Collaboration Across Boundaries for Social-Ecological Systems Science

Experiences Around the World

Edited by
Stephen G. Perz

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For those about to cross
For those who salute the strangers
For those who govern for sustainability

Preface

It was my turn to talk, but this would not be straightforward. I was in the country of my second language, but not everybody in the group spoke that language, so I resorted to my third tongue, which more of the visitors seemed to grasp. I hoped people would be able to follow along, especially since many were from nonacademic organizations like governmental agencies and nongovernmental organizations. But even the academics present weren't from my discipline, sociology: they were mostly hydrologists and limnologists. My introduction thus amounted to a strange proposition for a meeting that at first glance seemed like an absurd exercise. Why was an academic talking to academics of other disciplines, people from nonacademic organizations, in another country, in a language not native to that country in the first place? What was all this for?

The participants at that meeting had come together to better understand the dynamics of a threatened watershed, especially the part passing through a series of towns with rapidly changing land use due to urbanization. The watershed thus constituted a dynamic Social-Ecological System (SES) experiencing complex changes involving human settlements with new activities closely tied to terrestrial and aquatic ecosystems which have their own interactions. Everybody around the room had both academic as well as practical reasons to be present, since the watershed in question was not well-understood, and because it was experiencing rapid changes of political importance tied to water quality, flood control, and other concerns. What is more, everybody around the room knew that they only commanded a small portion of the issues and expertise that would be necessary to understand and then address the problems. They needed to talk to each other in order to improve their collective understanding and thereby clarify the basis for policies and other actions to better sustain the watershed and the human populations and ecosystems that depend upon it.

In other words, to adequately respond to the complex interplay of rapidly changing dynamics in the watershed as an SES, the parties present found it necessary to leave the confines of their institutional abodes and cross boundaries among academic disciplines, organizational types, and countries of origin in order to collaborate. This case is by no means unique, for SESs of many kinds around the world are experiencing rapid changes that are prompting shared concerns among diverse stakeholders, raising questions for scientists of various disciplines, governments of many countries, and businesses and communities alike. At the watersheds meeting, much as at many others with different kinds of players who seek to collaborate across boundaries, there were very good reasons to join forces, and thus ample goodwill. The shared concerns and complementary capacities among the parties present provided the incentive to reach out; the scientists could produce the data needed by other stakeholders in order to make informed decisions, notably governments with regard to policies that would affect other parties, hopefully for the better.

Be that as it may, significant challenges arise when groups reach out to each other across boundaries and try to engage to pursue joint actions. In the case described above, and in many others, stakeholders seeking to collaborate across boundaries discover that they make contrasting assumptions about the SES and its problems, so they adopt different perspectives about the nature of the issues and how they should be approached, and consequently reach divergent conclusions about what should be done. The upshot is often miscommunication, confusion and conflict, which in turn hinder discussion and impede advances toward joint action. Adequately understanding watersheds and other social-ecological systems presents challenges, as does improving their governance and the effectiveness of their management. Beyond those tasks is the additional obstacle course involving the groundwork required to manage the travails of crossing boundaries to make the necessary collaboration possible in the first place.

This book takes up issues of engaging in effective practice when crossing boundaries for collaboration, focusing on the specific case of understanding SESs in order to improve their governance and management for sustainability and resilience. We therefore focus on the challenges to scientific practice from collaboration across boundaries in the conduct of research on SESs. Our purpose is to better respond to the problems presented by rapid change in SESs by working in teams of scientists and other collaborators who are likely to span multiple kinds of divides. This requires recognition of the challenges of collaboration across boundaries in terms of the need to learn the skills necessary to work in diverse teams. Those skills come not from the sciences involved in understanding the technical details of SESs, but rather from other disciplines. The acquisition of skills such as in social learning and teaming will be indispensable if scientists and practitioners are to rise to the challenge of collaboration across boundaries for knowledge production and application. We pursue this agenda by working from what is known about the skills and practices essential for spanning divides to work as teams, and by reflecting on concrete experiences to derive specific lessons and thereby improve future practice in SES science.

Rather than speak from the experience of one person or even one team, this book recounts the experiences of a suite of teams working on complex SESs around the world. In the process, the teams crossed not one but multiple types of boundaries simultaneously. Along the way, the teams had to learn or find practices to manage the consequent challenges. In the event, the teams identified and developed a diversity of strategies to improve their collaborative practice as they spanned divides. In many cases, teams found their way to practices established in the applied behavioral science literatures on management and collaboration. The teams also engaged in highly innovative strategies, often taking advantage of long-standing relations of trust and happenstance to learn lessons and improve practice. If direct experience is a hard teacher, the lessons won are that much more valuable and worth sharing.

This book therefore lets those teams speak with their own voices, and often those of their partners, to report what they have learned. The teams were constituted under particular funding programs and thus had similar mandates, budgets and scientific goals, which permits comparisons among their cases. That said, the teams themselves have distinct histories, and studied a range of different SESs in a diversity of cultural and political contexts, all of which can affect the efficacy of specific strategies and practices they can implement to collaborate effectively. This permits comparative reflections on how team structure and constitution, as well as external circumstances, may affect team performance.

What stands to arise from comparisons of these many experiences are broader insights about collaboration across boundaries, in terms of challenges that are shared and those which are more context-dependent, strategic practices employed and their effectiveness across cases, and thus conclusions to be drawn from lessons learned. Our collective intent in this book is thus to detail challenges, strategies and lessons from collaboration across boundaries in SES science, in order to make recommendations and thereby improve future projects in support of sustainability and resilience initiatives. Just as the research projects reported in what follows permit in-depth understanding of SESs, as examples of team science that span divides, they also offer a deeper understanding of collaboration across boundaries that can benefit future partners in similar endeavors.

Gainesville, USA Stephen G. Perz

Contents

Notes on Contributors

Joseph A. Aistrup research primarily addresses issues pertaining to water use and policy and its impacts on communities in the western half of Kansas. His current research assesses the value of water and its associated biosphere in fresh water scarce watersheds.

Arren Allegretti teaches environmental studies, world geography, and human dimensions of Marine Protected Areas at Santa Clara University. She holds a Ph.D. in Ecology and an M.S. in Human Dimensions of Natural Resources from Colorado State University. Her Ph.D. focused in part of the experience of cross-cultural team science and participatory methods for integrating transdisciplinary and local knowledge systems in the MOR2 project.

Jay Angerer is Associate Professor at Texas A&M Agrilife Research & Extension Center at Blackland. His research currently focuses on using satellite imagery to improve landscape estimates of livestock forage and building decision support tools for improving livestock management on rangelands. He has worked extensively in East and West Africa and Mongolia.

Heidi Asbjornsen is an Associate Professor in the Department of Natural Resources and Environment at the University of New Hampshire. Her research interests fall broadly within the disciplines of ecosystem ecology, applied forest ecology, and sustainable agriculture, while encompassing aspects of plant ecophysiology, restoration ecology, ecohydrology, and sustainability science. She is particularly interested in the effects of climate change and land use change on the water cycle, and the linkages between plant–water interactions and nutrient and carbon cycles, in both forest and agricultural systems.

Gregory P. Asner is a staff scientist in Carnegie's Department of Global Ecology and also serves as a Professor in the Department of Earth System Science at Stanford University. He is an ecologist recognized for his exploratory and applied research on ecosystems, land use, and climate change at regional to global scales. Asner investigates the interactions between land use, climate, and ecosystems through a combination of extensive field study, airborne and satellite remote sensing, and computer modeling. His work has uncovered ecological change in remote forests and desert regions of the world. He also maintains a long-term research program on the chemical evolution of plants, and its relationship to Earth spectroscopy measured with airborne and orbital remote sensing instrumentation.

Sara A. Ates is a Ph.D. candidate in the Department of Oceanography and Coastal Sciences in the College of the Coast and Environment at Louisiana State University (USA). Her interests are in coastal hydrology and hydrodynamics, weather and climate, and geology.

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Batkhishig Baival holds a Ph.D. in Rangeland Ecosystem Science from Colorado State University, founded the Nutag Action Research Institute and is Mongolia Country Director for the Sustainable Fibre Alliance.

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Jason Bergtold is a Professor in the Department of Agricultural Economics at Kansas State University. Dr. Bergtold has a broad background in statistical and econometric modeling; design and administration of stated choice experiments and surveys; and modeling of human-decision making related to technology adoption, bio-energy and land use. Bergtold has conducted several studies using stated choice experiments and surveys in Kansas and in Brazil.

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Rebecca Bliege Bird is a Professor of Anthropology at Penn State. She is an ecological anthropologist interested in the socio-ecology of subsistence. She pursues such topics as the gender division of labor in hunting and gathering, cooperation, costly signaling, indigenous conservation/land management, and fire ecology, drawing on theory, models, and methods from behavioral ecology and landscape ecology to answer questions about how local social contexts influence economic decision-making and how such decisions impact local ecological communities.

Stephanie A. Bohlman is an Associate Professor in the School of Forest Resources and Conservation at the University of Florida. Her overall research interests are to understand how species/functional group composition and forest structure will respond to climate change and the effects of these responses on ecosystem functioning. She is particularly interested in landscape level patterns, which has led her to use remote sensing data extensively. She has focused on high resolution remote sensing as a bridge between field data and coarse scale satellite data. Her work has focused primarily on tropical forests, which has critical gaps in knowledge about carbon uptake and response to climate change.

Heng Cai is a Postdoctoral Research Associate in the Department of Environmental Sciences at Louisiana State University. Her dissertation focused on the assessment and modeling of community resilience to coastal hazards in the Lower Mississippi River Basin in southeastern Louisiana.

Marcellus Caldas is the K-State leading principal investigator. Caldas is an economic/environmental geographer who studies the interaction of social, economic, and environmental processes. His conceptual framework is derived from an economic and social perspective that considers the behavioral attitudes of agents, and implications for the environment. His research strategy combines both qualitative and quantitative methodologies, utilizing data and insight gained from field investigation, key informant interviews and geo-spatial techniques.

Christopher Caldwell is a Director of the Sustainable Development Institute at College of Menominee Nation. He is responsible for coordination of SDI staff and resources in the delivery of nonacademic programming, research, contractual services, and other projects in support of the Institute's mission, and the broader mission of CMN. A primary focus of this work is the advancement of the Menominee Theoretical Model of Sustainability. Chris is an enrolled member of the Menominee Nation and has worked in the sustainable forestry field for over twenty years.

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T. Trevor Caughlin is an Assistant Professor in the Department of Biological Sciences at Boise State University. His research focus is developing models to predict restoration outcomes across large areas, including theoretical models that provide general insight into the spatial dynamics of reforestation, statistical methods to confront theory with field data, and remote sensing to quantify forest cover change across regions and continents. His long-term goal is to translate quantitative forecasts into spatially-targeted interventions for forest landscape restoration.

Russell G. Congalton is a Professor of Remote Sensing and GIS in the Department of Natural Resources and Environment at the University of New Hampshire. His research interests are divided almost equally between basic research on spatial data uncertainty/map accuracy and applied research applying the tools of remote sensing including unmanned aerial systems, GIS, and spatial data analysis to solving natural resource problems. These projects have included habitat mapping, endangered plant habitat analysis, mapping forest change, fire and fuels management, and mapping eelgrass and vernal pools.

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Gabriel Granco is a Postdoctoral Fellow at the Department of Geography at Kansas State University. His research incorporates social, economic, and environmental, data and models to understand human decision-making processes towards sustainability. Dr. Granco uses geospatial data management to integrate disparate data at multiple scales enabling the analysis of environmental policy support and adoption in face of global environmental change.

Sarah J. Graves is a program coordinator in the Nelson Institute for Environmental Studies at the University of Wisconsin-Madison. She works with a diverse group of graduate students in applying environmental geospatial data to complex environmental issues in non-academic sectors. Sarah's graduate research at the University of Florida is using high-resolution airborne hyperspectral and LiDAR data to generate ecological data at the scale of the individual tree as a way to connect ecological questions with remote sensing data. Applications of this approach have been quantifying the species diversity, biomass structure, and growth rates of tropical and temperate forest landscapes.

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Matthew Marsik is a physical geographer by training, specializing in land change science and geospatial sciences. He develops hypotheses and toolsets to investigate questions regarding natural resource conservation and management. His research is integrative and multidisciplinary, providing a network of colleagues to conduct collaborative research on land cover change; watershed hydrology; climate variability; ecosystem services; remote sensing techniques; geospatial analyses; and geostatistical methods. Dr. Marsik has conducted individual and collaborative research in montane watersheds of Costa Rica; Amazonian tri-national frontier of Brazil, Peru and Bolivia; the US southeastern coastal plain forests; and forests and watersheds of the Pacific Northwest.

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Jacob Salcone is a Ph.D. candidate at Colorado State University in the Department of Human Dimensions of Natural Resources and a natural resource economist consultant for UN Environment. Jacob uses microeconomic tools to assess the distribution and value of ecosystem services. His Ph.D. research evaluated the impact of payment for ecosystem service programs in Mexico and modeled future land-use change scenarios. Jacob holds an M.S. in Agricultural and Resource Economics from Colorado State University and a B.A. in International Sustainable Development from the University of California, Santa Cruz.

