), Rome.

Beaudreau, A.H., and P.S. Levin (2014). Advancing the use of local ecological knowledge for assessing data-poor species in coastal ecosystems. *Ecological Applications* 24(2): 244-256.

Beebee, J. (1995). Basic concepts and techniques of rapid appraisal. *Human Organization* 54(1): 42-51.

Behnke, R., and C. Kerven (2013). Counting the costs: Replacing pastoralism with irrigated agriculture in the Awash Valley. In Catley, A., J. Lind, and I. Scoones (Eds.) *Pastoralism and Development in Africa: Dynamic Changes at the Margins*. (pp. 57-70). London: Routledge.

Belnap, J., J.A. Ludwig, B.P. Wilcox, J.L. Betancourt, W.R.J. Dean, B.D. Hoffmann, and S.J. Milton (2012). Introduced and invasive species in novel rangeland ecosystems: Friends or foes? *Rangeland & Ecology Management* 65(6): 569-578.

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

Berkes, F., J. Colding, and C. Folke (eds.) (2003). *Navigating Social-Ecological Systems:*

Building Resilience for Complexity and Change. Cambridge: Cambridge University Press.

Berkes, F. (2009). Evolution of co-management: Role of knowledge generation, bridging organizations and social learning. *Journal of Environmental Management*. 1692-1702.

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

Berkes, F., and H. Ross (2013). Community resilience: Toward an integrated approach. *Society and Natural Resources: An International Journal* 26(1): 5-20.

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

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

Biermann, F., M.M. Betsill, S.C. Vieira, J. Gupta, N. Kaine, L. Lebel, D. Liverman, H. Schroeder, B. Siebenhüner, P.Z. Yanda, and R. Zondervan (2010). Navigating the anthropocene: The Earth System Governance Project strategy paper. *Current Opinion in Environmental Sustainability* 2(3): 202-208.

Blaikie, C., S. Craig, B. Gerke, and T. Hofer (2015). Coproducing efficacious medicines. *Current Anthropology* 56(2): 178-204.

Blaschke, T., and G.J. Hay (2001). Object-oriented image analysis and scale-space: Theory and methods for modeling and evaluation multiscale landscape structure. International Archives of Photogrammetry and Remote Sensing 34(4/W5). "Challenges in Geospatial Analysis, Integration and Visualization", Athens, Georgia, USA 29-31 October, 2001.

Boiché, A., P. Gierlinski and G. Thiébaut (2010). Contrasting seasonal patterns in the acceptability of a naturalised and an introduced macrophyte for a generalist shredder. *Fundamental and Applied Limnology* 177(2): 133-141.

Bolker, B.M., M.E. Brooks, C.J. Clark, S.W. Geange, J.R. Poulsen, M.H.H. Stevens, and J.S.S. White (2008). Generalized linear mixed models: A practical guide for ecology and Evolution. *Trends in Ecology and Evolution* 24(3): 127-135.

Bowles, S., and H. Gintis (2002). Social capital and community governance. *The Economic Journal* 112(483): F419-F436.

Boyle, M., J. Kay, and B. Pond (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.

Bradley, B.A., D.M. Blumenthal, R. Early, E.D. Grosholz, J.J. Lawler, L.P. Miller, C.-J.B. Sorte, C.-M. D'Antonio, J.M. Diez, J.S. Dukes, I. Ibanez and J.D. Olden (2012). Global change, global trade, and the next wave of plant invasions. *Frontiers in Ecology and the Environment* 10(1): 20-28.

Breiman, L. (2001). Random forests. *Machine Learning* 45: 5-32.

Bremer, S. and B. Glavovic (2013). Mobilizing knowledge for coastal governance: Re-framing the science-policy interface for integrated coastal management. *Coastal Management* 41(1): 39-56.

Brinkman, T., K.B. Maracle, J. Kelly, M. Vandyke, A. Firmin, and A. Springsteen (2014). Impact of fuel costs on high-latitude subsistence activities. *Ecology and Society* 19(4): 18.

Brosius, J. P., A. L. Tsing, and C. Zerner (2005). *Communities and conservation: histories and politics of community-based natural resource management.* Walnut Creek, California: Rowman Altamira.

Brown, J.R., J.C. Scanlan, and J.G. McIvor (1998). Competition by herbs as a limiting factor in shrub increase: A test with different growth forms. *Journal of Vegetation Science* 9(6): 829–836.

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.

Brown, R.J., C. Brown, N.M. Braem, W.K. Carter III, N. Legere, and L. Slayton (2012). Whitefish Biology, Distribution, and Fisheries in the Yukon and Kuskokwim River Drainages in Alaska: a Synthesis of Available Information. Alaska Fisheries Data Series Number 2012-4. U.S. Fish and Wildlife Service. Technical Report.

Brunner, R.D., T.A. Steelman, C. Coe-Juell, C.M. Cromley, C.M. Edwards, and D.W. Tucker (2005). *Adaptive Governance: Integrating Science, Policy, and Decision Making*. New York: Columbia University Press.

Buck, L.E., C.C. Geisler, J. Schelhas, and E. Wollenberg (2001). *Biological Diversity: Balancing Interests Through Adaptive Collaborative Management*. Boca Raton, FL: CRC Press.

Buckley, Y.M. (2008). The role of research for integrated management of invasive species, invaded landscapes and communities. *Journal of Applied Ecology* 45: 397-402.

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

Butler, J.R.A., A. Tawake, T. Skewes, L. Tawake, and V. McGrath (2012). Integrating traditional ecological knowledge and fisheries management in the Torres Strait, Australia: The catalytic role of turtles and dugong as cultural keystone species. *Ecology and Society* 17(4): 34.

Cadag, J.R.D., and Gaillard, J.C. (2012). Integrating knowledge and actions in disaster risk reduction: The contribution of participatory mapping. *Area* 44(1): 100-109.

[CARE] CARE Ethiopia (2013). Mission and Vision. Retrieved from: http://www.care.org/about/mission-vision. Accessed April 9, 2015.

Carey, M.P., B.L. Sanderson, K.A. Barnas, and J.D. Olden (2012). Native invaders- challenges for science, management, policy and society. *Frontiers in Ecology and the Environment* 10(7): 373-381.

Carlsson, L., and F. Berkes (2005). Co-management: Concepts and methodological implications. *Journal of Environmental Management* 75: 65-76.

Carothers, C., C. Brown, K.J. Moerlein, J.A. Lopez, D.B. Andersen, and B. Retherford (2014). Measuring perceptions of climate change in northern Alaska: Pairing ethnography with cultural consensus analysis. *Ecology and Society* 19(4): 27.

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

Casselman, J.M. and C.A. Lewis (1996). Habitat requirements of northern pike (*Esox lucius*). *Canadian Journal of Fisheries and Aquatic Sciences* 53(Suppl. 1): 161-174.

Catley, A., J. Lind, and I. Scoones (Eds.) (2013). *Pastoralism and Development in Africa: Dynamic Changes at the Margins*. (pp. 57-70). London: Routledge.

Chaffin, B.C., H. Gosnell, and B.A. Cosens (2014). A decade of adaptive governance scholarship: Synthesis and future directions. *Ecology and Society* 19(3): 56.

Chambers, R. (1983). *Rural Development: Putting the Last First*. Longman, London.

Chapin, F.S. III, G.P. Kofinas, and C. Folke (eds.) (2009). *Principles of Ecosystem Stewardship: Resilience-Based Natural Resource Management in a Changing World*. New York:

Springer. Chasek, P., W. Essahli, M. Akhtar-Schuster, L.C. Stringer, and R. Thomas (2011). Integrated land degradation monitoring and assessment: Horizontal knowledge management at the national and international levels. *Land Degradation and Development* 22: 272-284.

Chucholl, C. (2013). Feeding ecology and ecological impact of an alien 'warm-water' omnivore in cold lakes. *Limnologica* 43: 219-229.

Clark, T. (2008). 'We're over-researched here!': Exploring accounts of research fatigue within qualitative research engagements. *Sociology* 42(5): 953-970.

Clark, D.A., and S. Slocombe (2011). Adaptive co-management and grizzly bear-human conflicts in two northern Canadian aboriginal communities. *Human Ecology* 39(5): 627-640.

Clark, J.R.A., and C. Semmahasak (2013). Evaluating adaptive governance approaches to sustainable water management in north-west Thailand. *Environmental Management* 51: 882-869.

Clark, R., A. Ott, M. Rabe, D. Vincent-Lang and D. Woodby (2010). The effects of a changing climate on key habitats in Alaska. Alaska Department of Fish and Game, Special Publication, No. 10-14, Anchorage.

Cochran, P.A.L., C.A. Marshall, C. Garcia-Downing, E. Kendall, D. Cook, L. McCubbin, and R.M.S. Gover (2008). Indigenous ways of knowing: Implications for participatory research and community. *American Journal of Public Health* 98(1): 22-27.

Cohen, J. (2008). The Wildland-Urban Interface Fire Problem: A Consequence of the Fire Exclusion Paradigm. *Forest History Today (Fall 2008)*. Retrived from: http://www.foresthistory.org/publications/FHT/FHTFall2008/Cohen.pdf.

Collins, S.L., S.R. Carpenter, S.M. Swinton, D.E. Orenstein, D.L. Childers, T.L. Gragson, N.B. Grimm, J.M. Grove, S.L. Harlan, J.P. Kayle, A.K. Knapp, G.P. Kofinas, J.J. Magnuson,
W.H. McDowell, J.M. Melack, L.A. Ogden, G.P. Robertson, M.D. Smith, and A.C.Whitmer (2011). An integrated conceptual framework for long-term social-ecological research. *Frontiers in Ecology and the Environment* 9(6): 351-357.

Cook, D.R., G.W. Campbell, and A.R. Meldrum (1990). Suspected Cryptostegia grandiflora (rubber vine) poisoning in horses. *Australian Veterinary Journal* 67(9): 344.

Cote, M., and A.J. Nightingale (2011). Resilience thinking meets social theory: Situating social change in socio-ecological systems (SES) research. *Progress in Human Geography* 00(0): 1-15.

Crall, A.W., C.S. Jarnevich, B. Panke, N. Young, M. Renz, and J. Morisette (2013). Using habitat suitability models to target invasive plant species surveys. *Ecological Applications* 23(1): 60-72.

Crane, T.A. (2010). Of models and meanings: Cultural resilience in social-ecological systems. *Ecology and Society* 15(4): 19.

Crate, S.A. (2006). Elder knowledge and sustainable livelihoods in post-Soviet Russia: Finding dialogue across generations. *Arctic Anthropology* 43(1): 40-51.

Crate, S.A., and A.N. Fedorov (2013). A methodological model for exchanging local and scientific climate change knowledge in northeastern Siberia. *Arctic* 66(3): 338-350.

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

Cutler, R.D., T.C. Edwards Jr., K.H. Beard, A. Cutler, K.T. Hess, J. Gibson, and J.J. Lawler (2007). Random forests for classification in ecology. *Ecology* 88(11): 2783-2792.

Daily, G.C. (1997). Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington.

Dale, A., and D. Armitage (2011). Marine mammal co-management in Canada's Arctic: Knowledge co-production for learning and adaptive capacity. *Marine Policy* 35: 440-449.

Dalton, R. (2006). Awash with fossils. *Nature* 439: 14-16.

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

Danielsen, F., N.D. Burgess, P.M. Jensen, and K. Pirhofer-Walzl (2010). Environmental monitoring: The scale and speed of implementation varies according to the degree of people's involvement. *Journal of Applied Ecology* 47: 1166-1168.

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

Dar, P.A., Z.A. Reshi, and M.A. Shah (2015). Roads act as corridors for the spread of alien plant species in the mountainous regions: A case study of Kashmir Valley, India. *Tropical Ecology* 56(2): 183-190.

Davidson, D.J. (2010). The applicability of the concept of resilience to social systems: Some sources of optimism and nagging doubts. *Society and Natural Resources: An International Journal* 23(12): 1135-1149.

Davies, J., and R. Bennett (2007). Livelihood adaptation to risk: Constraints and opportunities for pastoral development in Ethiopia's Afar region. *The Journal of Development Studies* 43(3): 490-511.

Dietz, T., E. Ostrom, and P. C. Stern (2003). The struggle to govern the commons. *Science* 302:1907-1912.

Di Nino, F., G. Thiébaut and S. Muller (2007). Phenology and phenotypic variation of genetically uniform populations of Elodea nuttallii (Planch.) H. St John at sites of different trophic states. *Fundamental and Applied Limnology* 168(4): 335-343.

Dormann, C.F., J. Elith, S. Bacher, C. Buchmann, G. Carl, G. Carré, J.R. Garcia Marquéz, B. Gruber, B. Lafourcade, P.J. Leitão, T. Münkemüller, C. McClean, P.E. Osborne, B. Reineking, B. Schröder, A.K. Skidmore, D. Zurell, and S. Lautenbach (2013). Collinearity: A review of methods to deal with it and a simulation study evaluating their performance. *Ecography* 36(1): 27-46.

Drew, C.A., Y.F. Wiersma, and F. Huettmann. (eds) (2011). *Predictive Species and Habitat Modeling in Landscape Ecology.* New York: Springer.

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).

Edelenbos, J., A. van Buuren, and N. van Schie (2011). Co-producing knowledge: Joint knowledge production between experts, bureaucrats and stakeholders in Dutch water management projects. *Environmental Science and Policy* 14: 675-684.

Elith, J., J.R. Leathwick, and T. Hastie (2008). A working guide to boosted regression trees. *Journal of Animal Ecology* 77: 802-813.

Elith, J., M. Kearney, and S. Phillips (2010). The art of modelling range-shifting species. *Methods in Ecology and Evolution* 1: 330-342.

Elith, J., S.J. Phillips, T. Hastie, M. Dudík, Y. En Chee, and C.J. Yates (2011). A statistical explanation of MaxEnt for ecologists. *Diversity and Distributions* 17: 43-57.

Ellawala, C., T. Asaeda, and K. Kawamura (2011). Influence of flow turbulence on growth and indole acetic acid and H2O2 metabolism of three aquatic macrophyte species. *Aquatic Ecology* 45: 417-426.

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

[ESAP] Ethiopian Society of Animal Production (2007). Pastoral Livestock Systems: Opportunities and Challenges as a Livelihood Strategy. Tamarat Degefa and Fekede Feyissa (Eds). Proceedings of the 15th Annual conference of the Ethiopian Society of Animal Production (ESAP) held in Addis Ababa, Ethiopia, October 4-6, 2007 Part I Plenary Session. ESAP, Addis Ababa. 82pp.

ESRI (2011). ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Evangelista, P., S. Kumar, T.J. Stohlgren, C.S. Jarnevich, A.W. Crall, J.B. Norman III, and D. Barnett (2008). Modeling invasion for a habitat generalist and a specialist plant species. *Diversity and Distributions* 14: 808-817.

