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Lessons Learned About Collaborating Across Coupled Natural-Human Systems Research on Mexico's Payments for Hydrological Services Program

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2.1 Introduction

Of the many ecosystem services, hydrologic services are arguably one of the most critical for sustaining human societies and yet one of the most threatened. With growing global dangers of water scarcity and declining water quality (Liu et al. 2017), payment for hydrologic service (PHS) programs have surged over the past two decades (Goldman-Benner et al. 2012; Kaplowitz et al. 2012; Leimona et al. 2015; Postel and

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Thompson 2005; Porras et al. 2008; Stanton et al. 2010). By connecting ecosystem service "suppliers" and "consumers" in ways that explicitly incorporate a market value for such services, PHS programs seek to eliminate the externalities distorting traditional markets and create incentives for conservation that are equal to or greater than the opportunity costs foregone by limiting land use options. If successful, such approaches could vastly improve the supply, quality, and regulation of water resources within individual countries and globally.

PHS policies inherently operate within coupled social-ecohydrological systems. PHS policies are designed to enhance hydrological services provided by *biophysical systems* by eliciting certain desirable behaviors from *social systems* through incentives that target the associated *economic systems*. PHS programs generally seek to forge linkages between upstream and downstream natural and human communities. These linkages result from hydrologic flows through watersheds as well

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as from the relationships between producers and consumers of water resources. Interactions and feedbacks within payments for hydrological services-social-ecohydrological systems may be intensified by intended or unintended effects on the social system, for example, poverty alleviation or the equitable distribution of resources (Wunder 2015), or the biophysical system, particularly carbon sequestration and biodiversity (Wendland et al. 2010). Such effects may interact either synergistically or antagonistically with hydrologic services, resulting in complex feedbacks, interactions, and tradeoffs that may lead to unexpected and often surprising outcomes within coupled social-ecohydrological systems (Jenerette et al. 2006; Lebel and Daniel 2009; Porras et al. 2008).

An academic debate around the effectiveness of PHS in social-ecohydrological systems has emerged in recent years due to the limitations in assessment of environmental and socioeconomic outcomes. This is in part because of the complexity of PHS schemes, combined with an overall lack of systematic monitoring and evaluation.

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For example, a global meta-analysis performed by Brouwer et al. (2011) found that only 47% of PHS programs actually monitor impacts on service provisioning. In Mexico, a study contracted by USAID found that 40% of 45 local matching programs do no monitoring whatsoever, with the rest monitoring forest cover rather than water resources per se (Saldaña-Herrera 2013). Consequently, PHS programs have come under increasing scrutiny worldwide (Börner et al. 2017; Muradian et al. 2013), and the potential for PHS programs to enhance watershed sustainability has been questioned (Asbjornsen et al. 2015). Thus, substantial uncertainty remains about the ability of PHS programs to directly influence peoples' decisions related to water resources, especially over longer time periods or in response to different PHS program structures (Brouwer et al. 2011; Hayes 2012). Accurately quantifying and predicting the effects of coupled PHS and social-ecohydrological systems interactions is therefore critical to establishing a sound theoretical framework for policy decisions that links scientific knowledge with practical solutions for protecting hydrological services, while maximizing benefits to society (Grima et al. 2016).

One of the first and longest-running PHS programs worldwide was established in Mexico by the national government in 2003. The program, referred to as *Programa de Pago por Servicios Ambientales Hydrologicos*, was created in response to a presidential decree that the protection of water resources—and the forests considered essential to providing those resources—is a matter of national security. The program expanded from US$17.9 million in payments to 272 landowners of 127,000 ha in 2003 to a total of US$628 million paid to 9521 landowner groups with holdings of 5.83 million ha by 2017. This program was financed through payment of water concessions made by the National Water Commission (CONAGUA) to the National Forest Commission (CONAFOR), as well as from funds directly allocated by Mexico's Congress. The PHS program was envisioned as a mechanism for providing financial incentives to landowners to conserve their forest cover in key watersheds identified on the basis of the presence of priority ecosystems, proximity to national parks and downstream cities, the degree of aquifer overexploitation, and overlap with poverty alleviation programs (Alix-Garcia et al. 2015; McAfee and Shapiro 2010;