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Robert M. Scheller is a Professor in the Department of Forestry and Environmental Resources at North Carolina University. His research focuses on forest landscape change: how forests have changed, how they will change, and why it matters. His research examines how policy, forest management, and natural disturbances generate or reduce forest health, specifically with regard to climate change. His research encompasses a range of disciplines including forest ecology, landscape and ecosystem ecology, silviculture, geospatial analytics, and social science.

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List of Figures

List of Tables

List of Boxes

1

Introduction: Collaboration Across Boundaries for Social-Ecological Systems Science

Stephen G. Perz

1.1 The Central Challenge

Collaboration across boundaries, such as interdisciplinarity via the formation of scientific teams, is by now widely recognized as an indispensable response to complex problems (Perz 2016). "Wicked problems" that defy established solutions within institutional and cultural silos are typically marshaled as examples of situations where crossing boundaries for collaboration is necessary (Balint et al. 2011; Brown et al. 2008). Illustrative cases of wicked problems include health care provision, environmental degradation, and immigration policy. Funders of innovative science increasingly seek projects with teams that span disciplinary and other divides (e.g., Gewin 2014). Similarly, various areas of practice, such as in environmental conservation, increasingly underscore governance approaches to management (e.g., Batterbury and Fernando 2006; Biermann and Pattberg 2008; Lemos and Agrawal 2006; Newig and

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Fritsch 2009; Young 1997), as via multi-stakeholder processes, comanagement, and other collaborative modes that feature joint action by governments and other stakeholders (e.g., Armitage et al. 2009; Brick et al. 2001; Buck et al. 2001; Carlsson and Berkes 2005; Colfer 2010; Galat and Berkly 2014; Hemmati 2002; Lauber et al. 2011; Manring 2007; Poncelet 2004; Warner 2007).

The institutions that define disciplines, organizations, countries, and other bounded domains for thought and action exist for many reasons. This carries the crucial implication that crossing boundaries among domains for collaboration is not an automatic or natural process. Bounded domains like disciplines have cultures, and those cultures rest upon assumptions and practices that support theories and methods that may or may not be commensurate across domains. Those assumptions and practices are thus not always obvious or intuitive, which bears the additional repercussion that they must be learned. Collaboration and crossing boundaries thus require the acquisition of knowledge and skills for effective practice.

It is therefore problematic that the knowledge and especially the skills for collaboration and crossing boundaries tend to be overlooked or assumed by specialists of a given domain, even among those who recognize that they need to span divides. There remains a strong tendency to focus on the wicked problem at hand, which is certainly honorable precisely because it is complicated and important. But that also often corresponds to paying insufficient attention to the practices that enable the expertise in collaboration and crossing boundaries to be effectively deployed to address said problem. Similarly, there remains an inclination to dismiss the interpersonal and managerial aspects of collaboration, and of crossing boundaries. While scientists are professional thinkers, and some are naturally sensitive and gregarious, it is incautious to assume that one's team has the requisite knowledge and skills for applying best practices for collaboration across boundaries. One does not merely collaborate; one manages to do so. Similarly, crossing boundaries is not a routine act, but rather a gesture out of the ordinary, which is subject to questioning due to suspicion. Crossing boundaries for collaboration thus implies a steep learning curve, and a lack of preparation poses significant risks to being able to advance effectively.

It is therefore heartening to note that there are sciences relevant to the effective practice of crossing boundaries for collaboration. However, these sciences differ from those typically invoked to address wicked problems. In the case of environmental problems, it is biophysical and socioeconomic sciences that are usually brought together. But those differ from the sciences required to support collaboration across boundaries per se. Those instead fall in the applied behavioral sciences, notably in psychology and management. While these sciences are not new, they have all too rarely found purchase among specialists in other sciences who would benefit from applying their insights. Hence there is something of a boundary between the sciences often brought to bear on the technical issues involved in wicked problems, and the applied sciences that support best practices in collaborating across boundaries to actually address said problems. The practice of the second is necessary to advance the first.

There are several bodies of thought and scientific literatures on collaboration. In terms of theory, perhaps the classic point of departure concerns the political science literature on the conditions under which collective action is possible. Olson's (1965) statement argued that self-interest undermines collective action in all but the smallest groups. Ostrom's (1990) reply however provided examples that identified the conditions under which collective action can occur among many social actors in a sustained fashion. More broadly, the business administration literature has a body of theory concerning management practices in bureaucratic organizations with hierarchical structures (e.g., Daft 2005; Gittel and Weiss 2004; Gittel et al. 2010; Gomez-Mejia et al. 2008; Heckscher and Adler 2006). Varied forms of hierarchical structures, chains of command, and their implications for the flow of authority and information are eminently germane to the conduct of business and other joint activity. In psychology, there are multiple literatures relevant to the enterprise of collaboration. The organizational behavior literature offers numerous insights concerning the relationship between organizational structure and behavior on various levels of scale, ranging among individuals in organizational cultures, team dynamics and productivity, and inter-organizational relationships (e.g., Hersey et al. 2007; Ott et al. 2003). As a complement, industrial psychology has highlighted various applied aspects of behavior in formal organizations, whether in terms of hiring procedures, training and workforce development, performance evaluation, and topics related to organizational performance and consumer behavior (e.g., Cascio 1995; Landy and Conte 2016). Out of research on business management and psychology has emerged work on the "science of teams" (e.g., Fiori 2008; Jones et al. 2008; Wildman and Bedwell 2013) which has focused on issues of the formation and social processes on teams.

Research in these applied behavioral sciences has identified suites of tasks necessary to pursue collaboration, along with challenges that arise in the pursuit of those tasks, and practices to facilitate collaboration. The key summary message that stems from these literatures is twofold. First, collaboration does require effort at learning in order to practice the skills needed to make possible the effective pursuit of shared goals, so collaboration should only be done when necessary. But second, collaboration via the application of those skills makes possible the achievement of shared goals that would otherwise be beyond the reach of the collaborators if they acted independently. As work from the management literature on collaboration has noted, there is "collaborative advantage" in terms of the achievements that become possible via collaboration, if one can learn the skills and apply best practices to avoid "collaborative inertia" (Huxham and Vangen 2005; Lank 2006).

Similarly, there are scholarly literatures on crossing boundaries. Crossing boundaries can complicate collaboration, and thus requires separate recognition. While the general set of skills and practices for crossing boundaries in many ways builds on those involved in collaboration itself, spanning divides often entrains very context-specific challenges and requires some emendations of those skills and practices. Literatures on crossing boundaries thus tend to focus on spanning specific kinds of divides and focus on particular insights from direct experiences. These literatures include work on the practice of interdisciplinarity, inter-organizational collaboration, and international cooperation, all of which I discuss below.

We should respond to calls to cross boundaries for collaboration to address wicked problems. But we also need to acknowledge what others have already learned about the skills required and the practices vital to be effective in spanning divides. In this book, we take up the case of social-environmental problems as a case of wicked problems in order to examine SES science, both in terms of knowledge production for understanding complex systems and for the application of that knowledge to better govern them. In the remainder of this chapter, I briefly review SES science and how it motivates the need for collaboration across boundaries. Then I offer a framework of the issues, tasks, challenges, and practices for effective collaboration, along with a discussion of the complications and strategies of crossing boundaries for collaboration, featuring interdisciplinarity, inter-organizational collaboration, and international cooperation, which are germane to the pursuit of SES science.

1.2 Social-Ecological Systems Science

By SES science, I refer to the integrated study of SESs by scientific teams that span various academic disciplines, and likely also organizational types, countries, and other boundaries. SESs constitute an example of complex dynamic systems (e.g., Anderies et al. 2006; Epstein et al. 2015; Folke 2006; Fischer et al. 2015; Walker et al. 2006). The focus on complexity arose in response to the inadequacies of established equilibrium approaches to the analysis of dynamic systems. Complex systems approaches have gained favor in the analysis of systems experiencing disturbances and thus far from equilibria or in the process of shifting from one state to another. Consequently, analysis of complex dynamic systems tends to feature nonlinearities in system behavior, generally observed in terms of some key indicator of system state whose dynamics either speed up or slow down, and whose observed values move in directions not seen previously. Such nonlinearities are attributed to other aspects of system complexity such as feedback processes among interacting system components wherein a change in one component affects another that feeds back to the first, whether via a positive feedback that accelerates the change or a negative feedback that dampens it. Another focus of inquiry to explain nonlinearities concerns cross-scale processes, or teleconnections, which may themselves involve feedbacks, constituting telecouplings (Friis et al. 2016; Liu et al. 2015). Complex systems may also exhibit critical thresholds (cf. Scheffer et al. 2012) such that a system component that reaches a particular value modifies relationships elsewhere in the system, leading to cascading changes that alter how the system is organized and resulting in a new system state. Complexity science thus features uncertainty and surprise in complex dynamic systems, in recognition that disturbances to systems may yield responses beyond the bounds of that seen historically, resulting in potentially undesirable outcomes.

SES science has emerged out of complex systems science as recognition has grown that SESs exhibit many of these traits seen in complex dynamic systems. This has, in turn, resulted in work to develop conceptual frameworks on SESs. Liu et al. (2007) offer an influential rendering of SESs as linked social and ecological subsystems, each with their respective system components and relationships. They underscore however the importance of social-ecological interactions between the two subsystems, and highlight that those interactions are reciprocal, thus leading to the potential for generating nonlinearities as via feedbacks, telecouplings, and so forth. More recently, Binder et al. (2013) and Boumans et al. (2015) have provided reviews of different approaches to modeling SESs, including system flows (as of energy, materials, and information), human decision behavior, product analyses as to their ecological ramifications, resilience and adaptation approaches, and capitals-based approaches.

In these and other publications (cf. McConnell et al. 2011), groups of scientists have highlighted specific aspects of SESs for purposes of analysis. Particular attention has gone to reciprocity in social-ecological feedback loops, especially with the goal of quantifying the extent to which the dynamics in each subsystem modify those of the other. Closely related to this concern has been interest in various forms of networks and connectivity among system components, which defines the structure of relationships and feedbacks (e.g., Barnes et al. 2017). Also relevant is the growing focus on cross-scale processes as they lead to telecouplings. This takes advantage of the classic problem of defining system boundaries to instead embrace the fact that localities are linked and may thus be affected by far distant drivers which they may, in turn, affect via feedbacks (Liu et al. 2015). SES science has featured the concern with critical thresholds as related to the issue of resilience (Lade et al. 2013; Gunderson et al. 2017). This stems in part from the ecological definition of resilience in terms of the disturbance required for an SES to shift from one state to another, which in turn relates directly to concerns about ecosystem degradation into undesirable states from both a social and ecological standpoint. Concerns about critical thresholds as "tipping points" in SESs is also tied to interest in surprise and uncertainty in SESs, especially as concerns human behavioral changes under shifting conditions. At the same time, there is interest in system trajectories and path dependency, whether based on initial conditions or later system dynamics that become self-reinforcing.

Drawing on these ideas, empirical research and dynamic modeling efforts have proliferated in recent years, as teams of scientists have taken up integrated study of SESs of various types around the world. While a full review is beyond the scope of this chapter, it is worth noting a selection of examples, especially as they feature the interactions of social and ecological subsystems in specific SESs, along with other prominent elements of SESs as complex dynamic systems.

Analyses of SESs often involve water bodies and water resources, including fisheries. Leslie et al. (2009) focus on a marine fishery in a coastal ecosystem being impacted by climate change as well as distinct groups of fishers that respond differently to regulatory mechanisms. Downing et al. (2014) similarly take up the case of a lake fishery, where multiple fish species have particular ecological relationships as well as specific economic values to different human fishing groups, all in turn affected by external economies and policies. Villamayor-Tomas et al. (2016) report on the possible impacts of a proposed hydropower plant on a watershed with fish species on which local stakeholders depend. Bury et al. (2013) evaluate the dynamics of a glacier-dependent watershed that is being modified by climate change via shifting precipitation and snowpack, leading to downstream conflicts among human user groups, which themselves are changing activities in the form of new mining and hydropower initiatives. Yu et al. (2015) evaluate the design of irrigation systems to manage the flows of ecological benefits to local species and economic benefits to agricultural user groups.

Other analyses evaluate resource use in terrestrial ecosystems. Qi et al. (2012) consider the soil dynamics in dryland agricultural systems being impacted by climate change and shifting human land use, which jointly modify both carbon and water fluxes. Oakes et al. (2015) provide analysis of forest ecosystems as they are impacted synergistically by both climate change and human activity. Carter et al. (2014) study conservation of ecosystems with large wildlife species and growing populations of human user groups, focusing especially on how external disturbances and telecouplings affect wildlife–human interactions.