Evangelista, P.H., T.J. Stohlgren, J.T. Morisette, and S. Kumar (2009). Mapping invasive Tamarisk (*Tamarix*): A comparison of single-scene and time-series analyses of remotely sensed data. *Remote Sensing* 1: 519-533.

Evans, J.M., A.C. Wilkie, and J. Burkhardt (2008). Adaptive management of nonnative species: Moving beyond the "either-or" through experimental pluralism. *Journal of Agricultural Environmental Ethics* 21: 521-539.

Evans, J., J. Oakleaf, S. Cushman, and D. Theobald (2014). An ArcGIS Toolbox for Surface Gradient and Geomorphometric Modeling, version 2.0-0. Available: http://evansmurphy.wix.com/evansspatial.

Fagerholm, N., and N. Käyhkö (2009). Participatory mapping and geographical patterns of the social landscape values of rural communities in Zanzibar, Tanzania. *FENNIA International Journal of Geography* 187(1): 43-60.

[Fairbanks CWMA] Fairbanks Cooperative Weed Management Area (2014). Retrieved from: http://www.fairbanksweeds.org.

Fall, J.A., N. Braem, C. Brown, S. Evans, D. Holen, T. Krieg, R. La Vine, T. Lemos, M. Marchioni, L. Hutchinson-Scarborough, L. Still, A. Trainor, and J. Van Lanen (2012). Alaska subsistence salmon fisheries 2009 annual report. Alaska Department of Fish and Game Division of Subsistence, Technical Paper No. 373, Anchorage. 234pp.

Fall J.A., N.M. Braem, C.L. Brown, S.S. Evans, L. Hutchinson-Scarborough, B. Jones, R. La Vine, T. Lemos, M.A. Marchioni, E. Mikow, J.T. Ream, and L.A. Still (2014). Alaska subsistence and personal use salmon fisheries 2012 annual report. Alaska Department of Fish and Game Division of Subsistence, Technical Paper No. 406, Anchorage. 279pp.

Fernandez-Gimenez, M.E., H.P. Huntington, and K.J. Frost (2006). Integration or co-optation? Traditional knowledge and science in the Alaska Beluga Whale Committee. Environmental Conservation 33(4): 306-315.

Fernandez-Gimenez, M.E., and F.F. Estaque (2012). Pyrenean pastoralists' ecological knowledge: Documentation and application to natural resource management and adaptation. *Human Ecology* 40(2): 287-300.

Fields, R.D., and J.D. Reynolds (2011). Sea to sky: Impacts of residual salmon-derived nutrients on estuarine breeding bird communities. *Proceedings of the Royal Society B* 278: 3081-3088.

Filippi, M.E., M. Hordijk, J. Alegría, and J.D. Rojas (2014). Knowledge integration: A step forward? Continuities and changes in Arequipa's water governance system. *Environment and Urbanization* 26(2): 525-546.

Finfgeld, D.L. (2003) Meta-synthesis: the state of the art – so far. *Qualitative Health Research* 13(7): 893–904.

Fisher, R., R. Prabhu, and C. McDougall (Eds.) (2007). *Adaptive Collaborative Management of Community Forests in Asia: Experiences from Nepal, Indonesia, and the Philippines*. Bogor, Indonesia: Center for International Forestry Research (CIFOR).

Flora, J. (1998). Social capital and communities of place. *Rural Sociology* 63(4): 481-506.

Folke, C., S. Carpenter, B. Walker, M. Scheffer, T. Elmqvist, L. Gunderson, and C.S. Holling (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.

Foster, J., and L.A. Sandberg (2004). Friends or foe? Invasive species and public green space in Toronto. *Geographical Review* 94(2): 178-198.

Franklin, J. (2009). *Mapping Species Distributions: Spatial Inference and Prediction*. Cambridge, MA: Cambridge University Press.

Friedman, J.H., and C.B. Roosen (1995). An introduction to multivariate adaptive regression splines. *Statistical Methods in Medical Research* 4: 197-217.

Gadgil, M., F. Berkes, and C. Folke (1993). Indigenous knowledge for biodiversity conservation. *Ambio* 22:151–56.

Gagnon, C.A., and D. Berteaux (2009). Integrating traditional ecological knowledge and ecological science: A question of scale. *Ecology and Society*, 14(2): 19-45.

García-Llorente, M., B. Martín-López, J.A. González, P. Alcorlo, and C. Montes (2008). Social perceptions of the impacts and benefits of invasive alien species: Implications for management. *Biological Conservation* 141: 2969-2983.

Garibay-Orijel, R., A. Ramirez-Terrazo, and M. Ordaz-Velazquez (2012). Women care about local knowledge, experiences from ethnomycology. *Journal of Ethnobiology and Ethnomedicine* 8: 25-36.

Geijzendorffer, I.R., B. Martin-Lopez, and P.K. Roche (2015). Improving the identification of mismatches in ecosystem services assessments. *Ecological Indicators* 52: 320-331.

Getachew, K.N. (2001). *Among the Pastoral Afar in Ethiopia: Tradition, Continuity and Socio-Economic Change*. International Books: the Netherlands.

Gettys, L.A., W.T. Haller and M. Bellaud (eds) (2009). Biology and control of aquatic plants: a best management practices handbook. Aquatic Ecosystem Restoration Foundation, Marietta GA. pp. 210.

Giday, M., and T. Teklehaymanot (2013). Ethnobotanical study of plants used in management of livestock health problems by Afar people of Ada'ar District. Afar Regional State, Ethiopia. *Journal of Ethnobiology and Ethnomedicine* 9: 8-17.

Gilchrist, G., and M.L. Mallory (2007). Comparing expert-based science with local ecological knowledge: What re we afraid of? *Ecology and Society* 12(1): r1-3.

Gilchrist, G., M. Mallory, and F. Merkel (2005). Can local ecological knowledge contribute to wildlife management? Case studies of migratory birds. *Ecology and Society* 10(1): 20-31.

Gobster, P.H. (2005). Invasive species as ecological threat: is restoration an alternative to fear-based resource management? *Ecological Research* 23: 261–270.

Gratani, M., J.R.A. Butler, F. Royee, P. Valentine, D. Burrows, W.I. Canendo, and A.S. Anderson (2011). Is validation of indigenous ecological knowledge a disrespectful process? A case study of traditional fishing poisons and invasive fish management from the wet tropics, Australia. *Ecology and Society* 16(3): 25.

Grêt-Reganmey, A., S.H. Brunner, J. Altwegg, M. Christen, and P. Bebi (2013). Integrating expert knowledge into mapping ecosystem services trade-offs for sustainable forest management. *Ecology and Society* 18(3): 34.

Grice, A.C. (1996). Seed production, dispersal and germination in *Cryptostegia grandiflora* and *Ziziphus mauritiana*, two invasive shrubs in tropical woodlands of northern Australia. *Australian Journal of Ecology* 21(3): 324–331.

Grice, A. (1997) Post-fire regrowth and survival of the invasive tropical shrubs *Cryptostegia grandiflora* and *Ziziphus mauritiana*. *Austral Ecology* 22: 49–55.

Grice, A.C., I.J. Radford, B.N. Abbott, D.M. Nicholas, and L. Whiteman (2008) Impacts of changed fire regimes on tropical riparian vegetation invaded by an exotic vine. *Austral Ecology* 33: 151–167.

Grudnik, Z.M. and M. Germ (2013). Spatial pattern of native species *Myriophyllum spicatum* and invasive *Elodea nuttallii* after introduction of the latter one into the Drava River (Slovenia). *Biologia* 68(2): 202-209.

Guillera-Arroita, G., J.J. Lahoz-Monfort, J. Elith, A. Gordon, H. Kujala, P.E. Lentini, M.A. Mcarthy, R. Tingley, and B.A. Wintle (2015). Is my species distribution model fit for purpose? Matching data and model applications. *Global Ecology and Biogeography* 24: 276-292.

Gunderson, L., and C.S. Holling (Eds.) (2002). *Panarchy: Understanding Transformations in Human and Natural Systems*. Washington, D.C.: Island Press.

Gunderson, L., and S.S. Light (2006). Adaptive management and adaptive governance in the everglades ecosystem. *Policy Sciences* 39: 323-334.

Habermass, J. (1987). *Theory of Communicative Action*. Cambridge, Polity Press.

Hage, M., P. Leroy, and A.C. Petersen (2010). Stakeholder participation in environmental knowledge production. *Futures* 42: 254-264.

Hagemeier-Klose, M., S.A. Beichler, B.J. Davidse, and S. Deppisch (2014). The dynamic knowledge loop: Inter-and transdisciplinary cooperation and adaptation of climate change knowledge. *International Journal of Disaster Risk Science* 5: 21-32.

Hahn, T., P. Olsson, C. Folke, and K. Johansson (2006). Trust-building, knowledge generation and organizational innovations: The role of a bridging organization for adaptive comanagement of a wetland landscape around Kristianstad, Sweden. *Human Ecology* 34: 573-592.

Hamunen, K., O. Virkkula, T. Hujala, J. Hiedanpää, and M. Kurttila (2015). Enhancing informal interaction and knowledge co-construction among forest owners. *Silva Fennica* 49(1): 1-15.

Hartley, T.W., and R.A. Robertson (2008). Stakeholder collaboration in fisheries research: Integrating knowledge among fishing leaders and science partners in northern New England. *Society and Natural Resources: An International Journal* 22(1): 42-55.

Hearne, D., and Powell, B. (2014). Too much of a good thing? Building social capital through knowledge transfer and collaborative networks in the southern Philippines. *International Journal of Water Resource Development* 30(3): 495-514.

Hejda, M., P. Pyšek, and V. Jarošík (2009). Impacts of invasive plants on the species richness,

diversity and the composition of invaded communities. *Journal of Ecology* 97(3): 393-403.

Hernandez, P.A., C.H. Graham, L.L. Master, and D.L. Albert (2006). The effect of sample size and species characteristics on performance of different species distribution modeling methods. *Ecography* 29(5): 773-785.

Herrmann, S.M., I. Sall, and O. Sy (2014). People and pixels in the Sahel: A study linking coarse-resolution remote sensing observations to land users' perceptions of their changing environment in Senegal. *Ecology and Society* 19(3): 29.

Hirzel, A.H., and R. Arlettaz (2003). Modeling habitat suitability for complex species distributions by environmental-distance geometric mean. *Environmental Management* 32(5): 614-623.

Holen, D.L. (2004). The Atna' and the political ecology of the Copper River Fishery, Alaska. *Arctic Anthropology* 41(1): 58-70.

Holling, C.S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology, Evolution, and Systematics* 4:1–23.

Holling, C.S. (1978). *Adaptive Environmental Assessment and Management*. Caldwell, NJ: Blackburn Press.

Huntington, H.P. (1998). Observations on the utility of the semi-directive interview for documenting traditional ecological knowledge. *Arctic* 51: 237-242.

Huotari, T. and H. Korpelainen (2013). Comparative analyses of plastid sequences between native and introduced populations of aquatic weeds *Elodea canadensis* and *E. nuttallii*. *PloS ONE* 8(4): 1-13.

Hussner, A. (2012). Alien aquatic plant species in European countries. *Weed Research* 52: 297-306.

Ingram, J. (2008). Agronomist-farmer knowledge encounters: An analysis of knowledge exchange in the context of best management practices in England. *Agriculture and Human Values* 25: 405-418.

Invasive Species Compendium (2014A). *Egeria densa* (leafy elodea) datasheet: Retrieved from: http://www.cabi.org/isc/datasheet/20491.

Invasive Species Compendium (2014B). *Cryptostegia grandiflora* datasheet: Retrieved from: http://www.cabi.org/isc/datasheet/16378.

[IPCC] Intergovernmental Panel on Climate Change (2013). The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

[IUCN] International Union for the Conservation of Nature (2000). *IUCN Guidelines for the Prevention of Biodiversity Loss caused by Alien Invasive Species*. Information Paper from the Fifth Meeting of the Conference of the Parties to the Convention on Biological Diversity, approved by the 51st Meeting of Council, February 2000. IUCN: Gland.

Jackson, S.E., M.M. Douglas, M.J. Kennard, B.J. Pusey, J. Huddleston, B. Harney, L. Liddy, M. Liddy, R. Liddy, L. Sullivan, B. Huddleston, M. Banderson, A. McMah, and Q. Allsop (2014). "We like to listen to stories about fish": Integrating indigenous ecological and scientific knowledge to inform environmental flow assessments. *Ecology and Society* 19(1): 43.

Jakobsen, C.H., T. Hels, and W.J. McLaughlin (2004). Barriers and facilitators to integration among scientists in transdisciplinary landscape analyses: A cross-country comparison. *Forest Policy and Economics* 6(1): 15-31.

Jarnevich, C., P. Evangelista, T.J. Stohlgren, and J. Morisette (2011). Improving national-scale invasion maps: tamarisk in the Western United States. *Western North American Naturalist* 71(2): 164-175.

Jarnevich, C.S., T.R. Holcombe, E.M. Bella, M.L. Carlson, G. Graziano, M. Lamb, S.S. Seefeldt, and J. Morisette (2014). Cross-scale assessment of potential habitat shifts in a rapidly changing climate. *Invasive Plant Science and Management* 7: 491-502.

Jenoft, S., B.J. McCay, and D.C. Wilson (1998). Social theory and fisheries co-management. *Marine Policy* 22(4-5): 423-436.

Jiménez-Valverde, A., J.M. Lobo and J. Hortal (2008). Not as good as they seem: The importance of concepts in species distribution modelling. *Diversity and Distributions* 14: 885-890.

Johansson, M.A., M. Fetene, A. Malmer, and A. Granström (2012). Tending for cattle: Traditional fire management in Ethiopia montane heathlands. *Ecology and Society* 17(3): 19.

Johnson, N., H. M. Ravnborg, O. Westermann, and K. Probst (2001). User participation in watershed management and research. *Water Policy* 3:507–520.

Johnson, N., L. Alessa, C. Behe, F. Danielsen, S. Gearheard, V. Gofman-Wallingford, A. Kliskey, E. Krümmel, A. Lynch, T. Mustonen, P. Pulsifer, and M. Svoboda (2015). The contributions of community-based monitoring and traditional knowledge to Arctic observing networks: Reflections on the state of the field. *Arctic* 68(1): 1-13.

Joshi, A.A., D. Mudappa, and T.R. Shankar Raman (2015). Invasive alien species in relation to edges and forest structure in tropical rainforest fragments of the Western Ghats. *Tropical Ecology* 56(2): 233-244.

Kalibo, H.W., and K.E. Medley (2007). Participatory resource mapping for adaptive collaborative management at Mt. Kasigau, Kenya. *Landscape and Urban Planning* 82: 145-158.

Kapler, E.J., J.R. Thompson, and M.P. Widrlechner (2012). Assessing stakeholder perspectives of invasive plants to inform risk analysis. *Invasive Plant Science and Management* 5(2): 194-208.