Muñoz-Piña et al. 2008; Perevochtchikova et al. 2012). In 2008, an additional local matching program was created by CONAFOR aimed at promoting greater participation by local stakeholders and financing for the PHS program by local governments and other partners that contribute at least 50% of operating funds (Nava-López et al. 2018). Recent trends throughout much of Mexico (including our study region) suggest a transition from the nationally supported program to matching fund programs cofinanced by both local sources and CONAFOR under diverse administrative structures. More recently, PHS programs throughout much of Mexico (including our study region) are managed under diverse institutional arrangements, including municipal government agencies and non-governmental organization (Nava-López et al. 2018). Mexico's PHS program typifies common approaches globally (e.g., Grima et al. 2016; Salzman et al. 2018; Sanchez 2015) and thus provides a model system for assessing interactions between PHS programs and complex dynamics occurring within coupled social-ecohydrological systems, as well as the associated constraints and opportunities for enhancing watershed sustainability. Due to the long history and diverse institutional arrangements, PHS programs in Mexico are representative of PHS programs throughout Latin America (Ingram et al. 2014; Grima et al. 2016; Hayes et al. 2015) and thus provide a model system for assessing interactions between PHS programs and complex dynamics occurring within coupled social-ecohydrological systems, as well as the associated constraints and opportunities for enhancing watershed sustainability.

Another emerging tool within watershed management among diverse actors is involving the public in scientific research, or citizen science (Bonney et al. 2009). Citizen science is increasingly recognized worldwide as an effective, low-cost means to collect large amounts of data for natural resource monitoring and management. Not only can citizen science provide data at spatial scales and resolutions never before attainable (Wright et al. 2015), but many argue that it can directly impact participants' perceptions, decisions, and behaviors in ways that are aligned with resource management goals (Crall et al. 2012). However, the success of these projects rests on the assumption that citizen science volunteers are easily recruited and valid data easily collected, despite a dearth of evidence on best practices for securing such participation (Bruyere and Rappe 2007). Moreover, few studies have examined the effect of citizen science interventions on stewardship behaviors and perceptions (Follett and Strezov 2015). Therefore, developing an approach to designing citizen science programs that explicitly allow for assessment of program impacts on volunteers can provide valuable data for determining the potential complementary role of citizen science in enhancing the effectiveness of PHS programs.

With this in mind, the overarching goal of our research was to advance the fundamental understanding of linkages, interactions, and feedbacks between Mexico's PHS program and coupled social-ecohydrological systems. Of particular interest was to conduct an interdisciplinary evaluation of the capacity of PHS in Mexico to achieve stated outcomes (e.g., enhanced forest conservation and water quality and quantity), as well as larger goals related to watershed sustainability, defined here as the ability to maintain the well-being of human societies without undermining the integrity of the hydrological cycle or the ecological systems that depend on it (Gleick 1998) and as measured through key indicators (Asbjornsen et al. 2015). Finally, a broader long-term goal is to facilitate improvements in PHS policy development and implementation by utilizing a transdisciplinary approach to understanding the relationship between PHS programs and the coupled natural-human systems (CNH) in which they operate. We focused our work on two contrasting PHS programs in Veracruz State, Mexico: one overseen by a local government trust (FIDECOAGUA) in the Gavilanes Watershed, and one managed by a non-governmental organization (PROSAPIX) in the Pixquiac Watershed. Our specific research objectives were to:

1. Examine the motivations underlying people's decisions to participate in the PHS program and the subsequent effects on their social and economic well-being, as well as their perceptions and planned behaviors in relation to watershed sustainability.
2. Assess the impacts of the major land use/land cover types on hydrologic services (i.e., water supply and quality) and the potential trade-offs with other ecosystem services (e.g., carbon sequestration, biodiversity).