There is also increasing attention to urban areas as SESs. Spies et al. (2014) take up the case of the wildland-urban interface in a fire-prone ecosystem, where there are human and natural causes of fire, and fire suppression policies lead to worse fires when they occur. Fan et al. (2014) consider the social-ecological dynamics of urban areas defined by government planners, occupied and used by other human stakeholders, but also inhabited by many other species that find ways to adapt to engineered landscapes.

In this and other research in SES science, there is agreement on the need for collaboration across boundaries. Many such discussions focus on the importance of teaming for interdisciplinary collaboration (e.g., Fischer et al. 2015; McConnell et al. 2011). Most of the references just cited involved publications of five or more coauthors, sometimes many more, and they frequently come from different disciplines, and/or different organizations or countries.

What is more, there is broad agreement that SES science can contribute to applications in environmental governance processes and management regimes for ecosystem sustainability (e.g., Armitage et al. 2009; Berkes et al. 2003; Ostrom 2009; Guerrero and Wilson 2016). To that end, Ostrom (2009) offers a framework for evaluating SESs, in which she further unpacks the system components. Her assemblage includes the resource system (biophysical processes), resource units (lands, watersheds, etc.), the governance system (government and stakeholders and decision processes) and resource users (user groups), and their interactions. Notable here is the focus on differentiating system components for purposes of applications in governance processes for SES management for sustainability.

In a related vein, there has been considerable emphasis on participatory approaches to both the study and the management of SESs (e.g., Devisscher et al. 2016; Mehryar et al. 2017). This complements the parallel recognition among scientists of the importance of local knowledge for the study and management of SESs (e.g., Berkes and Turner 2006; Ruiz-Mallén and Corbera 2013; Mantyka-Pringle et al. 2017; Winter and Lucas 2017). This work builds on the multi-stakeholder process literature noted earlier. All such work routinely highlights the importance of scientists crossing boundaries to work in a transdisciplinary mode with nonacademic stakeholders on governance and management problems. As with the science of teaming, crossing boundaries for governance and management of SESs has its own scientific literature (e.g., Berdej and Armitage 2016; Guimaraes et al. 2015).

There remains however a situation where training and thus learning about collaboration and crossing boundaries are in demand, and yet the knowledge, skills, and experiences remain in short supply. There is agreement that the study and management of SESs requires integrative approaches to span various divides, but the challenges put off those who would embark on the adventure. SES science is certainly complicated, and calls to read the literatures of one's collaborators to gain fundamental knowledge are certainly valid. But the skills required for collaboration across boundaries must also be explicitly outlined, or the practices vital to the collective enterprise cannot be acquired. Scientists have to learn these skills in order to take on the additional roles of being good brokers, communicators, managers, leaders, and so on. The next section offers a framework of the issues, tasks, challenges, and strategic practices for effective collaboration.

1.3 Collaboration: A Framework

Previous work on collaboration has offered various renditions of the many vagaries at play when forming teams and pursuing collective endeavors. Literature on collaboration includes classic statements from the management literature (e.g., Kraus 1980) and work on multi-stakeholder processes (e.g., Gray 1989). Research on collaboration in business administration has focused on joint ventures among different firms (e.g., Austin 2000; Cropper et al. 2008) and among divisions, departments, and other entities within firms (e.g., Hansen 2009; Heckscher and Adler 2006). In addition, there is work on collaboration among nongovernmental organizations (NGOs) (e.g., Poncelet 2004; Reuer 2004; Wondolleck and Yaffee 2000). These and similar statements provide lists of issues entrained by initiating collaborative efforts. Discussions typically highlight the exigencies involved and then call attention to the skills and practices necessary to avoid the pitfalls in order to move forward jointly toward shared goals. The issues commonly noted include the importance of effective communication, the joint definition of goals, establishment of a clear management structure, and routine reporting for coordination and accountability.

Here I offer a framework for collaboration based in part on previous work, as well as my own experience on SES science and conservation and development projects (Perz 2016). The framework is organized around seven issues: (1) introductions and communication, (2) inequalities and politics, (3) common interests and complementary capacities, (4) goals and objectives, (5) leadership, governance, and management, (6) expectations and benefits, and (7) uncertainty and surprise (Perz 2016, Chapter 3). These issues allow us to unpack the labor that is collaboration. This list runs somewhat beyond those typically noted in previous work on collaboration, notably by the attention paid to inequalities and politics as well as surprise and uncertainty. This is because those issues have received somewhat less attention than the others in most previous work on collaboration, and have in my experience proven to be particularly thorny in the context of crossing boundaries.

For each issue, I identify a suite of tasks to be performed to address the issue, challenges that may arise in the pursuit of those tasks, and strategic practices that can help with the tasks so that collaboration can proceed effectively. This means of organizing the labors of collaboration provides a framework that not only sets forth the difficulties likely to arise, but also affords as basis for addressing the exigencies. By directly relating the issues, tasks, and challenges to strategic practices, one gains an operational basis for collaboration to realize collaborative advantage. The following discussion offers a brief exegesis on the seven issues involved in the framework for collaborative practice. This is not intended to be a definitive discussion. Readers interested in a longer version of what follows can consult Perz (2016, Chapter 3) and sources cited in this section.

Introductions in particular and communication in general are well-known as vital to effective collaborative practice. Through introductions, potential collaborators begin to get to know one another, and key is learning what each knows and what each does not with regard to the shared interest at play. From the onset of introductions, communication skills play a determinant role as potential partners assess the prospects to achieve collaborative advantage. Tasks are immediately entrained, such as coming to a common understanding of the meaning of key terms and making assumptions explicit. The first is especially challenging on science teams that contain specialists with large technical vocabularies. The second bedevils collaborators in most all endeavors because assumptions are often implicitly held and thus hard to identify, or they are explicit but ideological and therefore viewed as inviolable and nonnegotiable. A useful strategic practice for introductions and communication is to understand the onset of collaboration in terms of courtships. This implies engaging in extensive side consultations to learn more about the prospective partner, and managing the emerging relationship as a measured process over time and not as a hasty decision based on a one-night stand. Both permit the social learning necessary to appraise the benefits of a prospective partner and help with comprehending new terms and dredging up assumptions for critical examination. Another strategic practice is to work through network brokers (cf. Manring 2007). These are well-connected individuals already familiar with both of the prospective partners and who can use that knowledge to facilitate introductions and communication.

If complementarities among collaborators beget collaborative advantage, the flip side of the same coin is that differences stemming from complementarities correspond to inequalities that can become political. Issues of power must be openly and immediately addressed for any collaborative effort to advance; otherwise, mistrust builds and endangers joint action. Insofar as SES science also proposes to generate findings that can be applied in policy and management, the external political context can greatly affect the impacts of a collaborative enterprise. Collaborators must therefore honestly assess their respective capacities as well as the broader political risks to their proposed course of action. The first is easier said than done, for more influential partners often seek to assert themselves and thus reproduce inequalities, often beginning with the framing of the problem or invoking a specific theoretical approach. Even if partners begin to build ties of trust, one may be riven with internal political conflicts. The second requires some structural analysis of the collaborators vis-à-vis the relevant powers-that-be, especially with regard to whether the two have any means of directly communicating. Further, the political context is subject to change, for better or worse. Problems stemming from partner inequalities and internal and external politics are especially difficult because they are sensitive, and they tend to recur over time. The resulting conflicts thus have to be managed; they cannot be solved (cf. Burton and Drakes 1990). Strategic practices however permit management of the challenges. Among partners with past histories of conflict, venting of grievances right up-front can help clear the air, or at least permit explicit recognition of issues to be addressed. Among new partners who are unequal, network brokers can moderate the discussion, which can include nonnegotiable issues as decided by weaker partners (cf. Edmunds and Wollenberg 2002). Network brokers can also exert moral authority by calling out partners, especially stronger ones, when they try to exercise dominance. Collaborators of partners with internal conflicts can adopt "non-aligned policies" with regard to the combatants in question, which helps keep the focus of the collaboration on shared interests. Collaborators can begin to address an unsympathetic political context by proactively providing information about the proposed activities and their benefits. At least in the cases where lack of knowledge or familiarity is the problem, communication can at a minimum clarify the disposition of vested interests. An extensive discussion of inequalities and politics in collaboration is available in Perz (2016, Chapter 6).

Crucial to realizing collaborative advantage is to square up the common interests with complementary capacities among partners. In SES science, shared interests generally stem from a social-environmental problem and some opportunity for knowledge production to improve management outcomes. Defining the approach to be taken then requires sorting out the knowledge funds, experiences and other capacities of each partner as they differ from and thus add value to those of the others. Shared interests can be defined through a process of independent free listing of interests that are then made public to identify common interests among the partners. The same procedure with the opposite logic can be pursued for identification of complementary capacities. Challenges arise when partners articulate their interests vaguely or overestimate their capacities. Interests and capacities must be clear enough to permit identification of gaps in needs to thereby afford planning of joint actions with a clear division of labor. As a strategic practice, there is a need to critically evaluate all claims about interests and capacities, especially in light of the problem at hand and in the context of previous responses and their limitations. This provides a basis for clarifying the approach to be taken, whether in terms of knowledge generation or management applications, in terms of aligning partner capacities with their proposed responsibilities. All this is not to say that partners must be entirely complementary in their capacities; some redundancy can be very useful, especially if one partner proves inadequate to meet the challenges they face.

Delineating goals and objectives is unequivocally important for collaborators, especially if SES science explicitly contemplates the application of knowledge to policy or management. In conservation and development work, goals and objectives are defined as part of the process of developing a theory of change (e.g., Breuer et al. 2016; Taplin et al. 2013) for purposes of monitoring and evaluating of performance (e.g., Hockings et al. 2005; Saterson et al. 1996). That is, defining a goal entrains identification of objectives to be achieved in order to attain the goal. In turn, identification of objectives requires definition of specific activities theorized to be necessary to achieve said objectives. That then necessitates setting of performance indicators and targets for the outputs of the activities. Underlying such logical frameworks for generating results is a theory of change, an argument as to why the actions proposed will yield the outcomes desired, along with assumptions underlying the argument as a means of risk analysis. The tasks of defining goals and objectives are thus quite extensive. Collaborators unfamiliar with theory of change approaches and the construction of logical frameworks for results thus pose challenges to the process of defining goals and objectives. Further, partners may not agree on goals, or objectives, or activities, or indicators, or targets, or their underlying assumptions. Fortunately, development of theories of change and results frameworks requires learning, and partners can learn together. Everybody needs to go dig up arguments and supporting information to justify goals and all the details that they might imply. The design of logical frameworks can proceed specifically on the basis of identified partner capacities, which helps divide the anticipated labor, clarify responsibilities, and allow for identification of weaknesses, whether in terms of time allowed for performance of work or otherwise. Critical analysis of the proposed sequence of activities and their outputs also serves as a reality check. If some partners end up with more responsibilities, the keys are that everyone learns and everyone takes on responsibilities commensurate with their experience and capacities.

Statements on collaboration have often featured the interrelated issues of leadership, governance, and management. The first pertains to the design of a collaborative structure that establishes a chain of command, as well as the roles and styles of leaders; the second concerns how the collaborative structure will define who gets to participate in making strategic decisions governing the collective enterprise; and the third focuses on day-to-day operational practices and oversight. Beyond the leaders, collaborative structures define functional roles for various specialists, whether scientific or administrative, and how they are to divide their labor and work together. Collaborative structures are also often supported by the establishment of written agreements, which involves approval by authorities of participating organizations. These tasks are outlined in detail in the literatures on business administration and organizational behavior. The challenges nonetheless bear noting. Partners may have differing leadership styles, or prefer different governance structures and procedures. Leadership may not understand or be disinclined to listen to technical staff. Partners may resist signing agreements, or fail to deliver on the commitments made therein. Collaborative structures have both vertical (chain of command) and horizontal (network) dimensions, and combining the two through partnering can be confusing to partners accustomed to one or the other. Strategic practices for managing these challenges include the concept of "servant leadership" (Greenleaf 2002), where leaders serve the partners by adhering to an ethic of advancing the shared interests of the collaborative endeavor, rather than the interests of an individual or organization. There must be clearly defined performance evaluation procedures based on stated goals and deadlines. At all turns, strategic practices in collaborative structures must prioritize the shared interests of the collaborative enterprise over the self-interests of particular constituencies. Beyond leadership styles and procedures, the design of collaborative structures is crucial for effective management of collaboration. "Distributed leadership" (Spillane 2006) is very useful, for it involves dividing responsibilities among managers or organizations such that they must discuss management problems and jointly take decisions in light of shared goals. Distributed leadership also helps to manage the tensions of vertical and horizontal relationships in collaborative structures. Both types of relationships are necessary for productive collaboration: vertical relationships define clear chains of command and permit efficiencies in getting work done; horizontal relationships facilitate the flow of information and thus innovation. A longer discussion of the design of collaborative structures can be found in Perz (2016, Chapter 5).