Kebede, F., P.D. Moelman, A. Bekele, and P. Evangelista (2012). Endangered Grevy's zebra in the Alledeghi Wildlife Reserve, Ethiopia: species distribution modeling for the determination of optimum habitat. *Endangered Species Research* 17:237-244.

Kebede, F., P.D. Moelman, A. Bekele, and P. Evangelista (2014). Predicting seasonal habitat suitability for the critically endangered African wild ass in the Danakil, Ethiopia. *African Journal of Ecology* 52(4): 533-542.

Keller, R.P., D.M. Lodge, M.A. Lewis, and F.A. Shogren (eds.) (2009). *Bioeconomics of Invasive Species: Integrating Ecology, Economics, Policy, and Management.* Oxford: Oxford University Press.

Kelly, D.J., and I. Hawes (2005). Effects of invasive macrophytes on littoral-zone productivity and foodweb dynamics in a New Zealand high-country lake. *Journal of the North American Benthological Society* 24(2): 300-320.

Khanum, R., A.S. Mumtaz, and S. Kumar (2013). Predicting impacts of climate change on medicinal asclepiads of Pakistan using Maxent modeling. *Acta Oecologica* 49: 23-31.

Klain, S.C., and K.M.A. Chan (2012). Navigating coastal values: Participatory mapping of ecosystem services for spatial planning. *Ecological Economics* 82: 104-113.

Krauss, M., G. Holton, J. Kerr and C.T. West (2011). Indigenous Peoples and Languages of Alaska. Fairbanks and Anchorage: Alaska Native Language Center and UAA Institute of Social and Economic Research. Retrieved from: http://www.uaf.edu/anla/map.

Kriticos, D.J., R.W. Sutherst, J.R. Brown, S.W. Adkins, and G.F. Maywald (2003). Climate change and biotic invasions: A case history of a tropical woody vine. *Biological Invasions* 5: 145-165.

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.

Kong, T.M., S.E. Marsh, A.F. van Rooyen, K. Kellner, and B.J. Orr (2015). Assessing rangeland condition in the Kalahari Duneveld through local ecological knowledge of livestock farmers and remotely sensed data. *Journal of Arid Environments* 113: 77-86.

Kooiman, J., and M. Bavinck (2005). The governing perspective. In: Kooiman, J., et al. (Eds.), *Fish for Life: Interactive Governance for Fisheries*. Amsterdam University Press, Amsterdam, pp. 11–24.

Langdon, S.J. (2006). Traditional knowledge and harvesting of salmon by *Huna* and *Hinyaa* Tlingit. Final Report, Fisheries Information Service (FIS) Project 02-104.

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

Levine, J.M. (2000). Species diversity and biological invasions, relating local processes to community pattern. *Science* 288: 852-854.

Leys, A.J., and J.K. Vanclay (2011): Social learning: A knowledge and capacity building approach for adaptive co-management of contested landscapes. *Land Use Policy* 28: 574-584.

Liendo, D., I. Biurrun, J.A. Campos, M. Herrera, J. Loidi, and I. Garcia-Mijangos (2015). Invasion patterns in riparian habitats: The role of anthropogenic pressure in temperate streams. *Plant Biosystems* 149(2): 289-297.

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.

Liu, S., A. Sheppard, D. Kriticos, and D. Cook (2011). Incorporating uncertainty and social values in managing invasive alien species: A deliberative multi-criteria evaluation approach. *Biological Invasions* 13: 2323-2337.

Lövbrand, E. (2013). Knowledge and the Environment. *Palgrave Advances in International Environmental Politics:* 1-27.

Low, B., E. Ostrom, C. Simon, and J. Wilson (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.

Lowe S., M. Browne, S. Boudjelas, and M. De Poorter (2000). *100 of the World's Worst Invasive Alien Species A selection from the Global Invasive Species Database*. Published by The Invasive Species Specialist Group (ISSG) a specialist group of the Species Survival Commission (SSC) of the World Conservation Union (IUCN), 12pp.

Luizza, M.W., P. Evangelista, C. Jarnevich, H. Stewart, & A. West (In Review). "Water is our life": Assessing the impacts of invasive *Elodea* spp. On aquatic resources and native

livelihoods in Alaska. *Environmental Management.*

Luizza, M.W., T. Wakie, P. Evangelista, & C. Jarnevich (Accepted). Integrating local pastoral knowledge, participatory mapping, and species distribution modeling for risk assessment of invasive rubber vine (*Cryptostegia grandiflora*) in Ethiopia's Afar region. *Ecology and Society.*

Luizza, M.W., H. Young, C. Kuroiwa, P. Evangelista, A. Worede, R.W. Bussmann, and A. Weimer (2013). Local knowledge of plans and their uses among women in the Bale Mountains, Ethiopia. *Ethnobotany Research and Applications* 11:315-339.

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

Mack, R.N., and M. Erneberg (2002). The United States naturalized flora: Largely the product of deliberate introductions. *Annals of the Missouri Botanical Garden* 89: 176-189.

Mapedza, E., J. Wright, and R. Fawcett (2003). An investigation of land cover change in

Mafungautsi Forest, Zimbabwe, using GIS and participatory mapping. *Applied Geography* 23: 1-21.

Markon, C. J., S. F. Trainor, and F. S. Chapin, III, 2012: The United States National Climate Assessment – Alaska Technical Regional Report. U.S. Geological Survey Circular 1379. 148 pp.

Marshall, C., and G.B. Rossman (2011). *Designing Qualitative Research (Fifth Edition).* Thousand Oaks, CA: Sage Publications.

Marshall, N.A., M. Friedel, R.D. van Klinken, and A.C. Grice (2011). Considering the social dimension of invasive species: The case of buffel grass. *Environmental Science and Policy* 14(3): 327-338.

Mattor, K., M. Betsill, C. Huayhuaca, H. Huber-Stearns, T. Jedd, F. Sternlieb, P. Bixler, M. Luizza, and A.S. Cheng (2014). Transdisciplinary research on environmental governance: A view from the inside. *Environmental Science and Policy* 42: 90-100.

Mauelshagen, C., M. Smith, F. Schiller, D. Denyer, S. Rocks, and S. Pollard (2014). Effective risk governance for environmental policy making: A knowledge management perspective. *Environmental Science and Policy* 41: 23-32.

McFadyen, R.E., and G.J. Harvey (1990). Distribution and control of rubber vine, *Cryptostegia grandiflora*, a major weed in northern Queensland. *Plant Protection Quarterly* 5(4): 152–155.

McLain, R.J., and R.G. Lee (1996). Adaptive management: Promises and pitfalls. *Environmental Management* 20(4): 437-448.

McNeeley, S.M. (2009). Seasons Out of Balance: Climate Change Impacts, Vulnerability and Sustainable Adaptation in Interior Alaska. PhD Dissertation. University of Alaska, Fairbanks. August, 2009.

McNeeley, S.M. and M.D. Shulski (2011). Anatomy of a closing window: Vulnerability to changing seasonality in Interior Alaska. *Global Environmental Change* 21: 464-473.

McIntosh, R.J., J.A. Tainter, S.K. McIntosh (Eds.) (2000). *The Way the Wind Blows: Climate, History, and Human Action*. New York: Columbia University Press.

Mekbeb, E.T., R.J. Lilieholm, D.J. Blahna and L.E. Kruger (2009). Resource use, dependence and vulnerability: Community-resource linkages on Alaska's Tongass National Forest. *Ecosystems and Sustainable Development VII* 122: 263-272.

[MEA] Millennium Ecosystem Assessment (2005). Ecosystems and human well-being: a

framework for assessment. Washington, DC: Island Press.

Médard, Jean-François. "Corruption in the neo-patrimonial states of Sub-Saharan Africa." *Political corruption: Concepts and contexts* 3 (2002): 379-402.

Mekonnen, Y. (1994). A Survey of plants (potentially) toxic to livestock in the Ethiopia flora. *Sinet, an Ethiopian Journal of Science* 17(1): 9-32.

Merriam, S.B., J. Johnson-Bailey, M. Lee, Y. Kee, G. Ntseane, and M. Muhamad (2001). Power and positionality: Negotiating insider/outsider status within and across cultures. *International Journal of Lifelong Education* 20(5): 405-416.

Moncrieff, C.F., and J. Klein (2003). Traditional Ecological Knowledge of Salmon Along the Yukon River. Yukon River Drainage Fisheries Association Report, May 2003. 150pg.

Mooney, H.A. and R.J. Hobbs (eds) (2000). *Invasive Species in a Changing World*. Island Press, Washington D.C.

Morisette, JT., C.S. Jarnevich, T.R. Holcombe, C.B. Talbert, D. Ignizio, M.K. Talbert and N.E. Young (2013). VisTrails SAHM: visualization and workflow management for species habitat modeling. *Ecography 36*(2): 129–135.

Morgan, D.L. (1997). *Focus Groups as Qualitative Research*. Second edition. Sage Books, Thousand Oaks, California, U.S.A.

Mulrennan, M.E., R. Mark, and C.H. Scott (2012). Revamping community-based conservation through participatory research. *The Canadian Geographer* 56(2): 243-259.

Musimba, N.K.R., and S.A. Bariagabre (2003). Cactus (Opuntia ficus-indica) growing as an alternative livelihood in the traditional Tigrian community of Wukro Wereda of arid Eastern Tigray region of Ethiopia. Rangelands in the New Millenium, Proceedings of the 7th International Rangeland Conference, 26-1 August, Durban, South Africa.

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

Nadasdy, P. (2003). *Hunters and Bureaucrats*. Vancouver, BC: UBC Press.

Natcher, D.C., S. Davis, and C.G. Hickey (2005). Co-management: Managing relationships, not resources. *Human Organization* 64(3): 240-250.

Nerbonne, J.F., and Lentz, R. (2003). Rooted in grass: Challenging patterns of knowledge exchanges as a means of fostering social change in a southeast Minnesota farm community. *Agriculture and Human Values* 20: 65-78.

[NISC] National Invasive Species Council (2008). 2008-2012 National Invasive Species Management Plan. 35 pp. Retrieved from: www.invasivespeciesinfo.gov/council/mp2008.pdf.

Nowacki, G., P. Spencer, T. Brock, M. Fleming and T. Jorgenson (2002). Ecoregions of Alaska and Neighboring Territories. U.S. Geological Survey, Washington, D.C. Open File Report 02-297.

Oba, G. (2013). The Sustainability of Pastoral Production in Africa. In Catley, A., J. Lind, and I. Scoones (Eds.) *Pastoralism and Development in Africa: Dynamic Changes at the Margins*. (pp. 29-36) London: Routledge.

Olsson, P., C. Folke, and T. Hahn (2004). Social-ecological transformation for ecosystem management: The development of adaptive co-management of a wetland landscape in southern Sweden. *Ecology and Society* 9(4): 2.

Olsson, L., A. Jerneck, H. Thoren, J. Persson, and D. O'Byrne (2015). Why resilience is unappealing to social science: Theoretical and empirical investigations of the scientific use of resilience. *Science* 1: e1400217.

O'Reilly, K. (2012). *Ethnographic Methods (Second Edition)*. New York, NY: Routledge.

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., M.A. Janssen, J.M. Anderies (2007). Going beyond panaceas. *PNAS* 104(39): 15176-15178.

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

O'Toole, K., and B. Coffey (2013). Exploring the knowledge dynamics associated with coastal adaptation planning. *Coastal Management* 41: 561-575.

Parker, V. (2001). Listening to the Earth: a call for protection and restoration of habitats. In McNeely, J.A. (Ed.) *The Great Reshuffling: Human Dimensions of Invasive Alien Species*. IUCN, Gland, Switzerland and Cambridge, UK. pp. 43.

Patton, M.Q. (2002). *Qualitative Research and Evaluation Methods* (third edition).Thousand Oaks, CA: Sage Publications.

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

Pejchar, L., and H.A. Mooney (2009). Invasive species, ecosystem services and human well-being. *Trends in Ecology and Evolution* 24: 497-504.

Perkins, J., M. Reed, L. Akanyang, J. Atlhopheng, R. Chanda, L. Magole, W. Mphinyane, K. Mulale, R. Sebego, L. Fleskens, B. Irvine, and M. Kirkby (2013). Making land management more sustainable: Experience implementing a new methodological framework in Botswana. *Land Degradation and Development* 24: 463-477.

Peterson, A.T., J. Soberon, R.G. Pearson, R.P. Anderson, E. Martinez-Meyer, M. Nakamura, and M.B. Araujo (2011). *Ecological Niches and Geographic Distributions*. Princeton University Press, Princeton, N.J.

Pfeffer, K., I. Baud, E. Denis, D. Scott, and J. Sydenstricker-Neto (2013). Participatory spatial knowledge management tools: Empowerment and upscaling or exclusion? *Information, Communication and Society* 16(2): 258-285.

Pfeiffer, J.M., and R.J. Butz (2005). Assessing cultural and ecological variation in ethnobiological research: The importance of gender. *Journal of Ethnobiology* 25(2): 240-278.

Phillips, S.J., M. Dudík, and R.E. Schapire (2004). A maximum entropy approach to species distribution modeling. *Proceedings of the* 21st *International Conference on Machine Learning*, Banff, Canada.

Phillips, S.J., R.P. Anderson, and R.E. Schapire (2006). Maximum entropy modeling of species geographic distributions. *Ecological Modelling* 190: 231-259.

Phillips, S.J., M. Dudík, J. Elith, C.H. Graham, A. Lehmann, J. Leathwick, and S. Ferrier (2009). Sample selection bias and presence-only distribution models: implications for background and pseudo-absence data. *Ecological Applications* 19:181–197.

Pickering-Sherman, K., J. Van Lanen, and R.T. Sherman (2010). Practical Environmentalism on the Pine Ridge Reservation: Confronting Structural Constraints to Indigenous Stewardship. *Human Ecology* 38: 507-520.

Pierce Colfer, C.J. (Ed.) (2005). *The Complex Forest: Communities, Uncertainty, and Adaptive Collaborative Management*. Washington, D.C.: Resources for the Future.

Pimentel, D. (2005). Update on the environmental and economic costs associated with alien-invasive species in the U.S. *Ecological Economics* 52: 273-288.

Pinkerton, E.W. (1994). Local fisheries co-management: A review of international experiences and their implications for salmon management in British Columbia. *Canadian Journal of Fisheries and Aquatic Sciences* 51: 2363-2378.

Plummer, R., and D. Armitage (2007). A resilience-based framework for evaluating adaptive co-management: Linking ecology, economics, and society in a complex world. *Ecological Economics*, 61: 62-74.

Plummer, R. (2009). The adaptive co-management process: An initial synthesis of representative models and influential variables. *Ecology and Society* 14(2): 24.

Plummer, R., D.R. Armitage, and R.C. de Loë (2013). Adaptive comanagement and its relationship to environmental governance. *Ecology and Society* 18(1): 21.

Poole, P. (Ed.) (1995). "Geomatics: Who needs it?" *Cultural Survival Quarterly* 18(4): 1-77.

