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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.

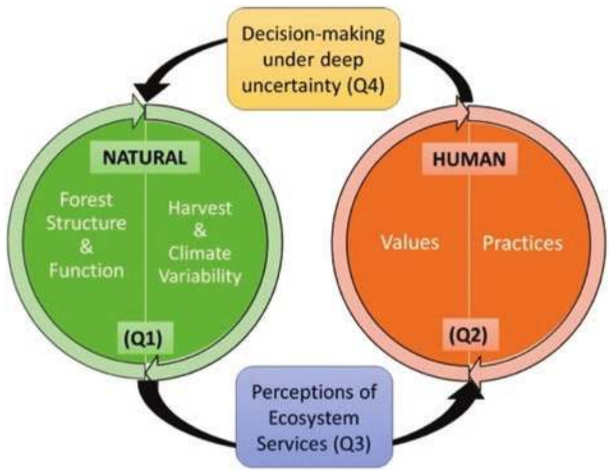

Fig. 5.1 Conceptual diagram showing feedbacks between natural and human systems in the Menominee forest sector (*Source* Figure created by the authors)

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),

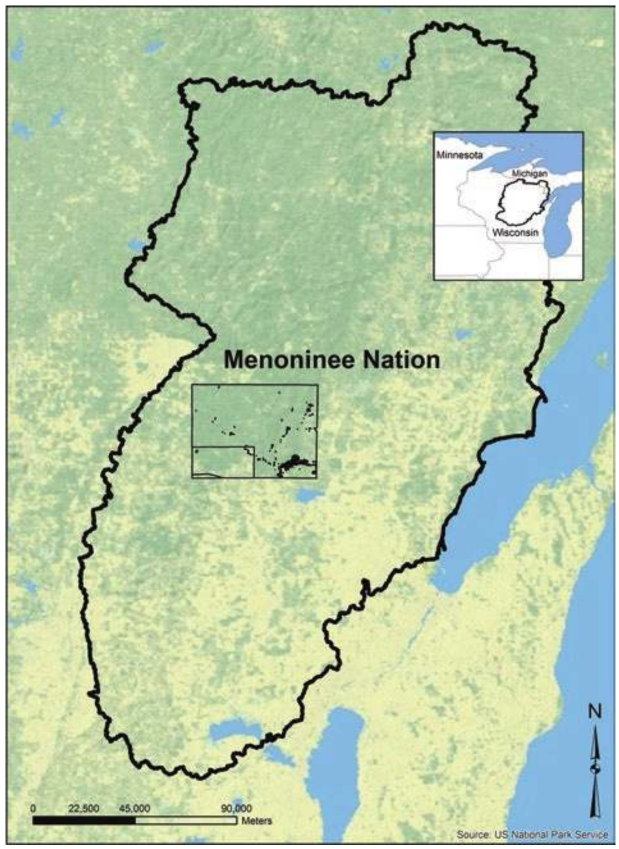

Fig. 5.2 Study area in northern Wisconsin, including Menominee Nation (in box) and adjacent watersheds (*Source* Map created by Melissa Lucash using ArcMap 10.5.1)

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

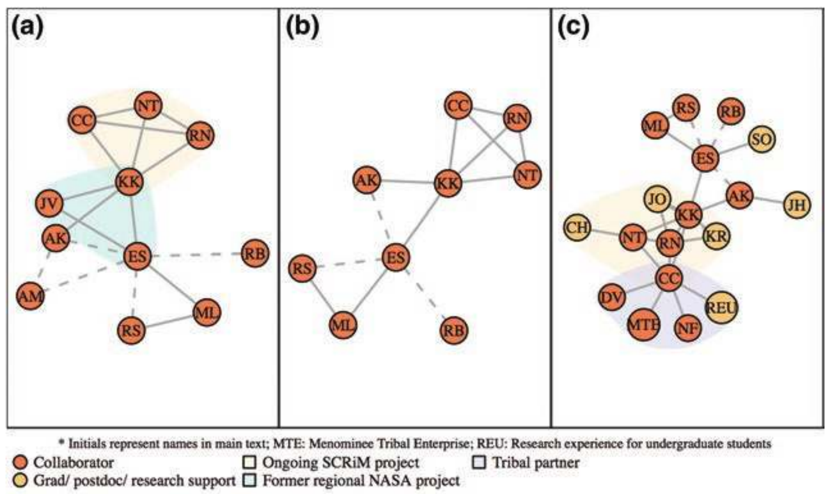

Fig. 5.3 Illustration of the collaborative network evolution of our project. Each node represents an individual who was connected to the project in some way. Solid lines represent formal academic linkage (funded project, co-authorship), whereas dotted lines indicate informal academic relationships (current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

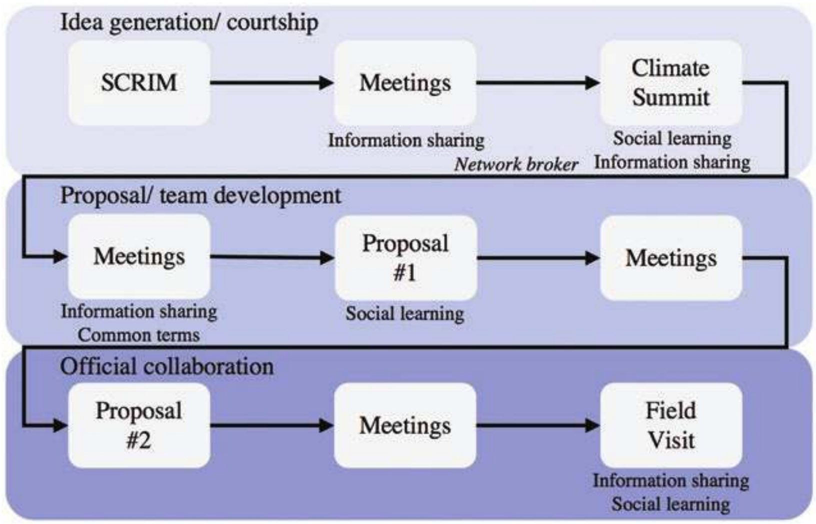

Fig. 5.4 Important phases and group processes that occurred through project development. Official collaboration did not occur until the project was funded on the second submission, almost two years after initial discussions (*Source* Figure created by the authors)

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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