With all that is involved in collaboration, partners must devote careful attention to the issue of expectations and benefits. Expectations refer to the responsibilities to be assumed for work done and products delivered; benefits refer to who gets what if they do what is expected. Both may be monetary or nonmonetary, and short or long term. Clarifying these aspects is crucial to avoid unhappy realizations and conflicts later. Similarly, partners need to talk out how each sees their respective expectations relative to benefits, as some may be asked to bear greater burdens than others for the sake of the collaborative enterprise. One challenge is therefore to be sufficiently clear up-front, as some partners may hold back for cultural or political reasons. As work unfolds, some technical tasks may prove more difficult than expected, and partners may want to renegotiate. Then there is the problem of what happens if somebody does not fulfill the expectations to which they have agreed. An obvious strategic practice is to hold an up-front workshop on these issues to promote dialogue and clarifications. A related practice is to be transparent about who gets what, especially in monetary terms; this includes talking about salaries in order to justify personnel budgets on funded projects. As noted above, the inequalities go on display so then they can be discussed instead of left to simmer. Especially for partners focused on short-term monetary benefits, discussion of nonmonetary and long-term benefits is a vital strategic practice. Collaboration forges network ties that can lead to downstream opportunities, including publications and future projects.

A final issue at play in collaboration concerns surprises and uncertainty. Collaborative enterprises are risky endeavors due to surprises that may stem from partners themselves as well as the broader context. Indeed, SES science projects may themselves be affected by the very environmental changes they propose to study, like extreme climatic events or systems crossing tipping points. Working with new partners necessarily entrains uncertainties, especially in larger networks. So does working in new contexts like other countries or rapidly changing regions. There are different management procedures to pursue, depending on the level of ambient uncertainty confronting collaborators. The classic default is rational planning, where partners can define future actions and outcomes with a reasonable degree of uncertainty, but that is only feasible under low levels of uncertainty. Researchers involved in environmental management have long recognized the limitations of rational planning and thus advocated adaptive management (cf. Holling 1978; Lee 1993), in which partners define plans, implement and gather data, and then adjust based on the findings. This permits a modicum of adaptation if uncertainty is somewhat greater. SES researchers have gone beyond adaptation to scenario planning (cf. Peterson et al. 2003; Shoemaker 1991) when uncertainty is yet higher. Collaborators facing significant uncertainty jointly develop several possible scenarios of future change in order to plan for each and thereby seek to pursue desirable pathways. If the level of uncertainty is so high that even a few scenarios are going to be insufficient to plan any course of action, then there is one final option: "muddling through" (cf. Lindblom 1959; Wollenberg et al. 2007). This amounts to a strategy of staying connected with local partners and waiting for opportunities to appear, however unexpected, and simply being ready to drop everything to try and respond. A more extensive discussion of surprise and uncertainty in collaboration is available in Perz (2016, Chapter 7).

1.4 Crossing Boundaries for Collaboration

Insofar as calls for SES science entrain teams of scientists who work across disciplines in various countries and seek to convey their findings to nonacademics, the strategy underlying the pursuit of SES science is that of collaboration across boundaries. The foregoing framework provides a roadmap for recognizing and responding to the exigencies of collaboration. When crossing boundaries, the complexity of the issues in that framework increases. It is one thing to collaborate with another scientist of one's discipline, organization, and country; it is another work with a researcher of a different discipline, organization, or country.

Having said that, I hasten to emphasize that crossing boundaries can amplify collaborative advantage (Perz 2016, Chapter 4). If all the issues of collaboration are magnified when crossing boundaries, from the struggles of communication through surprises and uncertainty, so too are the potential impacts. Hence just as inequalities may be wider and politics intensified when spanning divides, so too are the complementarities among partners, and thus the collaborative advantages of joining forces. Crossing boundaries for collaboration may present additional challenges, but it also increases collaborative advantages.

This section examines domains with boundaries relevant to SES science, focusing on disciplines, organizational types and countries. There are of course other forms of boundaries, whether defined culturally, institutionally, or politically. The sociological categories delimited by race/ethnicity and gender come to mind, as do institutional designations like scientist and technical staff or faculty and student. For present purposes, I discuss how interdisciplinarity, inter-organizational collaboration and international cooperation complicate the challenges of collaboration. I then note selected strategic practices to facilitate the realization of the additional collaborative advantages from spanning divides for joint action.

As SES researchers know well, academic disciplines constitute scholarly domains with boundaries (e.g., Becher and Trowler 1989; Kagan 2009). Disciplines require command over topical content and a suite of methodological skills. Boundaries between disciplines reflect their historical differences in their bodies of thought, their traditional methods, and their key insights. Disciplines thus constitute specialties that offer complementary contributions to the broader academic enterprise; one would not confuse a cultural anthropologist with a physical chemist. That said, boundaries also demarcate frontiers between disciplines, which can be difficult to cross, not only because disciplines have differing theories, methods, and insights, but also because they have different histories and cultures. Whereas the first group is often explicit and can be acquired by some reading, the second is often implicit and harder to apprehend. Crossing disciplinary boundaries is thus more than a matter of reading up on the fundamentals of another discipline; it requires time and dialogue with the players. This motivates the literatures on multi- and interdisciplinarity (e.g., Frodeman et al. 2010; Klein 1996, 2010; Weingart and Stehr 2000).

In turn, that work has outlined specific challenges and strategic practices in interdisciplinarity (e.g., Kainer et al. 2006; Lélé and Norgaard 2005). Whereas interdisciplinarity involves a conceptual synthesis in a single collaborative effort, much previous work on interdisciplinary collaboration has featured the importance of communication, specifically the issue of arriving at shared understandings of technical terms (e.g., Monteiro and Keating 2009; Pennington 2008). But disciplines are not created equal, so arriving at shared understandings of terms and framing problems becomes a political process (MacMynowski 2007; Oughton and Bracken 2009; Schoenberger 2001). Collaborators across disciplines thus need time to engage in critically interrogating all frames proposed for an interdisciplinary project, to manage the potential for domination by some partisans, and to better ensure integration of contributions from different disciplines. Good interdisciplinary collaborators are not afraid to reveal the “dirty laundry” of the assumptions, blind spots and limitations of their disciplines. This facilitates deeper ontological and epistemological discussions that inform theoretical and methodological choices in interdisciplinary project development. There is growing appreciation of the "cultural turn" in the social sciences by biological scientists (e.g., Moon and Blackman 2014).

SES scientists also know that applying their findings often requires partnering across the boundaries between different types of organizations (e.g., Cropper et al. 2008; Poncelet 2004; Robinson et al. 2000; Wondolleck and Yaffee 2000). This is the issue addressed in the literature on transdisciplinarity (e.g., Hirsch Hadorn et al. 2008; Pohl 2005). Such statements typically differentiate between academics and nonacademic stakeholders. It is important to go further and differentiate among organizational types, including universities, government agencies (GAs), for-profit businesses, nonprofit organizations (aka NGOs), community associations, and others. Each has their distinct mandates, strategic assets and liabilities, organizational structures, key personnel, cultural assumptions, and practical imperatives (e.g., Easterby-Smith et al. 2000; Knoben and Oerlemans 2006; Phillips et al. 2000). Contrasts in the last pair of these characteristics are illustrative, as cultural assumptions and practical imperatives present significant challenges to collaboration among different types of organizations. Universities view knowledge production and dissemination as inviolable mandates, but have countervailing imperatives between hierarchical authority from administrations to faculty and deeply felt values about faculty autonomy and freedom of inquiry. In contrast, NGOs often see themselves as filling needs left by GAs and other organizations, including for conducting applied research and providing outreach to communities on issues of concern, but NGOs rely on external funding for their activities, which also orients much of their focus. The prospect of universities collaborating with NGOs thus requires navigating the distinct cultural values on the roles of basic and applied research, the distinct imperatives that drive the timeframes of their operations, and other contrasts, such as in their organizational structures and key personnel.

The many contrasts in organizational types bear significant implications for inter-organizational collaboration. One issue is that organizations operate on different calendars, which distinct annual deadlines during which it becomes very hard to respond to requests from partners. This makes it very important to detail dates on flow charts for the timing of joint activities and submission of deliverables. Similarly, the operational protocols of different organizations likely differ, following the principle that bureaucracies are invariably designed to ensure their continued survival, on their own specific terms (Peters 2001). Hence the procedures of a GA may not square comfortably with those of a community association. This requires administrative points of contact in order to translate specific procedures in the paperwork of one into those of another, so papers from one are interpretable and acceptable by the other. Given the contrasting structures of different organizational types, it can be challenging to identify equivalent individuals to serve as the points of contact. This often occurs as a player in one organization reaches out to the authorities of another in order to find the appropriate counterpart. University faculty may or may not neatly match up with technical personnel in a GA or NGO. The work to gain an understanding of each other's organization is richly rewarding however, for then each becomes the diplomat of their organization to the other's, which is not only necessary but facilitative of inter-institutional ties. While perpetually asking questions to clarify bureaucratic procedures and organizational cultures might seem dull, it is an investment in knowledge that is rarely shared and very valuable, for it creates the conditions for recognizing complementarities vital for inter-organizational collaborative advantage.

Working in other countries (or multiple countries at the same time) poses similar challenges, but the cultural and historical depth of the differences is greater, especially when working in far-distant places (e.g., Chasek 2000; Gaillard 1994; Keating and Jarvenpaa 2016; Young 1989). Countries of course have territorial boundaries, historically determined, often set after various forms of conflicts. Hence the challenges of crossing national boundaries can be especially complicated. Language differences are the most obvious cultural manifestation of boundaries, but other cultural dimensions of boundaries may also impede collaboration, such as understandings of time as they inform when meetings actually begin (as opposed to when they are putatively set to begin). Institutional systems generally differ among countries, such that getting visas to enter, travel, and all manner of other logistical details will likely need considerable attention before any work can be done. And if the country of interest for collaboration has tense diplomatic relations with one's home country, then the sensitivities of working there become especially delicate, not only for oneself but especially for one's in-country collaborators. Crossing national boundaries is thus very demanding, and identification of motivated and capable collaborators is crucial.

Perhaps nowhere more than when crossing national boundaries are the travails as well as the benefits of crossing boundaries as evident. Finding partners well-disposed to serve as emissaries on behalf of their country is vital, for they can break down (or at least interpret and translate) the manifold cultural, institutional, and political barriers-that-be. This first requires careful attention to decoding one's own country's culture, institutions, and politics. If the discussion gets to the point where partners can raise concerns about each other's countries, especially the stronger of those represented, then a modicum of trust has been gained, trust to manage the potentially large inequalities at play (Stewart and Gray 2006). Sharing national beverages at a bar facilitates this process, but it is likely to be extended, for decoding cultures takes time, institutional procedures are difficult to learn, and politics can present sudden crises. Another key practice is to be ready when a partner has a locally induced crisis and makes requests of their collaborators to wait or otherwise modify their best-laid plans, with some cost to the activities and products contemplated. If the collaborators are ready to make sacrifices for the partner, productivity may drop, but political capital among the team is won. This creates the conditions for reciprocity later, reciprocity that may prove crucial to sustainable international cooperation. As with inter-organizational collaboration, forming multiple points of contact, as on the scientific and administrative fronts, can be very valuable, for this fosters broader communication and learning across national boundaries, which helps stabilize collaborative relationships. There is much more than can be said about strategic practices and crucial moments when spanning boundaries for collaboration, whether among disciplines, organizational types, or countries; a longer discussion is available in Perz (2016, Chapter 4).

1.5 Outline of the Book

The foregoing framework for collaboration and the discussion of crossing boundaries is merely a point of departure. Both stem from my experience working to collaborate across boundaries in the southwestern Amazon. A major point of this book is to draw on the experiences of other scientific teams working to improve understanding and management of SESs in other parts of the world. A key contribution of what follows is therefore to offer additional reflections from other cases of SES team science and its applications. The chapters that follow therefore draw from no less than ten different collaborative endeavors involving SES science that crossed one or more boundaries, whether those discussed above or others.

The teams share a common mandate as all but one formed to pursue SES science under the same scientific funding program. The "Dynamics of Coupled Natural and Human Systems" (CNH) program of the US National Science Foundation (NSF) has funded numerous scientific teams working around the world to improve understanding and management of SESs (NSF 2018). Like other NSF programs, CNH projects are evaluated in terms of their "intellectual merit" as well as their "broader impacts." Under the first rubric, "Research projects to be supported by CNH must include analyses of four different components: (1) the dynamics of a natural system; (2) the dynamics of a human system; (3) the processes through which the natural system affects the human system; and 4) the processes through which the human system affects the natural system" (NSF 2018). This all but necessitates interdisciplinarity teaming. Under the second, CNH teams must demonstrate the real-world relevance of their research by focusing on SESs where management outcomes will affect both human communities as well as ecosystems, which necessitates inter-organizational collaboration and frequently international cooperation. Hence CNH project teams operate under broadly similar conceptual frameworks of complex SESs, and pursue similar strategies in addressing SES management problems. These shared priorities ensure a degree of comparability among the cases that follow. Each CNH team crossed boundaries for collaboration in order to study and improve management of SESs for sustainability.