Powell, M.R. (2004). Risk assessment for invasive plant species. *Weed Technology* 18(sp1):1305-1308.

Pretty J., and H. Ward (2001). Social capital and the environment. *World Development* 29:209–227.

Pyšek, P., D.M. Richardson, M. Rejmánek, G.L. Webster, M. Williamson, and J. Kirschner (2004). Alien plants in checklists and floras: towards better communication between taxonomists and ecologists. *Taxon* 53(1): 131-143.

Pyšek, P., V. Jarošík, P.E. Hulme, J. Pergl, M. Hejda, U. Schaffner, and M. Vilà (2012). A global assessment of invasive plant impacts on resident species, communities and ecosystems: The interaction of impact measures, invading species' traits and environment. *Global Change Biology* 18: 1725-1737.

Quinlan, M. (2005). Consideration for collecting freelists in the field: Examples from ethnobotany. *Field Methods* 17(3): 1-16.

Ranjitkar, S., J. Xu, K.K. Shrestha, and R. Kindt (2014). Ensemble forecasting of climate suitability for the Trans-Himalayan Nyctaginaceae species. *Ecological Modelling* 282: 18-24.

Raymond, C.M., I. Fazey, M.S. Reed, L.S. Stringer, G.M. Robinson, and A.C. Evely (2010). Integrating local and scientific knowledge for environmental management. *Journal of Environmental Management* 91: 1766-1777.

Reed, M.S. (2008). Stakeholder participation for environmental management: A literature review. *Biological Conservation 141*: 2417-2431.

Reed, M.S., M. Buenemann, J. Atlhpheng, M. Akhtar-Schuster, F. Bachmann, G. Bastin, H. Bigas, R. Chanda, A.J. Dougill, W. Essahli, A.C. Evely, L. Fleskens, N. Geeson, J.H.Glass, R. Hessel, J. Holden, A.A.R. Ioris, B. Kruger, H.P. Liniger, W. Mphinyane, D. Nainggolan, J. Perkins, C.M. Raymond, C.J. Ritsema, G. Schwilch, R. Sebego, M. Seely, L.C. Stringer, R. Thomas, S. Twomlow, and S. Verzandvoort (2011). Cross-scale monitoring and assessment of land degradation and sustainable land management: A methodological framework for knowledge management. *Land Degradation and Development* 22: 261-271.

Reed, M.S., L.C. Stinger, I. Fazey, A.C. Evely, and J.H.J. Kruijsen (2014). Five principles for the practice of knowledge exchange in environmental management. *Journal of Environmental Management* 146: 337-345.

Refaeilzadeh, P., L. Tang, and H. Liu (2009). Cross-validation. Encyclopedia of Database

Systems. 532-538.

Reid, R. (2012). *Savannas of Our Birth: People, Wildlife, and Change in East Africa.* Berkeley, CA: University of California Press.

Roche, R.C., J.M. Monnington, R.G. Newstead, K. Sambrook, K. Griffith, R.HZ.F. Holt, and S.R. Jenkins (2015). Recreational vessels as a vector for marine non-natives: Developing biosecurity measures and managing risk through an in-water encapsulation system. *Hydrobiologia* 750(1): 187-199.

Rodda, G.H., C.S. Jarnevich, and R.N. Reed (2009). What parts of the U.S. mainland are climatically suitable for invasive alien pythons spreading from Everglades National Park? *Biological Invasions* 11: 241-252.

Rodríguez-Estrella, R., J.J.P. Navarro, B. Granados, and L. Rivera (2010). The distribution of an invasive plant in a fragile ecosystem: The rubber vine (*Cryptostegia grandiflora*) in oases of the Baja California peninsula. *Biological Invasions* 12: 3389-3393.

Rodriguez-Piñeros, S. and D.K. Lewis (2013). Analysis and deliberation as a mechanism to assess changes in preferences for indicators of sustainable forest management: A case study in Puebla, Mexico. *Journal of Environmental Management* 128: 52-61.

Rosenau, J.N. (1995). Governance in the twenty-first century. *Global Governance* 1: 13-43.

Rota, A., and S. Sperandini (2009). Livestock and Pastoralists. International Fund for Agricultural Development (IFAD) Livestock Thematic Papers: Tools for Project Design. Rome, Italy. Retrieved from: http://www.ifad.org/lrkm/factsheet/pastoralists.pdf.

Rupp, T.S. and A. Springsteen (2009). Projected Climate Change Scenarios for the Bureau of Land Management Eastern Interior Management Area, Alaska, 2001-2099. University of Alaska Fairbanks Report. Prepared for U.S. Department of the Interior Bureau of Land Management. 10pp.

Sagoff, M. (2005). Do non-native species threaten the natural environment? *Journal of Agricultural and Environmental Ethics* 18: 215–236.

Sala, O.E., F.S. Chapin III, J.J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. Huber-Sannwald, L. Huenneke, R.B. Jackson, A. Kinzig, R. Leemanns, D.M. Lodge, H.A. Mooney, M. Oesterheld, N.L. Poff, B.H. Sykes, B.H. Walker, M. Walker, and D.H. Wall (2000). Biodiversity scenario for the year 2100. *Science* 287: 1770–1774.

Savory, A. (1988). Holistic Resource Management. Washington DC: Island Press.

Schneider, F., and S. Rist (2014). Envisioning sustainable water futures in a transdisciplinary learning process: Combining normative, explorative, and participatory scenario approaches. *Sustainability Science* 9: 463-481.

Schwörer, T., R. Federer, and H. Ferren (2012). Managing invasive species: How much do we spend? Institute of Social and Economic Research, University of Alaska Anchorage. Retrieved from:
http://www.iser.uaa.alaska.edu/Publications/2012_07-InvasiveSpecies.pdf.

Schusler, T.M., D.J. Decker, and M. Pfeffer (2003). Social Learning for Collaborative Natural Resource Management. *Society Natural Resources*. 16(4): 309-326.

Scott, J.M., D.G. Goble, A.M. Haines, J.A. Wiens, and M.C. Neel (2010). Conservation-reliant species and the future of conservation. *Conservation Letters* 3: 91-97.

Selge, S., A. Fischer, and R, van der Val (2011). Public and professional views on invasive non-native species- A qualitative social scientific investigation. *Biological Conservation* 144: 3089-3097.

Sepulveda, A.J., D.S. Rutz, S.S. Ivey, K.J. Dunker and J.A. Gross (2013). Introduced northern

pike predation on salmonids in southcentral Alaska. *Ecology of Freshwater Fish* 22: 268-279.

Shackleton, S., D. Kirby, and J. Gambiza (2011). Invasive plants- Friends or foes? Contribution of prickly pear (*Opuntia ficus-indica*) to livelihoods in Makana Municipality, Eastern Cape, South Africa. *Development Southern Africa* 28(2): 177-193.

Shaffer, L.J. (2014). Making sense of local climate change in rural Tanzania through knowledge co-production. *Journal of Ethnobiology* 34(3): 315-334.

Shannon M.A. (1991). Resource managers as policy entrepreneurs. *Journal of Forestry* 89: 27–30.

Sillitoe, P. 1998. The development of indigenous knowledge: A new applied anthropology. *Current Anthropology*, 39(2): 223-252.

Simberloff, D. (2009). The role of propagule pressure in biological invasions. *Annual Review of Ecology, Evolution, and Systematics* 40: 81-102.

Smith, D.A. (2003). Participatory mapping of community lands and hunting yields among the Buglé of western Panama. *Human Organization* 62(4): 332-343.

[SNAP] Scenarios Network for Alaska Planning (2015) Alaska Climate Datasets. http://www.snap.uaf.edu/gis-maps. Accessed February 19, 2015.

Snover, A.K., N.J. Mantua, J.S. Littell, M.A. Alexander, M.M. McClure, and J. Nye (2013). Choosing and using climate-change scenarios for ecological-impact assessments and conservation decisions. *Conservation Biology* 27(6): 1147-1157.

Sonneveld, B.G.J.S.. M.A. Keyzer, K. Georgis, S. Pande, A. Seid Ali, and A. Takele (2009). Following the Afar: Using remote tracking systems to analyze pastoralists' trekking routes. *Journal of Arid Environments* 73: 1046-1050.

Sonneveld, B.G.J.S., S. Pande, K. Georgis, M.A. Keyzer, A. Seid Ali, and A. Takele (2010). Land Degradation and Overgrazing in the Afar Region, Ethiopia: A Spatial Analysis. In Zdruli, P., M. Pagliai, S. Kapur, and A. Faz Cano (eds.) Land Degradation and Desertification: Assessment, Mitigation and Remediation. London-New York: Springer. pp. 97-109.

[SRC] Stokholm Resilience Centre (2012). Adaptive Governance. Retrieved from: http://www.stockholmresilience.org/research/researchthemes/adaptivegovernance.4.aeea.4.aeea46911a3127427980006994.html.

Springer, A.C., D.E. Swann, and M.A. Crimmins (2015). Climate change impacts on high elevation saguaro range expansion. *Journal of Arid Environments* 116: 57-62.

Star, S.L. (2010). This is not a boundary object: Reflections on the origin of a concept. *Science, Technology and Human Values* 35(5): 601-617.

Stem, C., R. Margoluis, N. Salafsky, and M. Brown (2005). Monitoring and evaluation in conservation: A review of trends and approaches. *Conservation Biology* 19(2): 295-309.

Sternlieb, F., R.P. Bixler, H. Huber-Stearns, and C. Huayhuaca (2013). A question of fit: Reflections on boundaries, organizations and social-ecological systems. *Journal of Environmental Management* 130: 117-125.

Stewart, B.C., K. E. Kunkel, L. E. Stevens, L. Sun, and J. E. Walsh (2013): Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 7. Climate of Alaska. NOAA Technical Report NESDIS 142-7. 60 pp.

Stohlgren, T.J., and J.L. Schnase (2006). Risk analysis for biological hazards: What we need to know about invasive species. *Risk Analysis* 26(1): 163-173.

Stohlgren, T.J., P. Ma, S. Kumar, M. Rocca, J.T. Morisette, C.S. Jarnevich, and N. Benson

(2010). Ensemble habitat mapping of invasive plant species. *Risk Analysis* 30(2): 224-235.

Suich, H. (2010). The livelihoods impacts of Namibian community based natural resource management programme: A meta-synthesis. *Environmental Conservation* 37(1): 45-53.

Talbert, C. and M. Talbert (2012). User documentation for the Software for Assisted Habitat Modeling (SAHM) package in VisTrails. Fort Collins, CO: USGS Fort Collins Science Center. 69 p. Retrieved from: https://www.fort.usgs.gov/products/23399/.

Tengö, M., E.S. Brondizio, T. Elmqvist, P. Malmer, and M. Spierenburg (2014). Connecting diverse knowledge systems for enhanced ecosystem governance: The multiple evidence base approach. *AMBIO* 43: 579-591.

Thomson, A.M., K.V. Calvin, S.J. Smith, G.P. Kyle, A. Volke, P. Patel, S. Delgado-Arias, B. Bond-Lamberty, M.A. Wise, L.E. Clarke, and J.A. Edmonds (2011). RCP4.5: A pathway for stabilization of radiative forcing by 2100. *Climatic Change* 109: 77-94.

Thorne, S., L. Jensen, M.H. Kearney, G. Noblit, and M. Sandelowski. (2004) Qualitative meta-synthesis: reflections on methodological orientation and ideological agenda. *Qualitative Health Research* 14(10): 1342–1365.

Thuiller, W., D.M. Richardson, and G.F. Midgley (2007). *Will Climate Change Promote Alien Plant Invasions?* In W. Nentwig (Ed.) Biological Invasions, Ecological Studies, Vol. 193. Springer-Verlag. pp. 197-211.

Titeca, K., and T. Vervisch (2008). The dynamics of social capital and community associations in Uganda: Linking capital and its consequences. *World Development* 36(11): 2205-2222.

Tikssa, M., T. Bekele, and E. Kelbessa (2009). Plant community distribution and variation along the Awash River corridor in the main Ethiopian rift. *African Journal of Ecology* 48: 21-28.

Tomley, A.J. (1995). The biology of Australian weeds. 26. Cryptostegia grandiflora R. Br. *Plant Protection Quarterly* 10(4): 122-130.

Trimble, M., and F. Berkes (2013). Participatory research towards co-management: Lessons from artisanal fisheries in coastal Uruguay. *Journal of Environmental Management* 128: 768-778.

Trimble, M., and Lázaro (2014). Evaluation criteria for participatory research: Insights from coastal Uruguay. *Environmental Management* 54: 122-137.

Tsegaye, D., S.R. Moe, P. Vedeld, E. Aynekulu (2010). Land-use/cover dynamics in northern Afar rangelands, Ethiopia. *Agriculture, Ecosystems and Environment* 139: 174-180.

Tsegaye, D., P. Vedeld, and S.R. Moe (2013). Pastoralists and livelihoods: A case study from northern Afar, Ethiopia. *Journal of Arid Environments* 91: 138-146.

Tucker, C.J. (1979). Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment* 8:127–150.

[UNED] United Nations Conference on Environment and Development. Rio de Janerio, Brazil, 3 to 14 June 1992. Agenda 21, Chapter 35.5. Retrieved from: https://sustainabledevelopment.un.org/content/documents/Agenda21.pdf.

[UNEP] United Nations Environment Programme 2012 Conference on Sustainable Development. Nairobi, Kenya, 23 to 27 June 2012. Agenda 21, Chapter 26.3 Retrieved from: http://www.unep.org/Documents.Multilingual/Default.Print.asp?DocumentID=52&ArticleID=74.

Ungar, P., and R. Strand (2012). Inclusive protected area management in the Amazon: The

importance of social networks over ecological knowledge. *Sustainability* 4: 3260-3278.

Urgenson, L.S., H.E. Prozesky, and K.J. Esler (2013). Stakeholder perceptions of an ecosystem service approach to clearing invasive alien plants on private land. *Ecology and Society* 18(1): 26-38.

[USAID] U.S. Agency for International Development (2014). Misson, Visons and Values. Retrieved from: http://www.usaid.gov/who-we-are/mission-vision-values. Accessed April 9, 2015.

[USFWS] U.S. Fish and Wildlife Service (2014). Yukon Flats National Wildlife Refuge. Personal correspondence.

Vercessi, L. (2013). Alaska salmon fisheries enhancement program 2012 annual report. Fishery Management Report No. 13-05. Alaska Department of Fish and Game Division of Sport Fish and Commercial Fisheries.

Vilà, M., C. Basnou, P. Pyšek, M. Josefsson, P. Genovesi, S. Gollasch, W. Nentwig, S. Olenin, A. Roques, D. Roy, P.E. Hulme, and DAISE partners (2010). How well do we understand the impacts of alien species on ecosystem services? A pan-European, cross taxa assessment. *Frontiers in Ecology and the Environment* 8: 135-144.

Vitousek, P.M. (1990). Biological invasions and ecosystem processes: Toward integration of population biology and ecosystem studies. *Oikos* 57: 7-13.

Vitousek, P. M., H.A. Mooney, J. Lubchenco, and J.M. Melillo (1997). Human domination of Earth's ecosystems. *Science* 277: 494–499.

Voinov, A., and F. Bousquet (2010). Modelling with stakeholders. *Environmental Modelling and Software* 25: 1268-1281.

Wagner, C.L., and Fernandez-Gimenez (2008). Does community-based collaborative resource management increase social capital? *Society and Natural Resources: An International Journal* 21(4): 324-344.

Walker, B., S. Carpenter, J. Anderies, N. Abel, G. Cumming, M. Janssen, L. Lebel, J. Norberg, G.D. Peterson, and R. Pritchard (2002). Resilience management in social-ecological systems: A working hypothesis for a participatory approach. *Conservation Ecology* 6(1): 14.

Walker, B.H., C.S. Holling, S.R. Carpenter, and A.P. Kinzig (2004). Resilience, adaptability and transformability in social-ecological systems. *Ecology and Society* 9(2): 5.

Walsh J.E., W.L. Chapman, V. Romanovsky, J.H. Christensen, and M. Stendel (2008) Global climate model performance over Alaska and Greenland. *Journal of Climate* 21: 6156–6174.

Walters, C.J. (1986). *Adaptive Management of Renewable Resources*. New York, NY: McGraw Hill.

Wakie, T., P. Evangelista, C. Jarnevich, and M. Laituri (2014). Mapping current and potential invasion of *Prosopis juliflora* in the Afar Region of Ethiopia. *PLOS ONE* 9(11): e112854.

Way, E. (2013). Understanding Research Fatigue in the Context of Community-University Relations. Local Knowledge: Worcester Area Community-Based Research. Paper 3. Retrived from: http://commons.clarku.edu/localknowledge/3.

Weiss, K., M. Hamann, and H. Marsh (2013). Bridging knowledges: Understanding and applying indigenous and western scientific knowledge for marine wildlife management. *Society and Natural Resources: An International Journal* 26(3): 285-302.

Weller, S.C.and A.K. Romney (1988). *Systematic Data Collection*. Newbury Park, CA: Sage.

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.

White, P.C.L., A.E.S. Ford, M.N. Clout, R.M. Engeman, S. Roy, and G. Saunders (2008). Alien invasive vertebrates in ecosystems: Pattern, process and the social dimension. *Wildlife Research* 35: 171-179.

Wilhere, G.F. (2002). Adaptive Management in Habitat Conservation Plans. *Conservation Biology* 16: 20–29.

Willow, A.J. (2013). Doing sovereignty in Native North America: Anishinaabe counter-mapping and the struggle for land-based self-determination. *Human Ecology* 41: 871-884.

Wilson, R.R., J.R. Liebezeit, and W.M. Loya (2013). Accounting for uncertainty in oil and gas development impacts to wildlife in Alaska. *Conservation Letters* 6(5): 350-358.

Wisz, M.S., R.J. Hijmans, J. Li, A.T. Peterson, C.H. Graham, A. Guisan, and NCEAS Predicting Species Distribution Working Group (2008). Effects of sample size on the performance of species distribution models. *Diversity and Distributions* 14: 763-773.

With, K.A. (2004). Assessing the risk of invasive spread in fragmented landscapes. *Risk Analysis* 24(4): 803-815.

Wondolleck J.M., and S.L. Yaffee (2000). *Making Collaboration Work: Lessons from Innovation in Natural Resource Management*. Washington, DC: Island.

Wyborn, C. (2015). Co-productive governance: A relational framework for adaptive governance. *Global Environmental Change* 30: 56-67.

Yohannes, T., T. Awas, and S. Demissew (2011). Survey and documentation of the potential and actual invasive alien plant species and other biological threats to biodiversity in Awash National Park, Ethiopia. *Management of Biological Invasions* 2: 3-14.

Zia, A., P. Hirsch, A. Songorwa, D.R. Mutekanga. S. O'Connor, T. McShane, P. Brosius, and B. Norton (2011). Cross-scale value trade-offs in managing social-ecological systems: The politics of scale in Ruaha National Park, Tanzania. *Ecology and Society* 16(4): 7.

Zurlini, G., I. Petrosillo, K.B. Jones, B. Li, K.H. Riitters, P. Medgali, S. Marchiori, and N. Zaccarelli (2013). Towards the planning and design of disturbance patterns across scales to counter biological invasions. *Journal of Environmental Management* 128: 192-203.

Appendix 1

Full list of predictor variables considered in the ensemble models. Note: BIO2 (Mean Diurnal Range) and BIO3 (Isothermality) were not included, as these calculations require minimum and maximum values, which the Alaska-specific SNAP climate data does not provide, rather

Bioclimatic Predictor Variables
BIO1- Annual Mean Temperature
BIO4- Temperature Seasonality
BIO5- Mean Temperature of Warmest Month
BIO6- Mean Temperature of Coldest Month
BIO7- Temperature Annual Range
BIO8- Mean Temperature of Wettest Quarter
BIO9- Mean Temperature of Driest Quarter
BIO10- Mean Temperature of Warmest Quarter*
BIO11- Mean Temperature of Coldest Quarter*
BIO12- Annual Precipitation
BIO13- Precipitation of Wettest Month
BIO14- Precipitation of Driest Month
BIO15- Precipitation Seasonality
BIO16- Precipitation of Wettest Quarter
BIO17- Precipitation of Driest Quarter
BIO18- Precipitation of Warmest Quarter*
BIO19- Precipitation of Coldest Quarter
BIO20- Permafrost

Appendix 2
Predictor variable response curves for the current climate suitability ensemble, including Mean Temperature of Warmest Quarter (BIO10), Mean Temperature of Coldest Quarter (BIO11), and Precipitation of Warmest Quarter (BIO18). The X-axis is a range of temperature or precipitation values for a given predictor variable starting with the minimum value and ending with the maximum value and the Y-axis is the suitability index.
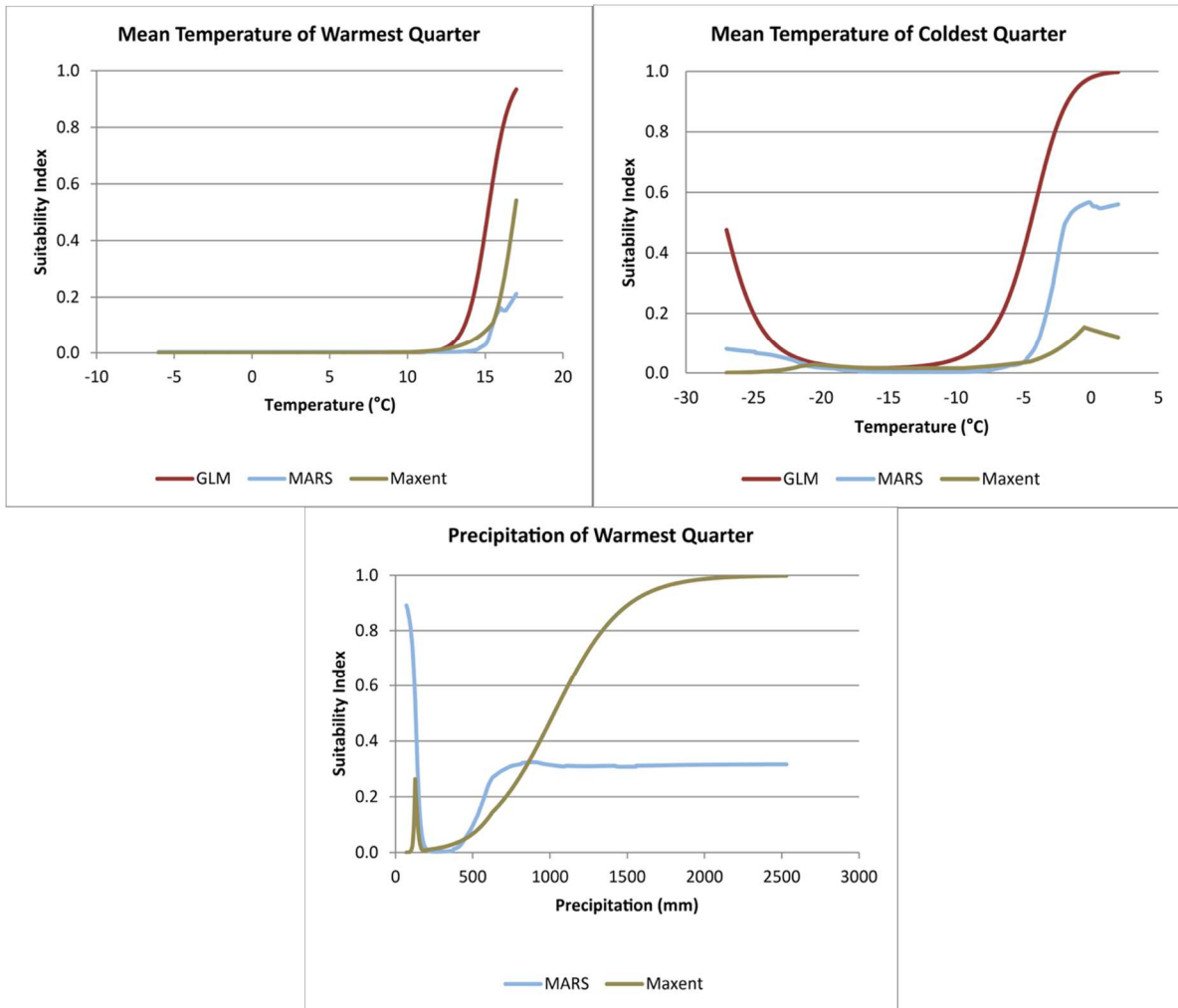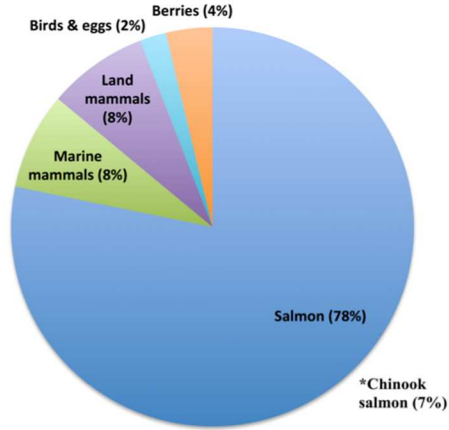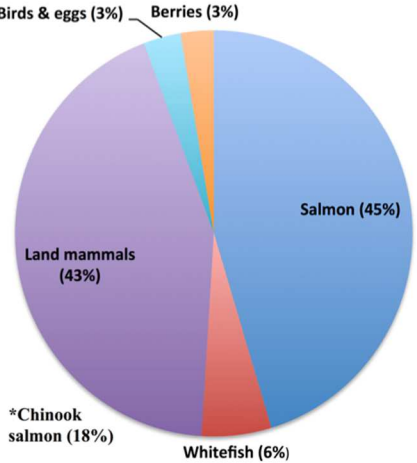
Appendix 3
SAHM Covariate Correlation and Selection Matrix (Final Ensemble
Model).
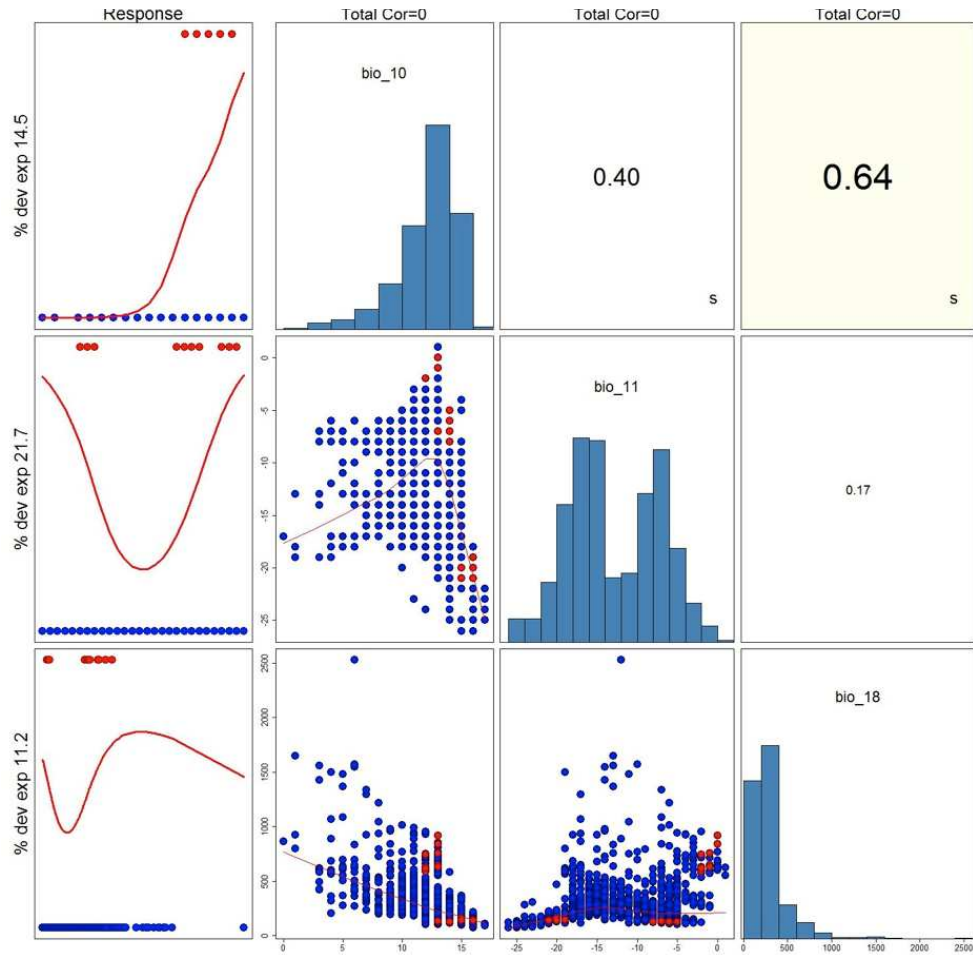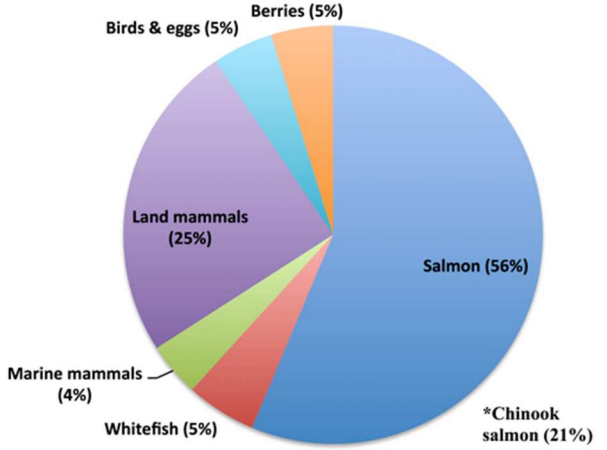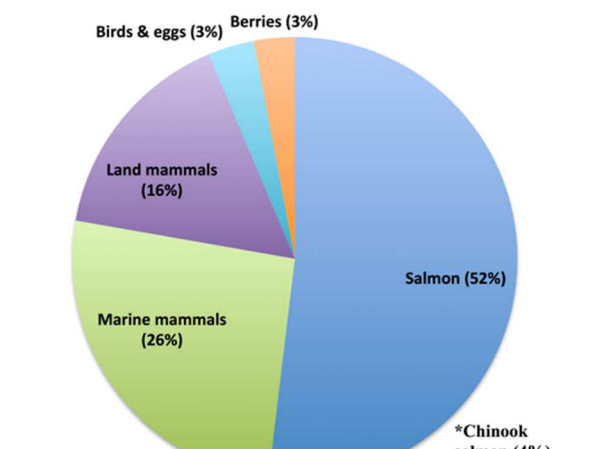
Appendix 4
Qualitative and quantitative triangulation of Native Alaskan subsistence practices.