In each chapter, a CNH team provides a discussion of their project, featuring how they have managed the vagaries of collaborating across boundaries in the pursuit of SES science and management. Each chapter begins with an introduction to the CNH problem being addressed, calling attention to the organizational aspects of the approach adopted. The team then provides a discussion of their conceptual framework of the SES under study, featuring its key components and relationships. This is followed by a description of the study region, noting salient aspects of its history and recent social and ecological dynamics. Teams then focus on how they formed, the structure of their organization, the key partners and the boundaries they crossed in order to collaborate. The heart of each chapter then discusses the exigencies of their experience in collaborating across boundaries, noting the salient issues, tasks and challenges, and then discussing the key strategic practices they employed. This discussion provides the basis for reflection on what worked, what did not, and why. Chapters then conclude by featuring key lessons learned that motivate recommendations for future practice among teams seeking to collaborate across boundaries for SES science with sustainability goals.

Together, the chapters offer a broad panoply of experiences in terms of the types of SESs studied, the structures of the teams formed, the locations of the study sites around the world, the key boundaries being crossed, the challenges encountered, the strategies for managing the challenges, and the recommendations offered. In Chapter 2, Pischke and colleagues report on the case of socio-ecohydrologic systems in Mexico and focus on the issue of scaling up various datasets for integrated modeling, and feature the issues of communication necessary for integration and interpretation of findings, notably for application in public policy. In Chapter 3, Laborde and colleagues reflect on the first author's role as an embedded observer of an interdisciplinary and international science team studying regimes shifts in the Logone Floodplain in northern Cameroon, discussing perspectives on developing a quantitative model as a focus for team cohesion when crossing boundaries, as well as a product of research. In Chapter 4, Uchida and colleagues discuss their research on mangrove ecosystem services in coastal Tanzania, highlighting how the rigors of fieldwork pose challenges to understanding of dynamics in this SES, and how the research can affect stakeholders and thereby provide a basis for management to avoid poverty traps. Smithwick and colleagues offer Chapter 5, on the integration of indigenous knowledge with virtual reality technologies for sustainable future management of forests of the Menominee Nation, featuring teaming that prominently incorporates Menominee members and use of 3-D visualizations in management decisions. Fernández-Giménez and colleagues present Chapter 6, on the Mongolian Rangelands and Resilience Project, a collaborative effort among multiple universities and NGOs seeking to integrate data from fieldwork, monitoring systems and stakeholders, in which they offer reflections on lessons from simultaneously crossing multiple boundaries. In Chapter 7, King and Nibbelink report on an innovative transdisciplinary graduate training program, which prompts their in-depth discussion of the challenges to graduate training and mentoring to prepare young scientists to collaborate across boundaries for SES science. Caldas and colleagues offer Chapter 8, on the integration of models to understand coupling between hydrosystems, ecosystems and land use in the context of climate change and varying degrees of environmental concern among stakeholders in the Central Great Plains of North America. Caughlin and colleagues provide Chapter 9, which takes up issues concerning human decisions and secondary vegetation succession in Panama, featuring a dispute over the interpretation data due to scale mismatch that led to use of high-resolution satellite imagery, followed by eliciting stakeholder via role-playing games so the science team could confirm if its new interpretation of land cover was valid. Perz and colleagues provide Chapter 10, which focuses on their modeling project to evaluate the social and ecological impacts of highway paving in the southwestern Amazon, featuring a suite of issues stemming from the development as well as evaluation of dynamic simulation models. Lam et al. outline in Chapter 11 their experience in crossing disciplinary boundaries to better understand the Mississippi River Delta as a coupled natural and human system. In Chapter 12, I conclude by offering a comparative perspective on the experiences of the teams in the projects reported in terms of their key insights, shared challenges, factors that affected the difficulty of the challenges, notable strategic practices to address the challenges, and recommendations for future teams proposing to collaborate across boundaries.

There is a general conclusion that bears repeating from these diverse experiences. While there are additional travails of collaboration across boundaries, let us not lose sight of the point of these enterprises: they make possible what would otherwise be beyond the reach of the individuals and organizations involved if they worked separately. It is also worth reminding ourselves of the larger purpose of SES science: the understanding and sustainable management of SESs. The road via collaboration across boundaries may be winding and onerous, but the goal is not only valuable but vital. Further, if spanning divides poses additional difficulties, they are complications that can usually be managed through the application of strategic practices. May future collaborators proposing innovative SES science benefit from the hard-won lessons of the teams who took the time to reflect on their experiences in the chapters that follow. This book is for them all, and their respective partners, and the sustainability of SESs everywhere.

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5

Learning About Forest Futures Under Climate Change Through Transdisciplinary Collaboration Across Traditional and Western Knowledge Systems

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5.1 Introduction

Transdisciplinary science is increasingly recognized as critical for sustainability in a time of unprecedented global change (Mauser et al. 2013). However, its effectiveness depends upon addressing many of the challenges

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faced historically with the emergence of interdisciplinary training (Rip 2004; Morse et al. 2007; Borrego and Cutler 2010; Carew and Wickson 2010). Moreover, transdisciplinarity poses additional and unique challenges for successful collaboration (Crowston et al. 2015) when different knowledge systems are involved.

Here we reflect upon the evolution of transdisciplinary collaboration within the context of a coupled natural and human systems (CNH) project about sustainability and future forest landscapes in the context of climate change. Our CNH project integrates diverse expertise and perspectives from a broad span of disciplinary domains including the humanities, natural sciences, and computational sciences, as well as alternative ways of knowing within indigenous and western knowledge systems. While only in the second year of a five-year project, our experience highlights the challenges and opportunities of boundary crossing

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that, upon reflection, have emerged from: (1) the evolution of collaborative networks and team development, (2) group processes and social learning, (3) uncertainties, surprises, and flexibility, (4) inequalities, power, and positionality, and (5) governance and leadership. Our collective navigation through these spaces has illuminated the challenges and practices of transdisciplinary work, while providing a roadmap for deeper learning opportunities.

Transdisciplinary science has many embedded concepts but generally involves elements of (1) *boundary crossing* (disciplinary and research praxis), (2) *critical evaluation and evolution of methodology* ("collaborative deconstruction"), and (3) an intention to *cross knowledge systems* to inform solutions to "wicked" or messy problems (Carew and Wickson 2010; Yarime et al. 2012). Compared to inter- and multi-disciplinary approaches, there is an elevated focus on translational ecology, i.e., including a broader range of stakeholders (Enquist et al. 2017), especially practitioners outside of academia (the scholarship/scholar/praxis nexus),

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and a strong focus on solving problems (Borrego and Cutler 2010; Gibbons et al. 1994). While this mission is aligned perfectly with the purpose of the Sustainable Development Institute (SDI) of the College of Menominee Nation (CMN), a key project partner, it remains a relatively new challenge to western academic institutions. Common barriers to implementation in western academic cultures can include (1) trouble with designing the initial research agenda; (2) advocating for sufficient resources (personnel, time, and money); (3) management of large, complex teams; (4) clear statement of outcomes or impact; and (5) a lack of broadly accepted evaluation metrics (Carew and Wickson 2010).

A key goal of transdisciplinary research is to transcend and transform traditional and often-siloed pathways of knowledge production to unite processes, products, and context (e.g., "Transdisciplinary Wheel" of Carew and Wickson 2010). When transdisciplinarity involves different knowledge systems, as among different cultures, the navigation of differences among pathways of knowledge becomes especially challenging. Given that our CNH project engages in transdisciplinary collaboration spanning indigenous and western knowledge systems, it was necessary to adequately incorporate contributions from both. Moreover, in our project, such translational science is an ongoing evolutionary process in which pathways of knowledge generation are influenced bidirectionally through the interactions of the knowledge systems.

In this chapter, we analyze the challenges of boundary crossing in the context of sustainable forest management under climate change. First, we briefly review our conceptual model of the Menominee forest as a CNH system. Then, we describe key issues and challenges we have encountered thus far, presenting approaches to solutions where applicable. We then discuss some general reflections about how best to manage these challenges in the context of our project. Finally, we conclude with recommendations about stewardship of successful collaboration in the context of transdisciplinary endeavors that address multiple ways of knowing. We hope our lessons learned provide guidance for other transdisciplinary projects with similar struggles or at other stages of project development. More fundamentally, our team aspires to support indigenous peoples' sustainability in the face of the challenges of settler colonialism and climate change, starting with the Menominee experience and finding common experience to assist other indigenous cultures. We aim to support indigenous planning for sustainability by identifying processes that help give voice to indigenous values and finding innovative practices in support of continuance of indigenous identity and resilience. While outcomes may have relevance for sustainability planning in non-indigenous cultures, our concern is centered on the indigenous planning process specifically (Whyte et al. 2018).

5.2 Project Overview

The impacts of climate change are already being felt by American Indians and Alaska Natives (Bennett et al. 2014; Norton-Smith et al. 2016). While the specific impacts vary by region, there are commonalities in the ways these changes are experienced by indigenous peoples, including reduced social capacity for resistance and resilience in the face of historical and ongoing colonialism (Norton-Smith et al. 2016). In the case of the Menominee and other indigenous cultures, innovation has been central to sustainability in the face of historical colonialism, and will be especially important in the context of the current situation given the magnitude of the expected changes and continued oppression of indigenous action in response to such threats. Resilience in response to climate change thus requires approaches to sustainable planning that deepen and strengthen indigenous capacity for innovation. Our project explores an approach that links human values, ecological projections, and visualizations of future forests, with the expectation that this approach can aid indigenous sustainability planning under deep uncertainty (i.e., where both magnitude and probability of future events are uncertain Lempert 2002).

Our project addresses this challenge through two overarching themes. First, we aim to explore feedbacks within and between CNH systems (Fig. 5.1). Feedbacks within the human system occur due to a reciprocal relationship between values and practices, including traditional knowledge (TK) and decision-making. This feedback dynamic influences how individuals and communities arrive at decisions that are often confounded by competing objectives, values, and ultimately, outcomes (e.g., Singh et al.

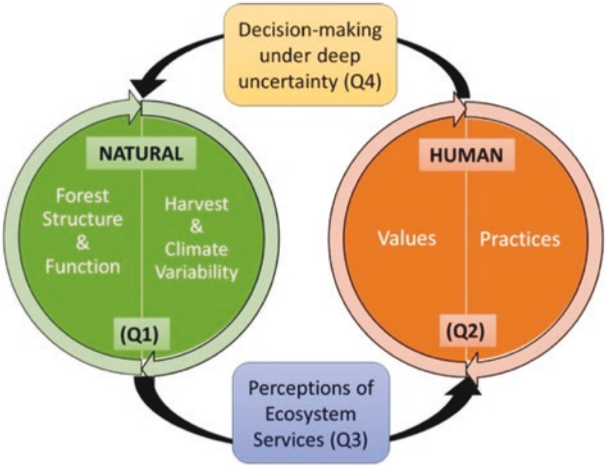

Fig. 5.1 Conceptual diagram showing feedbacks between natural and human systems in the Menominee forest sector (*Source* Figure created by the authors)

2015). Feedbacks within the natural system include interactions between forest change and forest function in the context of climate variability, but are also continuously influenced by processes within the human system, such as management activities that both respond to and cause modification of the natural environment. Feedbacks between the natural and social systems also arise through the benefits people gain from ecosystem services, which inform the decisions they make about natural resource management.

Our second overarching theme is the incorporation of both traditional and western knowledge systems into our science practice. We emphasize this theme to allow a greater space for values transparency. While TK about forests held by many indigenous communities has been recognized as important in the recent US climate change assessment (Bennett et al. 2014), such knowledge does not easily translate into western-style landscape-level planning processes that are often prescriptive and top–down. Rather, tribal planning is often embedded into communal living, through which knowledge evolves through collective planning and doing (a "learning by doing" approach). Our project analyzes these interactions through a collaborative approach that integrates forest change, cultural values, customary practices, immersive experiences, and decision analysis for forests of the Menominee Nation. We hypothesize that decisions that underpin management practices can be made most sustainable when they embrace values (cultural, spiritual, ethical, aesthetic) held by a broad range of individuals and communities. We ask: (1) What are the human values and customary practices that influence preferences in sustainable forest structure and function, and how do they differ among members of the community? (2) How does climate govern changes in forest species composition, productivity, and disturbance dynamics, and how do these changes influence human perceptions of forest condition? And (3) How will human preferences for future forest condition, including those embedded within traditional ways of knowing, influence forest management choices and, consequently, future landscape structure and function?

5.2.1 Study Area

Our study area includes indigenous forest lands of the Menominee Nation and surrounding watersheds located in northern Wisconsin, United States (Fig. 5.2). This region is climatically sensitive and is already experiencing climate change impacts that are reducing forest health and complicating management decisions (Janowiak et al. 2014). Model projections suggest that increasing temperatures will cause declines in many important tree species in the northern lake states under conventional management practices (Duveneck et al. 2014; Janowiak et al. 2014). Projections similarly indicate future expansions of exotic species (e.g., emerald ash borer, *Agrilus planipennis*) in the area. Both changes present numerous management challenges.

Tribal interests are a component of the National Climate Assessment (Bennett et al. 2014), and many tribal groups, including the Menominee, are actively engaged in developing climate adaptation plans or acquiring resources to prioritize adaptation activities. In the traditional culture of the Menominee people, the relationship with nature is embodied in stories describing Menominee origins and governance. The five main clans of the Menominee that symbolize core Menominee principles are: Bear (law), Golden Eagle (justice), Wolf (hunting/gathering), Crane (art, architecture),

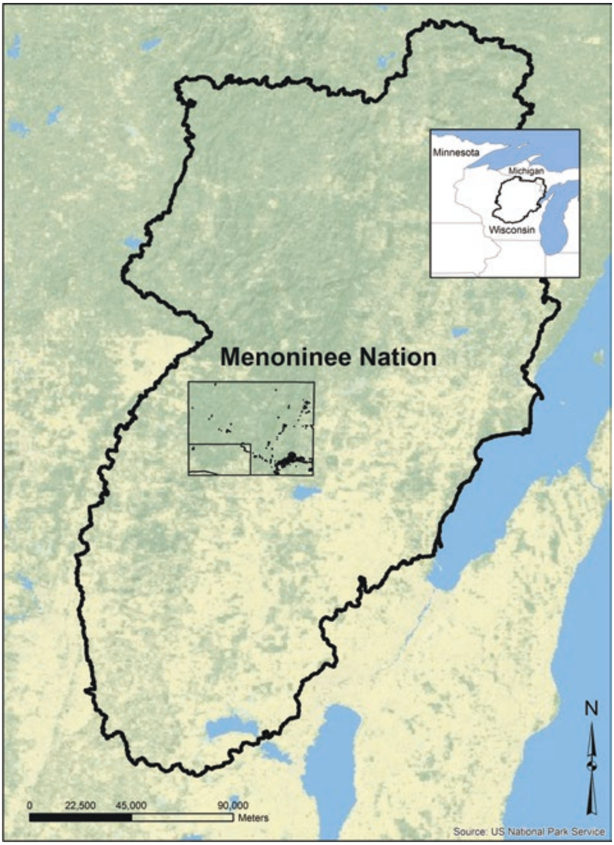

Fig. 5.2 Study area in northern Wisconsin, including Menominee Nation (in box) and adjacent watersheds (*Source* Map created by Melissa Lucash using ArcMap 10.5.1)

and Moose (community and individual security) (MITW 2009). In the nearby region of the Grand Portage Band of Lake Superior Chippewa, moose herds have declined by as much as 60% since the 1990s, which has largely been attributed to changes in climate (Dybas 2009). Biodiversity is thus implicit in the articulation of tribal cultural principles. Hence, threats to biodiversity from climate change could threaten key aspects of tribal identity and management practices.

Through collaborative and sustained work by the SDI of CMN, sustainability has come to be viewed as a dynamic process that spans across at least six dimensions of community life including institutions, economics, natural environment, technology, land and sovereignty, and human behaviors, perceptions, and relationships (Dockry et al. 2015). For example, key *institutions* that influence the governance of the Menominee include the Menominee Tribal Legislature, and the Menominee Indian Tribe of Wisconsin, which is the tribal government structure. In relation to the forest, the Menominee Tribal Constitution, the Trust and Management Agreement, and all forest management plans require that forest lands be managed using sustainable-yield practices. Forest management is conducted by Menominee Tribal Enterprises (MTE), a chartered entity under the Menominee tribal constitution to manage forest harvests, reforest, and produce forest products from Menominee forest lands. *Economic* factors that influence sustainability include the monetary benefits from logging that contribute millions of dollars to the community, as well as subsistence and customary activities such as harvesting of wild rice, medicinal plants, and wild berries, hunting (especially deer), and fishing. In addition to the role of *biodiversity* represented in cultural principles in the creation stories described above, sustainable timber management has been part of Menominee tribal identity and the formal economy since at least the mid-1800s when sawmills were first established on the reservation. Sustainable timber management is driven by a commitment to landscape-level biodiversity and optimal age class distributions to ensure continual productivity for future generations. This stems from the related understanding that forest health and human health are intertwined concepts, which reflects an indigenous worldview in which humans are part of the *natural environment*. *Technology* has been a contributing factor not only in how Menominee community life has changed, but in how they have adapted to change. For example, the Menominee make use of modern technologies such as geographic information systems and harvesting equipment in order to meet sustainable forest management goals as set forward in the MTE forest management plan. Technology has been important in framing tribal identity as well. Satellite imagery of the Menominee reservation clearly demarcates a zone of deeply green forest amidst a sea of agriculture, affirming the forest as a key component of tribal identity and as evidence of Menominee sustainable forest management practices. *Land and sovereignty* affect Menominee values in many other ways, notably through the importance of land and landscape in creation stories, and the dichotomy between the extent of ancestral lands (>10 million acres) and current reservation allotment (~250,000 acres) due to European settlement/American colonialism.

5.3 Boundary Crossing

Below we describe some of the central issues our team encountered during our initial two years of transboundary collaboration. These issues are (1) the evolution of collaborative networks and team development, (2) group processes and social learning, (3) uncertainties, surprises, and flexibility, (4) inequalities, power, and positionality, and (5) governance and leadership. Given that our project goes beyond transdisciplinary collaboration to also address ways of knowing between indigenous and western knowledge systems, our project may be unusually challenging. We describe each challenge in the context of our specific project, hoping to provide an overarching roadmap for other projects, but assume that these challenges may be represented differently in transboundary efforts in other cultural contexts.

5.3.1 Collaborative Networks and Team Development

The organization of our project reflects an evolving network that links key participants and subgroups across departments and institutions over time (Fig. 5.3). The network structure initially leveraged ongoing or past collaborative experiences among team members (Fig. 5.3a). As the project ideas were developing, Nicholas (RN), Caldwell (CC), Tuana (NT), and Keller (KK) were collaborating on a federally funded research project, providing the connections between the CMN and The Pennsylvania State University. That project (a National Science Foundation research network on Sustainable Climate Risk Management

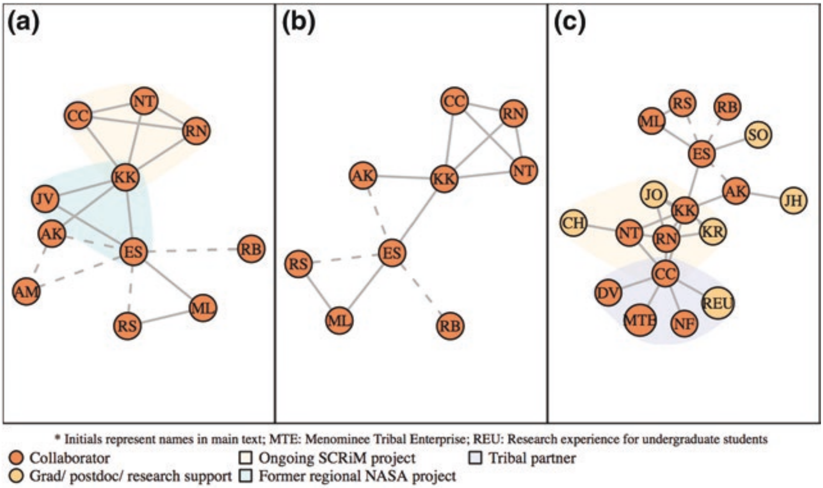

Fig. 5.3 Illustration of the collaborative network evolution of our project. Each node represents an individual who was connected to the project in some way. Solid lines represent formal academic linkage (funded project, co-authorship), whereas dotted lines indicate informal academic relationships (current or former colleagues or peers) (*Source* Figure created by the authors)

(SCRiM)) was a critical foundation for developing trust among institutions and personnel. Moreover, key network brokers Smithwick (ES) and Keller had collaborated on a federally funded NASA research project (Chequamegon-Nicolet Ecosystem-Atmosphere Project (ChEASii)) that had recently concluded, and it was through that experience that trust had developed, and through which familiarity with the region and collaborations with other stakeholders in the region (e.g., US Forest Service) had been initiated. In addition to previous and ongoing funding, other academic roots had been established when Smithwick met Lucash (ML) at a workshop on modeling root dynamics in ecosystems, an experience that led to a co-authored paper (Smithwick et al. 2014). Smithwick and Scheller (RS) had known each other from their time at the University of Wisconsin in their roles as a postdoc and grad student, respectively. Thus, when Smithwick was looking for a modeling group with whom to collaborate, that positive work experience and historical connection was critical, as it provided confidence in a productive relationship. Smithwick was the node that connected the various subnetworks into a larger whole, serving as a network broker. Equally critical was the receptiveness of the subnetworks to engage in initial project discussions. That process was facilitated by respective leaders in each subnetwork, which set the intellectual stage and purpose for deeper interactions among members of the full team.

These past and ongoing relationships were important but did not provide sufficient capacity to carry forward the research plan that was envisioned. Fulfillment of the project's mission also required expertise from people not actively connected through past or current projects. These new participants were familiar to Smithwick or others, either as departmental colleagues or through interdisciplinary centers and institutes. At its core, it was clear we needed people with expertise in philosophy (Tuana), TK and sustainability (Caldwell), landscape ecology (Smithwick), ecological modeling (Lucash, Scheller), robust decision-making (Keller), and climate (Nicholas). In our first proposal, we planned to visualize forests through LiDAR data, via remotely sensed 3-D visualizations of forest structure based on existing datasets. We also sought to include a decision analysis tool and to utilize geoanalytics and geovisualization to aid decision-making. However, our proposal was not successful in this first submission. As a result, the shape of the network shifted as we incorporated reviewer and panel feedback, with the result that two members (JV and AM) voluntarily dropped out between the first and second submission of the proposal as their expertise became less relevant to the direction the project was moving (Fig. 5.3b). These uneasy decisions were made carefully over time, through group deliberations and subsequent one-on-one discussions led by Smithwick. We then added expertise in immersive technologies (Klippel (AK)) and anthropology (Bird (RB)).

Importantly, the project network has continued to evolve over time, as new people have joined the project (e.g., postdoctoral scholars, undergraduate and graduate students, and Menominee faculty; Fig. 5.3c). From the initial set of nine faculty in the submission, we subsequently added informal collaborations with other faculty at CMN (Dennis Vickers (DV)), student interns with the SDI as part of our Research Experience for Undergraduate (REU) program (Curtis Wilhelmi, Nicholas Schwitzer, and Jacob Schwitzer). We also hired computer/data technicians (Jared Oyler (JO) and Kelsey Ruckert (KR)), graduate students (Jiawei Huang (JH) and Stacey Olson (SO), and a postdoc (Casey Helgeson (CH)). We have also strengthened relationships with key personnel at MTE in the context of our project. We continue to build our network as new collaborative opportunities emerge. Recognition of the dynamic evolution of the team network, both in terms of its composition and configuration, has continued to shape the collaboration process. Inclusion of new members brings energy and new expertise, while also building capacity. Yet, it also requires efforts to conscientiously foster inclusion and to provide learning spaces for new members, in order for them to feel fully integrated and empowered to contribute.

5.3.2 Group Processes and Social Learning

In our project, learning has occurred through several types of social experiences, both in the proposal phase and during implementation (Fig. 5.4). Sharing information about the region and about our specific disciplinary tools was a critical process that occurred through meetings and at team events. In addition, we posit that our group also developed collectively as a unit (across disciplines, geographies, and cultures) at key pivot points that went beyond information exchange to involve the development of common purpose and deeper personal bonds that cemented the network structure; we call this "social learning." Across time, we have identified three main phases of this collaboration: Idea generation/courtship, proposal/team development, and official collaboration. As described above, subnetwork structures (e.g., SCRiM, ChEASii) provided momentum and leadership that spawned initial meetings and informal discussions. This led to a visit by the project PI and other team members to the Menominee Nation for a climate summit (further described below), which cemented the common commitment to write a proposal. Proposal development also involved meetings to set the stage for common terminology, problem framing, and the identification of transformative approaches that would be competitive at NSF. The subsequent failure to secure the award in the first proposal (accompanied by

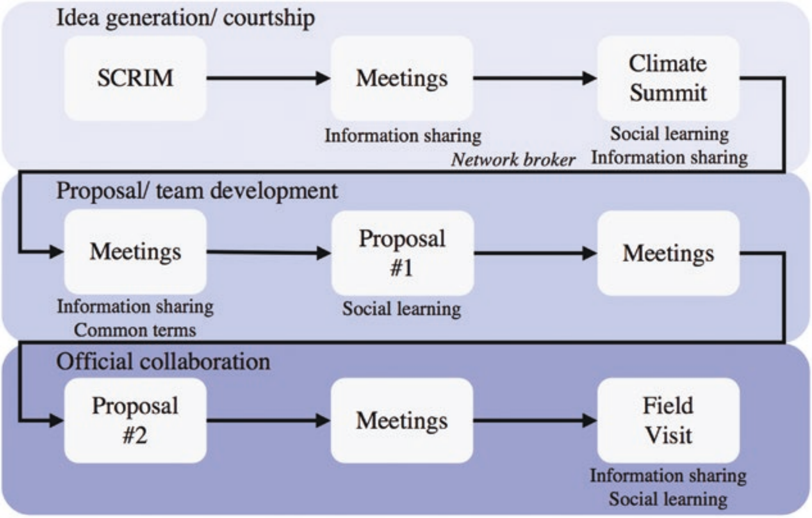

Fig. 5.4 Important phases and group processes that occurred through project development. Official collaboration did not occur until the project was funded on the second submission, almost two years after initial discussions (*Source* Figure created by the authors)

overall positive reviews) provided motivation for continued discussions and meetings that ultimately led to the resubmission. Official collaboration after we secured our award was thus preceded by at least two years of group work. Our group dynamics continued to evolve through initial stages of the project, both through meetings and in-person field visits. Below we describe the importance of some of these key group processes.