Cultural/Linguistic Group	Subsistence Practices (*sources)	Alaska Fish and Game Subsistence Survey Data	Relative Risk of Elodea Impacts
Alutiiq/Sugpiaq	Pacific salmon, marine mammals, halibut, marine mollusks, caribou *Salomon et al. (2007), Reedy-Maschner (2013), Reedy & Maschner (2014)	Berries (4%), Birds & eggs (2%), Land mammals (8%), Marine mammals (8%), Salmon (78%), *Chinook salmon (7%)	Current climate: **(Low to Moderate)**. Chinook and whitefish make up 7% of subsistence harvest. Regions of high climate suitability for elodea restricted to the Kenai Peninsula where known infestations exist. Future climate: **(Moderate)**. High climate suitability for elodea predicted by all 5 GCMs across the entire Alutiiq/Sugpiaq region by 2040-2059.
Athabascan	Moose, caribou, Pacific salmon, bear, water fowl, berries, whitefish *McNeeley (2009), Brown et al. (2012), Van Lanen et al. (2012), Brinkman et al. (2014)	Birds & eggs (3%), Berries (3%), Salmon (45%), Land mammals (43%), *Chinook salmon (18%), Whitefish (6%)	Current climate: **(Moderate to High)**. Chinook and whitefish make up 24% of subsistence harvest. Region of high climate suitability for elodea in the Yukon Flats which contains a major lake district and the confluence of a number of major rivers for the state, in addition to the Kenai Peninsula. Future climate: **(High)**: Increased climate suitability for elodea predicted by all 5 GCMs across the Athabascan region by 2040-2059.

| Inupiaq | Marine mammals, whitefish, birds and eggs, dolly varden, caribou, Pacific salmon (pink and chum)

*Moore et al. (2007), Brown et al. (2012), Moerlein & Carothers (2012), Carothers et al. (2013) |
Berries (2%)
Birds & eggs (2%)
Salmon (14%)
Whitefish (11%)
Land mammals (36%)
Marine mammals (35%) | Current climate: (**Low**). Whitefish make up 11% of subsistence harvest. Chinook salmon makes up 0%. No GCMs predict high climate suitability for elodea in this region.

Future climate: (**Low**). Small pockets of high climate suitability for elodea predicted by all 5 GCMs by 2040-2059 do not coincide with any recorded Chinook salmon or whitefish spawning and rearing sites. |
| Southeastern Tribes | Pacific salmon, halibut, steelhead, marine mammals, bird eggs, berries, moose, deer, mountain goat

*Betts & Wolfe (1992), Langdon (2006) |
Birds & eggs (1%)
Berries (9%)
Land mammals (29%)
Salmon (54%)
Marine mammals (7%)
*Chinook salmon (9%) | Current climate: (**Low to Moderate**). Chinook salmon makes up 9% of subsistence harvest. Whitefish make up 0%. Regions of high climate suitability for elodea span the region, but few recorded Chinook salmon spawning and rearing sites.

Future climate: (**Low to Moderate**). Increased climate suitability for elodea predicted by all 5 GCMs across the region by 2040-2059, but few recorded Chinook salmon spawning and rearing sites are present. |

Yup'ik	Marine mammals, Pacific salmon, water fowl, moose, caribou, bird eggs, berries, roots, whitefish * Zavaleta (1999), Brown et al. (2012), Kolahdooz et al. (2014)		Current climate: (**Low**). Chinook salmon and whitefish make up 26% of subsistence harvest. No areas of high climate suitability for elodea predicted for the region. Future climate: (**Moderate to High**): Increased climate suitability for elodea predicted by all 5 GCMs across southern stretches of the region by 2040-2059.
Unangan (Aleut)	Marine mammals, Pacific salmon, water fowl, halibut, marine mollusks, cod * Duncan et al. (2014), Reedy & Maschner (2014), Young et al. (2014)		Current climate: (**Low**). Chinook salmon makes up 4% of subsistence harvest. Whitefish make up 0%. No regions of high climate suitability for elodea exist. Future climate: (**Low to Moderate**). Increased climate suitability for elodea predicted by all 5 GCMs across the region by 2040-2059, but few recorded Chinook salmon spawning and rearing sites are present.

170

Pastoralist Perceptions and Use of Invasive Mesquite (*Prosopis juliflora*): Utilization Assessment and Documentation of Local Knowledge of Mesquite and Ecosystem Services in Northeastern Ethiopia

Verbal Consent Script

The Research Study

Hello. My name is (*interviewer state name*). Thank you for speaking with me today. I am from Colorado State University in the United States of America. We are inviting you to take part in a research study. Please ask me to explain anything you do not understand. You can ask questions now or anytime during the study. You will have a chance to ask questions before you make your decision. We are looking for local men and women to help with our research project. For this research we are collecting information on the beneficial economic uses of mesquite as well as its negative impacts in Afar.

Your Help

I am asking you to be in a group interview (or we can talk talk privately) to help identify beneficial economic uses of mesquite as well as its negative impacts in Afar, and provide information on local plants and animals. The interview will take around four hours and is voluntary. You may stop at any time. And you may skip any question that you do not want to answer. We will share our research results with you. You may or may not benefit from being in the study. But we hope it will help your community with local concerns about plants and animals in the area. Knowledge we gain from this study may benefit others in the future.

Risks

There are no known risks to being a part of this study. Our team will do everything possible to protect the health and safety of everyone helping us with this project. Your name will not be written down or used in our reports. No personal information of yours will be shared with other people of groups outside of our team.

Questions

If you have any questions please ask me. I will also give you the name and contact information for local team members, and team members at the university in the United States: Tewodros Wakie (Colorado State University, United States of America): tdwakie@gmail.com, Matthew Luizza (Colorado State University, United States of America): mwluizza@rams.colostate.edu, Paul Evangelista (Colorado State University, United States of America): paulevan@nrel.colostate.edu, Emebet Abera W/Senbet (Addis Ababa): +251-0910145507, emebetabera28@yahoo.com, and Dr. Amanuel Kassie (Addis Ababa): +251-0911408276.

Will you be a part of the interview?

Interview Protocol

A series of 11 semi-structured focus group interviews will be conducted with men and women from rural pastoral communities located in the Afar region of northeastern Ethiopia. A focus group approach will be conducted to afford diverse perspectives simultaneously, allow unanticipated information to emerge, and facilitate a rapid appraisal approach. Focus groups of 2-4 people will be conducted at each of the 11 research sites (approximately 44 respondents total), and will encompass two full weeks (April 28, 2014 through May 11, 2014), with each focus group interview lasting approximately four hours.

A series of open-ended questions will be asked that are grouped into the following categories: Landscape-Scale Changes, Plants and Animals, *Prosopis* Economics, Water, and Governance. These questions will be followed by two participatory mapping activities focusing on water features and invasive species and how the village interacts with them:

Part 1: Participants will be provided with two sets of satellite image and/or semi-transparent mylar topographic maps. The first set will be at the community/village scale, and the other will be at the scale of the surrounding region. The group will then discuss and decided what types of water-related features to map and what symbols will be used to represent them. Once this is established, participants will begin marking and labeling water access points and water-related features—first on the community-scale maps, and then on the regional maps. As the maps are marked, each feature will have a number of attributes recorded using the provided template (see page 13 of this document).

When the group is satisfied with the water features, they will be asked to mark at least five landmarks on the satellite image. These will be located in the field and marked with GPS units to serve as ground control points for eventual digitizing and geo-referencing of the drawn maps. The resultant digitized maps and tabular data will be incorporated into a Geographic Information System for use in geospatial analysis and map creation.

Part 2: Participants will be asked to add to the water feature sketch maps, additionally depicting existing locations of the globally invasive mesquite species *Prosopis juliflora*, and how the local pastoral community interacts with the species at each site.

Participants will be provided with the same satellite image and/or topographic map from the water features mapping exercise and will be asked to additionally mark and label existing *Prosopis juliflora* locations and their relation to other landscape features and community assets as described in the questionnaire (see page 14 of this document). These images/maps will later be digitized and incorporated into a Geographic Information System for use in geospatial analysis and map creation.

Interview Questions

Location _____

Date _____

Land Cover Category (farmland, grassland, rangeland; if more than one, answer for the category where *Prosopis* is of most concern)

Study Site *Prosopis* Density Class (Scattered (less than 20%), Moderate (20-40%), Dense (over 40%))

Demographics (list for all respondents in focus group)

---

1. Gender: Male   Female

2. Age: 15-20 21-25 26-30 31-35 36-40 41-45 46-50 51-55 56-60 60+

3. Primary Occupation (Pastoralist, Agro-pastoralist, Farmer)

4. Were you born from here? If not, when and why did you move here?

5. How many people are in your household?

6. Do you have children?   Yes   No   How many? _____

Landscape-Scale Changes

1. Are there changes to nature which you have observed in your community during your lifetime, for
example, changes in plants, water, soils, or wildlife?

2. What do you think caused this change?

3. Has the timing of the seasons changed over time?

Seasons: Note which have changed

Early wet	Wet	Late wet	Early	Dry	Late dry

4. If yes, how has it changed?

7. If no to #6, describe how it varies (e.g. early, later, shorter, longer)?

8. Is the amount of rain different?

9. Does flooding and/or drought happen more or less, or is less predictable?

10. Does this affect your livestock and/or crops?

5. When do the rains come? Jan Feb Mar Apr
May Jun Jul Aug Sep Oct Nov Dec   11. Does this affect wildlife?

6. Is it the same time every year?

Plants and Animals

1. Do you use plants for medicine or go to the doctor?

2. Are there plants that you consider bad? Are any of these new to the region?

3. Are any of these plants taking the place of useful plants and cannot be controlled?

4. What are the most important plants to you?

5. Why are they important?

6. What type of wood do you prefer to burn?

7. What wildlife are beneficial to you and why?

8. What wildlife are harmful and why?

9. Is there anything we didn't ask regarding plants and animals in the area that you'd like to share?

Participatory Mapping

Participants will be provided with a satellite image and/or topographic map of the region and asked to mark and label water access points and water-related features described in the questionnaire.

SAHM Covariate Correlation and Selection Matrix (Final Model) for
invasive rubber vine model, Afar, Ethiopia.
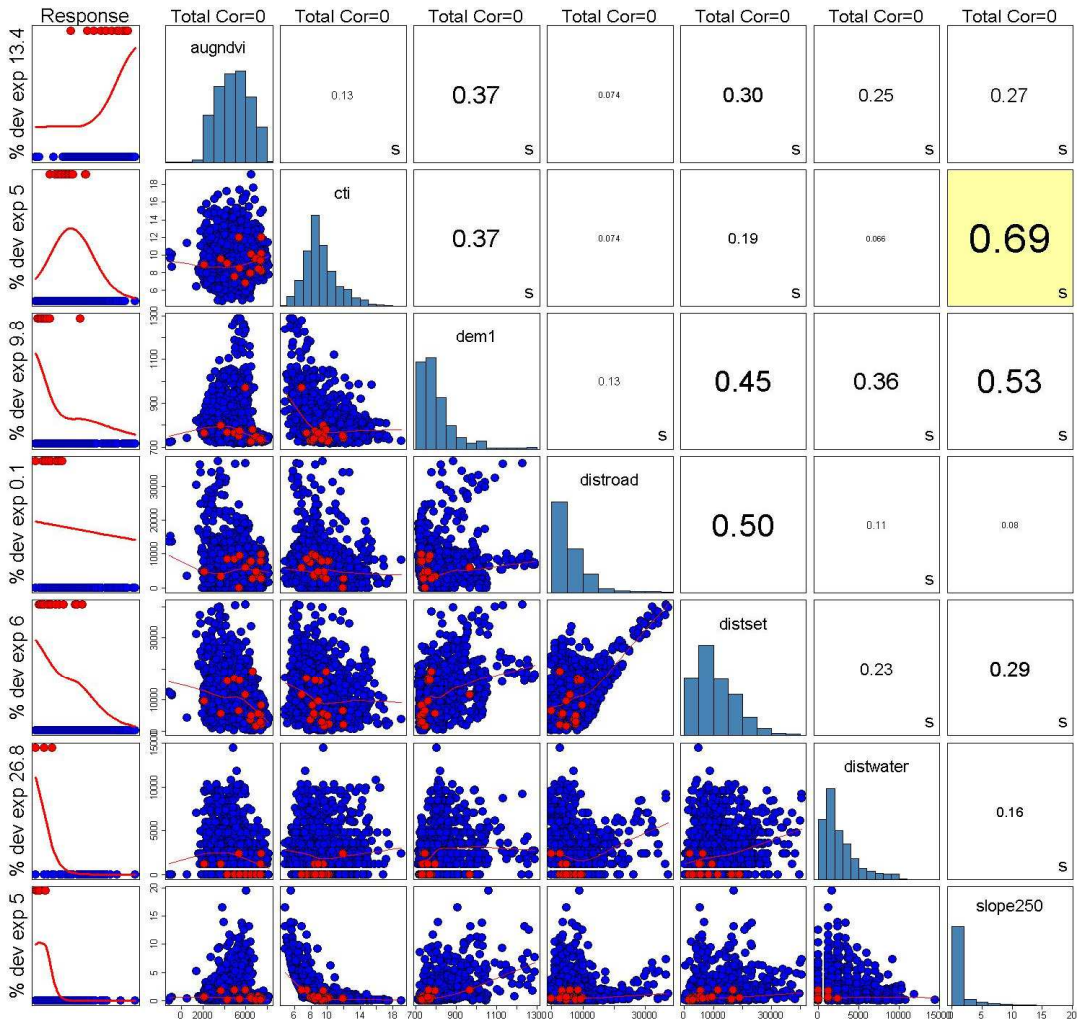
Most important native trees used by Afar pastoralists for firewood. Trees listed in order of importance (determined by focus group participants) with scientific name, local Afar name and all provisioning ecosystem services provided (uses) listed.