One of the most critical group processes has been regular, bi-weekly meetings for information exchange. In addition to discussing regular project management tasks, these meetings have been seen by the team as important for identifying divergent understandings of important technical concepts and stewarding group decision-making. In addition, social learning has occurred informally and at team events. For example, during the proposal phase, it was not uncommon for key discussions to occur while walking across campus or in the hallway. In these cases, it was important that the results of those discussions be communicated back out to the full group, which was usually the responsibility of the PI, either via email or meetings.

Two events in Fig. 5.4 represent longer, in-depth experiences that were critical to team evolution and social learning. In the proposal phase, this included a trip by three faculty members from Penn State to visit the Menominee Nation to participate in a tribal summit on climate change adaptation. This event was critical for better understanding of the locale for the Penn State team members and also allowed for deeper and richer conversations with Menominee tribal members, extant academic experts, practitioners, and project personnel. The meeting was a watershed event in several ways. It provided time to discuss key issues in person with our Menominee partner (Christopher Caldwell) and provided ample opportunity to consider indigenous perspectives on climate change adaptation. The fact that we had this collective experience helped to build trust and provided a common platform for subsequent discussions.

The second experience occurred approximately one year after the project was funded: a field trip with all PIs and Senior Personnel to the region, hosted by the CMN. The experience allowed all team members, particularly those not from the Menominee Nation, to come to the same intellectual place in terms of understanding the geography, institutions, and stakeholders. It allowed space for the team to have common though sometimes difficult or uncomfortable experiences, which were very important for shared learning. For example, the team had to consider how best to introduce our project so as to be respectful of other ways of knowing and other perspectives that were not, perhaps, adequately considered in the proposal phase. For this, we were guided by our co-PI, Chris Caldwell, a tribal member and Director of the SDI at CMN. Interestingly, the team was continuing to learn as a group and to navigate relationships across boundaries, even though we had already received our funding and had an agenda, or we feared, a perceived agenda. The field trip allowed for navigation of tensions among participants via formal and informal vetting of these concerns that would not have been possible within shorter meetings or video conferencing. In the process, the field trip also provided a chance for social bonding, especially for members of the team who had not yet met in person. Opportunities for breakfasts, dinners, long car drives, etc. allowed for telling of tales and shared experiences that gave rise to inside jokes. We now know who needs coffee first thing in the morning, what pizza not to order, and how to be flexible if the rental car gets a flat tire. These intangible shared understandings, which occurred early in our project, were critical for fostering social cohesion and a sense of common purpose in the team thereafter.

5.3.3 Uncertainties, Surprises, and Flexibility

Inevitably, every large project is met with uncertainties and surprises along the way, and ours was no different. In just the first two years of the project, we had turnover of staff helping to manage our budgets, leadership changes at key partner institutions, one PI switched institutions, babies were born, team members or their families got sick, and graduate students and postdocs were recruited and brought into the fold. These events typically bring new opportunities as well as management challenges. Most changes can be navigated logistically by shifting resources or adjusting timelines to ensure that every individual has the capacity to participate in their healthiest and most robust ways. Professional development and personal and family health are profoundly important at the individual level, and should be anticipated at the project level. Thus, we felt it was important to our team to navigate these changes respectfully and swiftly. By doing so, we gained confidence in our ability to adapt to unanticipated events.

A true test of team flexibility in response to uncertainties and surprises occurred across some of the intellectual boundaries spanned by the project. The first of these surprises, to many of us, was the gulf between modeling communities. In our project, we are deploying computational modeling approaches that have developed in two different disciplinary communities. Consequently, each modeling approach has its own scholarly literatures, data streams, technical requirements, software development practices, and objectives. While their union is, in and of itself, a scientific outcome of the project, we are continually surprised at how hard it is to bring them together. Challenges of integrating modeling approaches are not new, and we were not naïve about them. Indeed, we tried to anticipate roadblocks by devoting personnel and computing capacity to the effort and constraining our proposed outcomes to be commensurate with the task at hand. Yet, challenges have remained. At the outset, it became clear that the promised work of the proposal would require more computational resources than anticipated. Put simply, this is because one model (the donor model) feeds into the second model (the receiver model), but the former is computationally expensive, i.e., takes significant time and computer power to do the work. We thus faced challenges and questions such as the following: Would we be able to run enough modeling scenarios to sample the deep uncertainties sufficiently? Should we port the model across institutions to enhance its speed? Should we consider changes to the model software design and programing language to facilitate better model integration? Did we have the time and resources to devote to improving the donor model such that we would be able to implement the receiver model?

In addition to these challenges, the science of the donor model was itself being updated as a normal part of its evolution, causing necessary but unanticipated delays. As these issues were being navigated, a more esoteric but ultimately foundational quandary arose: What was meant by model calibration, and were the approaches translatable in a way that was trustworthy by both groups? Put simply, one approach was grounded in expert knowledge, skill, and empirical relationships (which was seen by some as containing more subjective elements than desirable to the other modelers and missing key diagnostics), while the other is rooted in physical logic and statistical metrics (which was perceived by some to have lower flexibility and transparency). In truth, these remain more as conceptual roadblocks than practical ones, but have fostered rich and unanticipated conversations about scientific practice.

While many issues remain, we have addressed some of these challenges in a preliminary fashion through several practices. First, we conducted an exercise to individually define key terms (e.g., calibration) by all project participants (not just the modelers). Although we have not converged on common definitions, and perhaps never will, the process enhanced transparency which has facilitated communication and common understanding. Second, we were able to leverage resources from other sources to devote more personnel time to port the model from desktop to high-performance computing systems. Our issues also aligned with strategies that Penn State was taking, in general, to improve high-performance computing and cloud-based resources; as a result, we donated some of our code to Penn State computing personnel to test. Subsequent discussions led to insights about how the donor model could be recoded to meet modern standards, an effort that has been pursued and completed outside our specific project objectives. Finally, we made the decision to have separate meetings devoted to modeling and computing capacity to allow for longer discussions about how to navigate these and future challenges.

A third surprise in our project occurred due to obstacles in the implementation of our human participant research. Approval was delayed due to institutional concerns about, most importantly, the sovereignty of TK. The surprises in question stemmed from the delay itself, which had cascading effects on project implementation. Although we had approval to commence our project, we were forced to consider a slower ramp-up to our human participant work. In the meantime, we decided to initiate a set of pilot projects, which could be done in advance, that would provide a testbed, incubator, and accelerator of our intended methods. Each of the pilot projects yielded pleasant surprises in the form of valuable insights that have facilitated important decisions regarding future directions of the overarching project. In the first pilot project, we recruited students at Penn State to test how best to elicit values from immersive virtual reality imagery, in this case related to trees on campus. This project has helped us refine our sampling strategy to be more efficient. In the second pilot, we are modeling the implications of emerald ash borer killing all ash trees in the region with the goal of providing proof-of-concept results that could be used in subsequent conversations with stakeholders, while providing insights into general data-model gaps or issues. In a third pilot, we attempted to develop a workflow for translating preliminary model results into virtual reality forest imagery. The work has resulted in a submitted publication. Finally, we came to depend more heavily than intended at this early stage of our project on archival data from previously completed interviews with tribal elders that were part of the public record. This accelerated analysis of archival data allowed us to move forward with the scenario modeling (i.e., the importance of emerald ash borer to multiple dimensions of the Menominee sustainability model). The scenarios in turn provided insights into customary practices of the Menominee (i.e., the cultural importance of understory plants), which is helping us identify opportunities for anthropological studies that intersect with the overarching goals of the project.

5.3.4 Inequalities, Power, and Positionality

Though our project is still in its early stages, our awareness of transdisciplinarity has engendered an openness to considerations of how inequalities, power, and positionality are already impacting our work. Political ecology (Adger 2001; Ingalls and Stedman 2016; Robbins et al. 2010), critical physical geography (Lave et al. 2018), work within science and technology studies (e.g., Jasanoff et al. 1995), critical indigenous studies (Moreton-Robinson 2016), to name a few subfields engaged in this discussion, all point to the very nature of what we are studying, why we are studying it, and how we are studying it as exemplifying both implicit and explicit power relations. Why are we studying forestry and not rice cultivation given that Menominee identity, though now rooted in forestry, was historically in rice cultivation? How do we acknowledge this colonial influence while still bounding our project around forests? Does work on individual interviews unveil a western assumption that imposes a value on individual knowledge, versus relational and collective knowledge? Does our choice of model design, by not explicitly including understory plants, create the perception that our project undervalues cultural, spiritual, and customary relations of those species? Even more fundamentally, the Menominee already view their decisions as being made with the best possible information, even in the face of uncertainty, and do conceptualize they are making "trade-offs" among competing objectives in this decision space. Rather, objectives are often seen as synergistic and mutually reinforcing. To what degree does greater transparency of these decisions actually add to the planning process? These and other questions underpin many aspects of our current and future project development.

In addition, the positionality of participants within the power structures of their own community or institution imposes unintentional imbalances within the team. For example, because many team members are positioned within a research-based, academic system, the professional (and personal) benefit of crossing ways of knowing is rarely recognized through traditional academic reward systems. In absence of this feedback, individual satisfaction about the process becomes more important for ensuring continued participation. Similarly, CMN does not have a graduate program and does not require its faculty to engage in research, reducing potential incentives for engagement. Moreover, because CMN is a tribal college, resources and staffing are a continual challenge for SDI, despite an increasing number of projects and tasks.

The very fact that our project is funded by the US National Science Foundation means that there is an obligation that the federal dollars spent on the project result in products that have "intellectual merit" and "broader impacts." This funding similarly supports the careers of both junior and senior students, postdocs, and faculty. As a result, for many project participants, there is an expectation of publishing in peer-reviewed journals, despite the fact that the project's goal (and, in particular, SDI's participation) is rooted in responding to the needs of the community. Although recognizing the needs of publication for project participants, there is concern from the Menominee about how those results may be interpreted in the future. As a result, deliberations about how to use TK in western publications and respect for data sovereignty are critical for building trust in the publication process. On top of this challenge, publication expectations are different among disciplines (e.g., humanities versus natural sciences). Making these disciplinary assumptions explicit constitutes an additional challenge to navigating differential expectations of benefits from the collaborative process. Spanning disciplinary and deep cultural boundaries represent different manifestations of how our position influences work flows and goals.

In addition to these philosophical and cultural considerations, there are more practical issues relating to project structure and management. For example, due to the fact that students and postdocs joined the team after project initiation, there has been uneven participation in social learning processes. Fostering a sense of inclusion is challenging when the team includes members who were not part of the original network, who joined at different times, or who have narrower or more specific roles in the project. Relating lessons learned from previous experiences to newer members is challenging out of context and could, in and of itself, be seen to foster boundaries (e.g., "you had to be there"). In addition, the evolving nature of the network means that not everyone entered the project with the same common understanding about how and why people or activities were stitched together. An inherited sense of team cohesion built from early experience may have inadvertently intimidated newer team members, especially those with positions that explicitly have less agency or power, from feeling comfortable to speak up. Navigating these perceived power differentials and communication deficits requires continual and intentional trust building. Cultivating common experiences throughout the project remains a critical priority to ensure that knowledge co-production includes all team members to the greatest degree possible.

Finally, latent power dynamics among senior and junior members of the team are inevitable in any academic endeavor. In our case, some participants are representative experts in their respective intellectual domain and the team depends on their guidance, especially at pivotal moments. However, respect for this contribution ought not to be conflated with power such that assumptions, ontologies, and epistemologies are not challenged or questioned. Being aware of such blind trust can subvert deeper critiques of contributions that may in fact have deeper value to the long-term project. Creating a space where those deeper questions are discussed (i.e., How does robust decision-making differ from other forms of decision-making? How do values-informed mental models actually work in practice? Why is it hard to model a tree in virtual reality?) has been critical to subverting tensions and finding common purpose.