Scientific Name	Afar Name	Uses	Notes
Acacia nilotica	**Keselto**	Firewood, charcoal, construction, forage, medicinal, other (shade).	One of the preferred firewood and charcoal sources (including high-end hookah charcoal). Bole and branches used in house construction. Pods, leaves and flowers critical forage source for livestock and wildlife. Bark ground, mixed with water, and applied to snake bite wounds.
Acacia senegal	**Adado**	Firewood, charcoal, construction, food, forage.	Number one charcoal source. Provides forage for livestock (especially camels and goats). Used to build strong fences to protect livestock. Produces edible gum that is mixed with camel's milk and consumed.
Combretum aculeatum	**Kilaito**	Firewood, charcoal, medicinal, cosmetic, forage, fodder.	Leaves, pods and flowers important forage source for livestock and wildlife. Leaves cut and gathered as fodder for all livestock. Wood is burned and a person allows the smoke to cover their body for skin health and beautification.
Acacia tortilis	**Ehebto**	Firewood, charcoal, construction, forage, other (shade).	Bole and branches used in used in house construction. Pods, leaves and flowers provide forage for livestock and wildlife.
Acacia mellifera	**Maka'arto**	Firewood, charcoal, construction, forage.	Provides forage for livestock (especially camels and goats) and wildlife. Used to build houses and fences to protect livestock.
Cordia spp.	**Mederto**	Firewood, construction, food, other (walking/herding/fighting sticks and rope).	Preferred firewood source but also used to start fires (sticks rubbed together). Used in construction of traditional Afar homes called **Afar arri** or **arri orburra**. Preferred source of walking/herding/fighting sticks. Bark used to make rope. Produces edible fruits.
Salvadora persica	**Adayto**	Firewood, medicinal, forage, other (toothbrush).	Has antibacterial and antiseptic compounds used for overall oral health and to treat oral ailments.

			Provides forage for livestock (especially camels and goats) and wildlife.
Cadaba rotundifolia	**Adengeli**	Firewood, medicinal, veterinary, forage, other (milk storage).	Leaves crushed and snorted or chewed to alleviate cold symptoms, asthma, or headaches. Ingested to combat any gastrointestinal issues. Leaves chewed and the paste applied to open wounds of people and livestock to assist the healing process. Critical source of drought forage (especially camels). Branches burned and smoke used to fumigate milk containers and improve the taste of milk.

Maxent Jackknife validation assessment model output, including area under the receiver-operating curve (AUC) and percent contribution of model predictor variables for each model.

Model Run	AUC	Variable Contribution
Model 1	0.644	Distance to water (78%), Distance to roads (10%), August NDVI (9%), Slope (2%), Elevation (1%), Distance to settlements, (0%), CTI (0%).
Model 2	0.998	Distance to water (75%), August NDVI (12%), Distance to roads (10%), Slope (2%), Elevation (1%), Distance to settlements, (0%), CTI (0%).
Model 3	0.989	Distance to water (73%), August NDVI (12%), Distance to roads (10%), Slope (3%), Elevation (2%), Distance to settlements, (0%), CTI (0%).
Model 4	0.792	Distance to water (62%), August NDVI (24%), Distance to roads (8%), Slope (5%), Elevation (1%), Distance to settlements, (0%), CTI (0%).
Model 5	0.980	Distance to water (73%), August NDVI (11%), Distance to roads (12%), Slope (3%), Elevation (1%), Distance to settlements, (0%), CTI (0%).
Model 6	0.931	Distance to water (68%), August NDVI (15%), Distance to roads (11%), Elevation (3%), Slope (3%), Distance to settlements, (0%), CTI (0%).
Model 7	0.964	Distance to water (71%), August NDVI (18%), Distance to roads (9%), Slope (2%), Elevation (0%), Distance to settlements, (0%), CTI (0%).
Model 8	0.262	Distance to water (66%), Distance to roads (17%), August NDVI (14%), Slope (2%), CTI (1%), Distance to settlements, (0%), Elevation (0%).
Model 9	0.927	Distance to water (69%), August NDVI (13%), Distance to roads (9%), slope (7%), Elevation (2%), Distance to settlements, (0%), CTI (0%).
Model 10	0.972	Distance to water (72%), August NDVI (12%), Distance to roads (9%), Slope (4%), Elevation (3%), Distance to settlements, (0%), CTI (0%).
Model 11	0.458	Distance to water (64%), August NDVI (13%), Elevation (12%), Distance to roads (8%), Slope (3%), Distance to settlements, (0%), CTI (0%).
Model 12	0.830	Distance to water (76%), Distance to roads (10%), August NDVI (10%), Slope (3%), Elevation (1%), Distance to settlements, (0%), CTI (0%).
Model 13	0.883	Distance to water (65%), August NDVI (24%), Distance to roads (8%), Slope (3%), Elevation (0%), Distance to settlements, (0%),

		CTI (0%).
Model 14	0.529	Distance to water (68%), August NDVI (20%), Distance to roads (8%), Slope (2%), Elevation (2%), Distance to settlements, (0%), CTI (0%).
Model 15	0.891	Distance to water (68%), August NDVI (13%), Distance to roads (9%), Slope (7%), Elevation (3%), Distance to settlements, (0%), CTI (0%).
Model 16	0.846	Distance to water (65%), August NDVI (20%), Distance to roads (10%), Slope (3%), Elevation (2%), Distance to settlements, (0%), CTI (0%).
Model 17	0.967	Distance to water (71%), August NDVI (17%), Distance to roads (9%), Slope (2%), Elevation (1%), Distance to settlements, (0%), CTI (0%).
Model 18	0.479	Distance to water (69%), August NDVI (21%), Distance to roads (7%), Slope (2%), Elevation (1%), Distance to settlements, (0%), CTI (0%).

Overview of the geographic location, stakeholder arrangement, research methods and key findings of all 45 knowledge integration and knowledge co-production case studies assessed and my two dissertation cases. TEK= traditional ecological knowledge, LEK= local ecological knowledge, IK= indigenous knowledge, and NGO= non-governmental organization.

Study Location	Mechanism(s)	Stakeholders	Methods	Findings	Citation
United States	Evaluation of **knowledge integration** (LEK and conventional science) for a sustainable agriculture monitoring team	Farmers, university and agency researchers, and non-profit staff	Interviews, field notes, and content analysis	Knowledge integration provided opportunity for empowerment through sharing of LEK and valuing of alternative knowledge systems by scientific researchers. Trust building between stakeholders a key result of process. Major challenges still existed throughout process linked with distinct worldviews and epistemologies between scientific researchers and farmers.	Nerbonne et al. (2003)
Russia	**Knowledge integration** (TEK) of village elders into community definitions of sustainability	Local communities and research scientists	Focus groups, interviews, and surveys	TEK integration of elder community members was shown to bolster local sustainability definitions and goals, as well as enhance inter-generational knowledge transfer between community elders and youth.	Crate (2006)
United States	Evaluation of **knowledge integration** (TEK and conventional science) for applied co-management research	Research scientists, land managers and Native Alaskan hunters	Interviews, participant observation, document analysis and workshops	Various roles of TEK integration. Strong dissemination of integrated research findings. Genuine power sharing promoted successful integration. Inclusion of TEK in all phases of research and long-term relationship building afforded multiple opportunities for informal interactions between stakeholders (enhanced trust-building and transparency). Some conflicts between different observations of conventional science and TEK. Potential for co-option of knowledge still exists based on underlying power imbalances.	Fernandez-Gimenez et al. (2006)
Sweden	Evaluation of local knowledge generation and	Government officials (local, regional and	Interviews, historical document analysis	Flexible organizational structure of municipal wetland group and strong leadership (enhanced by vertical and horizontal	Hahn et al. (2006)

	integration with a municipal wetland group for adaptive co-management processes	national), organization staff, local farmers and landowners, and national non-profits		institutional linkages) facilitated knowledge generation and created an arena for enhanced trust-building, conflict resolution, and collaborative learning. Informal nature of organization makes it potentially vulnerable, as no legal mandates exist and all collaboration related to organization is voluntary.	
Kenya	**Knowledge integration** (LEK) for biodiversity conservation and adaptive collaborative management	Local farmers and research scientists	Participatory mapping, transect walks with photo documentation and recorded narratives	LEK integration of men and women through participatory mapping and photo documentation revealed gendered distinctions in how people valued and portrayed the local landscape based in part on different resource use patterns. Historical timelines relayed important cultural resources and changes on the landscape. Process enhanced understanding of resource diversity and links to local livelihoods.	Kalibo & Medley (2007)
United States	Evaluation of **knowledge integration** (LEK and conventional science) for ecological stewardship and monitoring among 7 community forestry efforts	Community residents, community forestry organization staff, scientists, migrant workers, university researchers, land managers, Native American tribes, environmental organizations, loggers	Interviews, participant observation, document analysis and workshops	Collaboration on joint reports between community members and scientists. Redistribution of power through diverse knowledge sources. Traditionally underrepresented groups still having limited knowledge integration and involvement.	Ballard et al. (2008)
United States	Evaluation of **knowledge integration** (LEK and conventional science) for fisheries management	Local fishers, commercial fishers, and research scientists	Surveys	Survey results revealed that a vast majority of stakeholders felt LEK integration very important to bring fishermen's information experience, and expertise into the scientific framework for necessary management and that cooperative research is beneficial, but not overwhelmingly convinced it can be achieved due to lack of trust and communication between fishermen and scientists.	Hartley & Robertson (2008)
United	Evaluation of	Local farmers and	Semi-structured	Knowledge exchange and integration	Ingram (2008)

Kingdom	knowledge exchange and **integration** (LEK and conventional science) for sustainable farming practices	private agricultural advisors (agronomists)	interviews	processes noted to often be characterized by power imbalances (in favor of agronomists), distrust and the divergence of knowledge (steeped in opposing values). Some instances based in dialogue and knowledge sharing/integration, provided opportunities for mutual learning and adoption of legitimized knowledge into farming practices.	
Canada	Evaluation of **knowledge integration** (TEK and conventional scientific) knowledge about arctic fox and snow goose ecology for a co-management effort	First Nations tribes and land managers	Workshops, semi-directive interviews, mapping, focus groups, participatory observations, and an elders-youth camp	Complementarity of integrating TEK and conventional science across spatial and temporal scales. Knowledge comparison expanded the spatial and temporal scales of documented scientific knowledge about both species. Facilitated generation of new insights and new hypotheses. Did raise some tensions around distrust of goose ecologists by tribal members who feel their studies have disrupted the birds.	Gagnon & Berteaux (2009)
Kenya, Switzerland, Bolivia and Nepal	Evaluation of **knowledge co-production** and the role of researchers within sustainability projects	Local community members (farmers, agro-pastoralists), NGOs, scientific researchers, government representatives	Case study comparison	Knowledge integration as an important part of co-production process. Different roles of researchers as "reflective scientist" (facilitating common understanding and incorporating local knowledge), "intermediary" (bridging different stakeholder concerns and approaches around common issue) and "facilitator of a joint learning process" (reconciling different worldviews). Sustainable development provides a crucial normative framework for co-production. Sustainability researchers acting as boundary organization for knowledge co-production between scientific and non-scientific communities.	Pohl et al. (2010)
United Kingdom, Solomon Islands, and Australia	Evaluation of **knowledge integration** (LEK and conventional science) for	Local stakeholders, research scientists, and resource managers	Comparative case-study analysis	Knowledge integration is a complex process. No single optimum approach for integrating LEK and conventional science. Needs to be a shift from seeking knowledge integration products to developing problem-focused	Raymond et al. (2010)

	environmental management			knowledge integration processes that are reflexive, systematic and include multiple views and methods.	
Panel on Indigenous Peoples and Climate Change (multiple Arctic communities)	**Knowledge integration** (indigenous observations of climate change and global climate assessment data)	Arctic tribal representatives, indigenous knowledge scholars, climate scientists	Indigenous knowledge (IK) documentation and collating of IK narratives with peer-reviewed scientific studies. Narratives overlaid on GIS map of climate change impact studies from 1970- 2004	Complementarity of integrating indigenous knowledge (IK) with Global climate assessments, which have largely excluded IK from their reports. IK filling in gaps of conventional science by providing important information on climate patterns in regions with limited instrumental records. Narratives provide needed human dimension to climate change research, a voice to resource dependent communities and insight into adaptive strategies.	Alexander et al. (2011)
Canada	Evaluation of **knowledge co-production** as a mechanism for learning and adaptation in a co-management arrangement	Inuit and Inuvialuit community members, resource managers and government officials	Interviews, participant observation and document analysis	Importance of long-term commitment to institutional building, diverse modes of interaction, deliberation and communication. Knowledge integration noted to be a dimension of knowledge co-production, but the latter having greater potential to avoid simple knowledge without meaningful participation.	Armitage et al. (2011)
Canada	Evaluation of **knowledge integration** (TEK and conventional science) for adaptive co-management of grizzly bear-human conflict	Aboriginal hunter and trapper committees, Wildlife Management councils, Territorial governments	Interviews	Horizontal and vertical institutional connections and leadership important for facilitating knowledge integration.	Clark & Slocombe (2011)
Canada	Evaluation of **knowledge co-production** for building adaptive capacity within a co-management arrangement	Inuit communities and resource managers	Interviews	Knowledge co-production enhanced channels of communication, built trust, fostered the formation of problem solving networks and facilitated social learning, but it is a long-term investment. Knowledge integration acted as an important dimension of co-production. Compartmentalized views of knowledge and	Dale & Armitage (2011)

				top-down management approaches pose barriers to adaptive and collaborative management.	
Netherlands	Evaluation of **knowledge co-production** for effective water management	Scientists, civil servants and policy makers and local citizens	Comparative case study with participant observation, document analysis and interviews	Inherent challenges for engaging in knowledge co-production between local citizens and other stakeholders, leading to issues of legitimacy in policy relevant knowledge production and decision-making. Resistance to incorporate citizen knowledge in decision-making by policy-makers. Knowledge co-production occurred between other stakeholders due to discipline congruence and institutionalized relationships.	Edelenbos et al. (2011)
Australia	**Knowledge integration** and validation (IK and western science) for invasive fish management within a co-management arrangement	Aboriginal elders and research scientists	Interviews and laboratory experiments	Knowledge validation project initiated by aboriginal elders and not deemed as disrespectful, but empowering and necessary for their knowledge to be understood and appreciated by scientists. Process of knowledge socialization whereby new knowledge goes through steps of comprehension, contextualization and valuation, built trust and mutual respect. Argue for importance of collaborative cultural cross validation (not just one-sided evaluation of IK), which could result in knowledge co-production.	Gratani et al. (2011)
Australia	Evaluation of **knowledge integration** (TEK and western science) for fisheries management in an emerging co-management arrangement	Melanesian local fishers, fishery managers and scientists	Surveys	Different application of knowledge integration across fisheries. Importance of cultural keystone species (provide significant ecosystem services for communities and international conservation interests) for stimulating cross-cultural resource adaptive governance and potential local co-management efforts.	Butler et al. (2012)