5.3.5 Governance and Leadership

Among team members, there is uneven understanding of the management structure of our project. Based on an informal, internal review, some team members view the project as run through a "standard" PI type management structure in which PIs and Senior Personnel lead the decision-making, with an absence of a formal group decision-making process. To others, the management structure is seen to be part of an egalitarian group planning process with space for significant individual self-direction, as part of a "weak hierarchy." Yet others see the project as multi-core in that there are "specializing groups" that meet outside of the full group to work on separate topics, exchanging products and thoughts intermittently with the full group, but that decision-making within the full group is collaborative.

Regardless of its label, the lack of group consensus about the management structure has both fostered and constrained our team's work. On the positive side, there is a shared sense of ownership about the project, i.e., that everyone has a role and that everyone's ideas are welcomed and addressed. Everyone is genuinely interested in advancing the project science and is thus willing to contribute. The relatively egalitarian collaboration among PIs has been a necessity because of the extensive breadth of disciplines involved; everyone needs each other to push the project forward.

On the other hand, the complexity of the project can be overwhelming, especially when there are conceptual or practical misunderstandings. We all bring different knowledge and skills to the project, but this can be confusing at times, especially if there is not enough sustained work to unpack some of the more critical questions. Our early approach to this has been to split into subgroups for the deeper work, coming together regularly for face-to-face meetings to report back and prompt group decision-making. There simply have not been sufficient resources in our project to promote deeper collaborative interfaces. Though arguably a necessity for the early stage of the project, an unfortunate outcome is a perception of "stove-piping" project elements, in which subgroups focus on a narrow subset of the full problem before regrouping, which could result in some aspects moving forward more quickly than others or dismissing the important but hard work of collaborating on difficult problems with input from the larger team. One example of this has been model integration. Over time, different disciplinary workflows, conceptual framings, and technical limitations among model subgroups have become increasingly transparent. Being aware of conceptual or practical differences has however only emerged slowly over time as groups re-align their efforts. The differences are not necessarily bad—they enhance learning, once perceived—but there is an argument for addressing them up-front.

Navigating such a complex research team and set of challenges and their cryptic opportunities naturally places a significant spotlight on the leadership of the PI. Being receptive to input from others and ensuring that all parts of the project are integrated, at the right times and in the right ways, is a crucial duty. This is particularly challenging when work occurs in subgroups, as there are expectations that the PI ought to be aware of their progress, as well as emerging issues in subgroups that might threaten that progress or undermine team cohesion. This necessarily means more meetings and emails, of course, and more work to tether groups together along the way. Being aware of when to intervene, and alert to when issues rise to the level that they ought to be discussed in the full group, is critical for gaining trust by team members. To date, this has largely manifested in respectfully “leading from behind,” allowing subgroups or individuals to move forward at their own pace, while coordinating their interactions from above. Such an approach is dependent on the PI having deep trust in the workings of those groups, based on a sense of the underlying group cohesion and common purpose. Ensuring that everyone is on the same page—even if it is only clear to the PI—can be difficult. Shadowy understandings of the plan, within or among subgroups, can foster insecurity about the group’s common purpose, which can sow group tension. It is the role of the PI to detect when the group may be stuck, heading into potential dead-end situations, or mired in uncertainty. While a natural part of science generally, leadership that navigates these difficulties well is even more critical in transdisciplinary teams.

5.4 Discussion: Managing the Challenges of Transdisciplinarity

A transdisciplinary approach includes team-based efforts to engage deeply with and understand the methodological approaches of each other’s disciplines to the point that those methods can be deployed effectively and synergistically with other approaches to meet project goals.

This is expressed through iterative evaluation and evolution of methods, including the development of new methods that facilitate interactions *across* disciplines. As described in the previous section, it has become clear in the first couple years of the project that surface-level comprehension of, for example, how a particular model works, has been insufficient to provide meaningful understanding of how that model (1) can be effectively utilized or (2) can be tethered to other tools or models. More generally, it has become clear that the need to understand "under-the-hood" workings of particular methodologies necessarily permeates across all our project components (e.g., ecosystem modeling, values-informed mental models, robust decision-making, immersive virtual reality, and customary practice), and that collaborative deconstruction requires a substantial devotion of time.

Although there is no expectation that other team members become experts in each other's tools, the success of our project depends on elements being expertly interwoven throughout the duration of the collective enterprise. While other interdisciplinary projects may get by through passing off completed products from one subgroup to another, or merging stove-piped work packages only at end of the project, our project requires and is motivated by the idea that integration occurs early and often. Specifically, we rely on ecosystem model results to produce visualizations of forest futures, from which we aim to elicit values. This had to happen early in the project, since a key later step is to evaluate how trade-offs among values can inform robust decision analysis in the context of value framings and model uncertainties. What is more, these efforts are iterative, such that new information about value trade-offs can support new strategies in ecosystem modeling and visualization.

Managing disciplinary gaps is an inevitable but critical process for managing our transdisciplinary collaboration. First, many of us are not used to working in close collaboration with scholars from disciplines as diverse as the physical or biophysical sciences and the humanities. While many researchers entered the project with experience in interdisciplinary teams, these experiences could only marginally inform the current project. This is because all participants are working with at least one, if not more, new disciplines, such that none of us were exempt from climbing a steep learning curve. Second, as in any endeavor involving multiple disciplines, the challenges are often emergent, and how a team responds is dependent on the individuals in the group and the particular problem being addressed. In our case, we identified significant language barriers around key terms (for example, "sustainability" or "calibration") that continue to cloud coherent application of the terms in the work of the project. While language or ontological barriers are not a particularly novel challenge in interdisciplinary work, the particular terms, and the particular ways in which the communication challenges are manifest, is likely to be a project-specific problem. However, early identification of these challenges are also targeted opportunities for group learning and consensus building, as demonstrated earlier in Fig. 5.4.

In addition to disciplinary boundaries, our project also crosses boundaries of ways of knowing across indigenous and western knowledge systems, providing additional lessons about managing collaboration. Though our project embraces this challenge explicitly, many of us continue to struggle to understand when we are crossing boundaries across knowledge systems. Although members of the Menominee nation are included in the leadership team, and although many of us have experience working with people from other cultures, detecting signposts that we have inadvertently misinterpreted each other's intentions or overstepped cultural norms is a persistent challenge. While our project has hopefully not committed any grievous error in this regard, the conscious awareness that we *could* do so provides a cautionary (and, we think, healthy) overtone to most of our interactions. Yet, in most cases, we do not know what we do not know and cannot anticipate lines that could be crossed, despite good intentions. Deepening cultural competency about Menominee history, traditions, practices, and worldviews is a critical, and ongoing, necessity for our team moving forward. Practices and opportunities for doing so are difficult. To ameliorate this, we have a common shared computer folder for sharing important papers about practices for engaging scientifically with TK. We also place value in on-site field visits for gaining cultural competencies. And, we rightly have a member of the Menominee Nation (Caldwell) as a co-PI on our project, who can guide us and be a network broker in the community.

Finding new ways to communicate and collaborate across physical boundaries has been a key component of our team's successful collaboration. This is a critical consideration given that our academic institutions are spatially remote across four states: Pennsylvania, Wisconsin, North Carolina, and Oregon. Although critical for the deeper work of collective, sustained deliberation and opportunities for gaining cultural competencies, it strains the financial resources of the project. Despite these efforts, we are aware that we are continually crossing cultural divides and ways of knowing among knowledge systems, likely missing opportunities for informal learning. Also, given that we are meant to create immersive experiences about the forest environment, being in and near the forest is critical, but this has not been possible on a regular basis for many on our team, particularly those charged with developing the imagery and stories. Thus, we continue to leverage our project to seek additional internal and external resources to support this travel, with some success. For example, we have provided resources to CMN for personnel from the college to be trained on how to use the cameras so that they can collect imagery on behalf of the project. One of the most salient ways we have addressed the problem of not having resources for senior personnel to collect digital data is by bundling project activities. Specifically, we decided to focus our REU program on immersive experiences. In its first year, our REU program supported three interns at the SDI at CMN to collect and develop immersive digital videos. Having students engaged for up to 10 weeks with the sole purpose of focusing on immersive products was extremely helpful. The students were able to interact with tribal elders, visit key forest areas, and then subsequently come to Penn State to use virtual laboratory space and software to develop a product that was shared back to the community and which provided imagery and information that we will use in subsequent scientific efforts.

5.5 Recommendations

Based on the reflections above, we put forward a set of overarching recommendations for stewardship of successful collaboration in the context of transdisciplinary endeavors.

5.5.1 Recommendation #1. Adopt an Iterative, Reflexive, Respectful, and Reciprocal Social Learning Process

Our project development and initial implementation has highlighted the importance of an iterative and a multi-tiered and social learning process. Lessons from other domains (e.g., in software development: Royce 1970; Boehm 1988; Scheller et al. 2010) also point to the importance of evolutionary and adaptive processes in group learning. In our case, this has manifested through multiple levels of learning experiences (e.g., meetings, field trips, breakout groups). For example, given everyone's busy schedules, it is easy to dismiss the importance of the regular bi-weekly meetings. In contrast, our team finds these to be critical for regular communication as well as for shorter deliberations around key issues. In addition to these iterative events, there is also a craving for experiences that provide opportunities for reflexive learning, where the hard work of reconciling ontologies or methods is done. For example, our approaches to model calibration are very different between ecological modelers and those involved in robust decision analysis. While an interdisciplinary approach would have the potential for success if one model group passed off the model results to another team, our transdisciplinary project necessitates richer conversations about how choices about calibration inform uncertainty or constrain computational capacity in light of downstream applications with non-academic stakeholder groups. Ensuring a multi-tiered approach that embraces both iterative and reflexive components requires greater attention to project management, more time, and greater flexibility and patience among participants.

Moreover, navigating opportunities for reciprocal social learning across western and TK systems requires respectful and reciprocal engagement among participants. Logistical constraints (funding, time, geographic distance, differential institutional obligations) hinder the ability to react quickly and can slow the learning process. To address this, it is important to embrace respectful and reflexive approaches from an early stage in the process so as to anticipate challenges and, as much as possible, start from a position of shared trust. Many of these approaches are well-studied in critical indigenous research methodologies (Angal et al. 2016; Harding et al.

2012). In our case, there was also a recognition that it would be important to involve tribal members purposefully as project leaders, with the understanding that this could increase the resilience of indigenous planning processes for climate change (Norton-Smith et al. 2016). We included tribal members as co-PIs in the project, beginning with the proposal phase. We also ensured a tribal review as part of the institutional review board (IRB) approval process for participatory research. Finding additional ways to decolonize our methodology presents an opportunity to be reflexive in response to Menominee culture and history, while respecting ways of knowing that may be unfamiliar to western knowledge systems. Ensuring there is respect for this process, as well as for all participants at a personal level, is very important for spurring intentional, integrative work.

5.5.2 Recommendation #2. Foster Curiosity

Curiosity is vital to discovery. Thus, in order to explore the interstitial spaces among disciplines, it is critical to turn any uncertainties into questions. In so doing, unsettled intellectual spaces between disciplines can lead to new questions and new insights. Individuals may have uneven capacity to embrace these uncertain spaces. It is therefore critical that the PI work to ensure that (1) exploration of these intersections is a positive and mutually enriching experience, by (2) communicating to all participants (especially new and junior participants) that they are in a space that is not fully understood (even by the PIs), in order to then (3) provide the guidance needed to navigate these gray areas. To do so, it is important to nurture and embrace curiosity by being aware of when the project has hit a gray space between disciplines and calling for reflection as an opportunity for learning. It is also critical that the project ensures an equitable environment that stimulates healthy and robust discussions about the true nature of inter-domain question(s) and whether there are resources to adequately address them.

5.5.3 Recommendation #3. Cultivate Common Purpose

Overall, despite the challenges of navigating transdisciplinarity and the hard work involved, our group has been dedicated, actively engaged, and productive, and we are enjoying it. Why? One reason may be the tremendous *respect* about what each individual contributes to the team effort. Even if some understanding is lacking, we are respectful in the way people—and their disciplines or knowledge systems—are treated in the team. Respect is revealed in interactions at a personal, individual level, in one-on-one dialogues, and in group settings. Another reason concerns a sense of *integrity,* a general sense that we all want to do the project well. This may partially reflect a collective humility that we are seeking to cross wide, deep boundaries, as between very different disciplines and profoundly different knowledge systems, that are difficult to navigate. Yet, we, individually and collectively, feel the work is important, *right*, and meaningful.

Our project is based on a shared understanding stemming from a common framing of the general challenge of transdisciplinarity: that there are difficult trade-offs among epistemic and ethical values when spanning knowledge systems. Perhaps more so than in many interdisciplinary projects, or other transdisciplinary and translational projects, our explicit focus on crossing knowledge systems between indigenous and western cultures necessitates that we have a deep understanding of these epistemic and ethical issues. As such, our project promotes a sense of integrity from its very foundation, which is further promulgated by individual intentionality rooted in mutual respect. As a result, there is a current permeating our work which is to do the right kind of science that helps humans and non-humans navigate uncertain futures. Dedication, respect, responsibility, reciprocity, and integrity are the roots that support our stem of common purpose, which in turn branches out into our joint activities, bearing the fruits of learning about sustainable systems.

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