Philippines	**Knowledge integration** (LEK and conventional science) for flood risk assessment and disaster risk reduction planning	Community members, local and municipal government, regional NGO, research scientists	Participatory mapping	Participatory mapping facilitated the broad understanding of geo-referenced data and the incorporation of LEK and scientific knowledge about vulnerability through collaborative learning. Foundation of trust and communication key for engaging a wide array of stakeholders. Process empowered the most marginalized people by providing access to scientific knowledge and legitimizing their LEK.	Cadag & Gaillard (2012)
Ethiopia	Traditional ecological knowledge documentation and **integration** for fire management plan development	Local pastoralists and research scientists	Interviews, field observations, and landscape level vegetation age structure analysis	TEK of pastoralists revealed high level of understanding regarding fire behavior and effects. Observations and vegetation analyses corroborated sustainable nature of traditional burning practices that is based on community needs of increasing grazing value, controlling a toxic caterpillar, and reducing predator attacks, but also provides important firebreaks and diverse vegetation mosaic. TEK could inform sanctioned government management fire planning.	Johansson et al. (2012)
Canada	**Knowledge co-production** (TEK and conventional science) for enhanced community-based participatory research	First Nation community members and research scientists	Interviews, workshops, participant observation, and field-based surveys	Knowledge co-production, in concert with a community-defined research agenda, collaborative equitable partnerships at all phases of research, an emphasis on local relevance, and a long-term commitment, fostered critical basis for enacting environmental protection and strengthening local institutions. Key outcome being knowledge exchange within and beyond the native community.	Mulrennan et al. (2012)
Colombia	Ethnographic evaluation of **knowledge co-production** for decision-making efforts in a co-management arrangement	Scientific researchers, park staff and indigenous Tikuna community members	Participant observation, focus groups, informal interviews, workshops	No evidence of co-produced knowledge informing management. Management efforts not built on open deliberation around collectively created knowledge, but rather a need to create, maintain or mobilize multi-scale social networks to respond to crises and long-term social-ecological dynamics. Noticeable lack of trust between many stakeholders. Importance of understanding	Ungar & Strand (2012)

					socio-political underpinnings.	
Russia	**Knowledge integration** (LEK and conventional science) for enhanced climate change knowledge exchange	Native agropastoralists and research scientists	Focus groups, interviews, surveys, and comparison of community perceptions with regional climate change data		Knowledge integration and participatory knowledge exchange process proved beneficial for more quickly fostering understanding among stakeholders of global and local levels of climate change impacts on landscapes and livelihoods.	Crate & Fedorov (2013)
Switzerland	**Knowledge integration** (LEK) into spatially explicit valuation of forest ecosystem services	Scientific researchers, environmental economists, local farming community experts	Surveys, mapping workshops, GIS-based Bayesian Networks		Iterative process important for improving ecosystem services value maps and reduced uncertainty by filling in data gaps. Enhanced mutual learning that could foster adaptive resource management and understanding of valuation of forest ecosystem services under land use and climate change impacts.	Gret-Reganmey et al. (2013)
Australia	Evaluation of knowledge exchange dynamics and **integration** for coastal adaptation planning	State and local government, research scientists, NGOs, community groups, coastal catchment representatives, and industry representatives	Semi-structured interviews		Knowledge exchange and integration greatly limited. Divergence in views of legitimacy of different forms of knowledge for decision-making, with knowledge heavily fragmented across sources that do not engage one another or openly share information. Need for more social and collaborative learning processes and move away from linear, technocratic, top-down knowledge transfer, to integrating diverse knowledge forms.	O'Toole & Coffey (2013)
Uruguay	Evaluation of participatory research as a **knowledge co-production** approach	Artisanal fishers, government, university and NGO members	Participant observation, interviews and workshops		Participatory research enhanced trust building, shared learning and knowledge co-production among stakeholders. This is argued to potentially pave the way towards future co-management arrangements. Knowledge integration noted to be a critical part of knowledge co-production, to facilitate trust-building and mutual respect, which are needed for power and responsibility sharing in co-management arrangements.	Trimble & Berkes (2013)
Botswana	**Knowledge integration** (LEK,	Local tribal communities,	Interviews, workshops,		LEK integration important for defining sustainability goals and understanding drivers	Perkins et al. (2013)

189

	and conventional science) for the Desertification Mitigation and Remediation of Land Project	scientific researchers	participatory modeling, and process-based modeling	of desertification. Scientific knowledge provided insights into degradation indicators. Modeling provided important scenario analyses including scope and impacts for implementing projects like biogas production. Challenges to this approach include high poverty and illiteracy rates, slowing the initiation of projects and local technology access.	
Mexico	**Knowledge integration** (LEK) of communal forest owners for sustainable forest management	Local land owners and research scientists	Surveys and interviews	Incorporating LEK of communal forest owners through a deliberative and iterative setting (multiple engagements at different stages of the process) revealed shifts in forest owners' preferences about sustainable forest management indicators. Importance of a participatory process that promoted shared learning.	Rodriguez-Piñeros & Lewis (2013)
Australia	Evaluating the utility of **knowledge integration** and interpretation (IK) for marine wildlife co-management	Indigenous and non-indigenous Australian resource managers, government policy makers and academic researchers	Interviews	Indigenous and non-indigenous managers noted the utility of empirical information within indigenous and western knowledge systems. Long-term relationships built on trust and frequent communication critical. Argue that increasing respect for different ways of knowing will enhance collaborative co-management efforts.	Weiss et al. (2013)
United States	Quantitative modeling approach to **knowledge integration** (LEK) and evaluation of variance in fisheries observations	Local fishers and divers and scientific researchers	Interviews and bootstrapping and statistical modeling	Synthesizing LEK over 70 year period proved to be a valuable source of ecological information. Variation in local knowledge existed based of age group and information environments (characterized by how, when and where individuals acquired ecological information). Arguably this holistic nature of including diverse knowledge sources could overcome some issues of "shifting baseline syndrome" due to lack of long-term ecological data that may lead to misconceptions about the ecological integrity of a given system.	Beaudreau & Levin (2014)
Alaska	**Knowledge**	Iñupiat and	Participant	TEK consensus was found to be highly	Carothers et al.

	integration (TEK) for measuring perceptions of climate change and related impacts on subsistence practices	Athabascan communities and scientific researchers	observations, interviews, and cultural consensus analysis	consistent in regards to local perceptions of a broad range of changes impacting subsistence practices, but variation existed within communities regarding certain observations (i.e. precipitation patterns). Combining cultural consensus and detailed ethnography noted to be an important tool for resource management.	(2014)
Peru	Evaluation of **knowledge integration** (LEK) for a river basin council	Farmers, government, and mining representatives	Interviews, participatory mapping, and a workshop	Incremental changes have been made through greater stakeholder participation but traditional power structures have not changed (including heavy mining influence). Knowledge integration not occurring in a meaningful way due to barriers such as a lack of dialogue and divergent views of water as "commodity" versus "social" or socio-ecological good", but could offer an opportunity to transform governance if engaged.	Filippi et al. (2014)
Germany	**Knowledge integration** (conventional science across fields) for climate scenario planning	Research scientists and government agencies	Workshops, focus groups, interviews, and participatory mapping	Scenario planning process facilitated social learning through a platform of diverse knowledge integration and exchange (from distinct epistemologies) and may enhance adaptive capacity. Collaborative process further enhanced by participatory mapping exercises.	Hagemeier-Klose et al. (2014)
Phillipines	Evaluation of **knowledge integration** (TEK and conventional science) for integrated water management	Members of civil society, public, academic, corporate, and other sectors (not defined)	Interviews and surveys	Evidence of integration of TEK and scientific knowledge into local decision-making. Critical nature of social capital, linked with leadership and flexible institutional network. These things facilitated creating a shared vision for management among stakeholders. High bonding social capital but need for more bridging relationships. Stakeholder dialogue and participatory networks deemed important.	Hearne & Powell (2014)
Senegal	**Knowledge integration** (LEK) of local land users with remote sensing imagery to	Researchers and local land users (agricultural, pastoral, and agro-pastoral)	Time series of remote sensing imagery, participatory methods (focus	LEK of land users corroborated re-greening trends (reversing of desertification) found in remote sensing analyses, but challenged dominant assumptions of re-greening overall improving the landscape. Instead degradation	Herrmann et al. (2014)

	understand perceptions and trends in land degradation and desertification		groups, mapping and matrix scoring)	a common theme related to undesired shifts in species compositions. Revealed importance of LEK for interpreting remote sensing trends and assisting with monitoring and rehabilitation efforts.	
Australia	Evaluation of **knowledge integration** (IK and conventional science) for improved water planning/ management	University research scientists and indigenous landowners from three language groups	Focus groups and interviews	Comparison of knowledge systems revealed both to compliment each other. New knowledge was generated for both scientific and indigenous participants (knowledge co-production coming out of integration process). Process enhanced scientific knowledge of fish species but also provided opportunities for indigenous landowners to share stories about fish, including their cultural significance and assisted in building community capacity to contribute to water management planning.	Jackson et al. (2014)
United Kingdom	Evaluation of **knowledge integration** (agency knowledge) within a central government department for environmental risk governance	Employees across different teams within the central government department	Semi-structured interviews	Lateral knowledge integration across teams working in different policy areas found to be key source of new knowledge and learning (facilitated by open, informal communication and collaboration). Governance structures focused on centralized and vertical knowledge transfer do not support this informal knowledge transfer and integration. Potential vulnerability of knowledge loss with staff turnover.	Mauelshagen et al. (2014)
United Kingdom	Evaluation of local and expert knowledge exchange, generation, and **integration** across 13 environmental management research projects	Project experts (project managers, academic researchers, and non-academic stakeholders)	Document analysis, expert workshop, and interviews	Evaluation produced a set of research principles for conducting knowledge exchange, generation and integration work that need to be designed into research, including the needs of diverse stakeholders being systematically represented, and long-term relationships built on trust and open dialogue between researchers and stakeholders to produce new knowledge. Process must be flexible, monitored and adapted.	Reed et al. (2014)
Switzerland	Evaluation of **knowledge co-**	Community members,	Participatory observations and	Meaningful deliberative dialogue and knowledge co-production coming out of	Schneider & Rist (2014)

192

	production for transdiciplinary water governance	recreation managers and scientists	scenario planning, rapid appraisals, focus groups	transdisciplinary process. Iterative process that brought knowledge back to stakeholders at multiple cycles facilitated learning and trust building. Requires great flexibility of stakeholders and creating conditions where different forms of knowledge are on equal footing.	
Tanzania	Evaluation of **Knowledge co-production** for local scale climate change monitoring	U.S. and Tanzanian researchers and local communities	Participatory data collection and analysis. Scientific observations analyzed in light of TEK. Interviews	Much congruence between TEK and conventional scientific observations. Empowered communities to explore local climate adaptation and policy-making and facilitated sharing of information between districts. Trust critical to support an environment conducive of knowledge co-production.	Shaffer (2014)
Uruguay	Evaluation of **knowledge co-production** (LEK and conventional science) for a coastal artisanal fishery case	Local fishers, government representatives, academic researchers, and NGO representatives	Case study process evaluation, interviews, and workshops	Participatory research approaches, which involved interested stakeholders at all stages of the research, collective decision-making through deliberation and adaptability through iterative cycles, produced positive outcomes of knowledge co-production, learning, strengthened social networks, and conflict resolution.	Trimble & Lazaro (2014)
Tibet	**Knowledge co-production** (diverse practitioner knowledge) for preserving and enhancing traditional Tibetan medicinal practices	Traditional Tibetan medicine practitioners and scientific researchers	Workshop (collaborative event ethnography), participant observation, and interviews	Knowledge co-production platform facilitated shared learning as well as co-generation of tangible and intangible things (shared knowledge and medicines). Mutual respect for different forms of knowledge, flexibility and adaptability in how the process was conducted, a neutral workshop site, and use of Tibetan language provided added opportunities for enhanced knowledge co-production and empower participants.	Blaikie et al. (2015)
Finland	Evaluation of knowledge sharing and **co-production** (LEK and conventional science) for	Forest owners and forest professionals (government agencies)	Focus groups	Potential for knowledge co-production exists, but not occurring extensively. Expert-led knowledge of government forest professionals dominates in a one-way transfer, with some informal knowledge communities happening among rural neighbors and families. Need for	Hamunen et al. (2015)

				learning environments where participation can occur at multiple levels.	
Arctic Observing Summit (multiple Arctic communities)	Evaluation of **knowledge co-production** (TEK and conventional science) for community-based monitoring	Indigenous communities, resource managers, and scientific researchers	Literature review and observations at 2013 Arctic Observing Summit	The state of community-based monitoring in the Arctic shows processes focused on community needs and interests where TEK and science produce fine-grained local-scale data, readily accessible to communities and decision-makers. Need for connecting efforts, as they are often undocumented and disconnected among wider networks.	Johnson et al. (2015)
South Africa	**Knowledge integration** (LEK) and comparison with remotely sensed and field data to assess rangeland conditions and assist in remote rangeland monitoring	Livestock farmers, research scientists	Remote sensing, statistical variance analysis, photo elicitation and participatory field evaluations	Local knowledge explained significant differences in field sampled vegetation classes. Remote sensing correlated poorly to field-measured vegetation classes to do spectral noise and high iron oxide content of soil, revealing LEK to be highly useful for monitoring efforts.	Kong et al. (2015)

Study Location	Mechanism(s)	Stakeholders	Methods	Findings	Citation
Alaska	**Knowledge integration** (TEK and LEK) for risk assessment of stakeholder-defined provisioning ecosystem services to invasive species under current and future climate conditions	Native Alaskan tribal representatives, federal and state land managers, research scientists	Integrative geospatial modeling: Species distribution modeling, participant observation, informal interviews	Knowledge integration provided an important rapid appraisal opportunity for the co-definition of critical conservation targets and threatening disturbance drives between LEK of land management agencies and TEK of Native Alaskan tribal representatives. Diverse land manager LEK facilitated access to an array of spatial data sets incorporated into analyses.	Luizza et al. (In Review)
Ethiopia	**Knowledge integration** and **knowledge co-production**	Indigenous pastoralists and research scientists	Integrative geospatial modeling: Species distribution modeling,	Pastoral revealed a new invasive species in the region, unknown to research scientist stakeholders and receiving little attention from government agencies and NGOs.	Luizza et al. (Accepted)

194

| | (indigenous pastoral knowledge) for risk of stakeholder-defined provisioning ecosystem services to invasive species | | participant observation, focus group interviews, participatory data collection, participatory mapping | Participatory approaches of knowledge co-production empowered communities and provided setting of mutual respect for different knowledge sources, facilitating shared learning and trust building. Much congruence between pastoral knowledge and conventional scientific observations, with the former expanding scientific understanding of the invasive species in question. | |