3. Assess the potential for citizen science water monitoring programs to enhance PHS program effectiveness through the effects of participation on environmental knowledge, perceptions, and stewardship behaviors over time, and by providing scientifically validated water flow measurements to improve capacity to monitor changes in watershed services over time.
4. Integrate the socioeconomic and biophysical data into a CNH modeling framework to simulate the impact of different land use scenarios on hydrological services and tradeoffs and apply this model to understanding impacts on stakeholder decision-making processes within the context of participatory workshops.

In this chapter, we present our experiences with this interdisciplinary project in Mexico, including the challenges and boundaries we faced while conducting research, while also highlighting our achievements. We present key lessons learned so that others can benefit from our experience. In the remainder of this chapter, we discuss our study area (Sect. 2.2), the CNH system we studied (Sect. 2.3), how we organized our team (Sect. 2.4), the challenges we encountered (Sect. 2.5), the successes we achieved (Sect. 2.6), and conclude with a summary of the key lessons learned and recommendations for other teams (Sect. 2.7).

2.2 Study Area

We conducted our research within two adjacent watersheds in central Veracruz with PHS programs (Figs. 2.1 and 2.2): Gavilanes (~4000 ha) and Pixquiac (~10,000 ha). These watersheds have similar biophysical and climatic characteristics, yet they differ in key socioeconomic and land use characteristics (Fig. 2.3). One difference is that the Gavilanes watershed is entirely within the municipality that uses its water, whereas the Pixquiac watershed covers several municipalities and the city of Xalapa. This means that Xalapa's government must negotiate among landowners in various municipalities to make payments related to the PHS program, which can be politically sensitive since these groups do not vote or pay taxes in Xalapa. A second key difference concerns

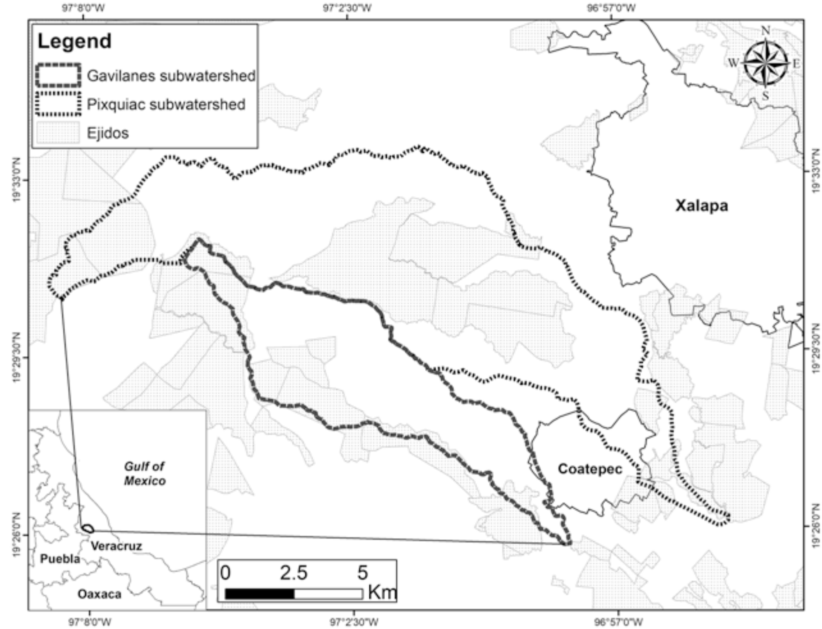

Fig. 2.1 Map of two study microwatersheds in central Veracruz State in Mexico receiving payments for hydrological services (*Source* Map made by Jose Von Thaden Ugalde using ArcMap 10.4.1)

higher population densities in the Pixquiac, since it includes Xalapa, Veracruz's second largest city (pop. 388,000), while Gavilanes supports the smaller city of Coatepec (pop. 50,000) and therefore experiences lower demands on water resources.

2.3 Coupled Natural-Human System: PHS Programs and Social-Ecohydrological Systems

The CNH system in Veracruz, Mexico, involves multiple linkages between ecosystem services and social and economic outcomes within human systems, as depicted in the conceptual model guiding this study

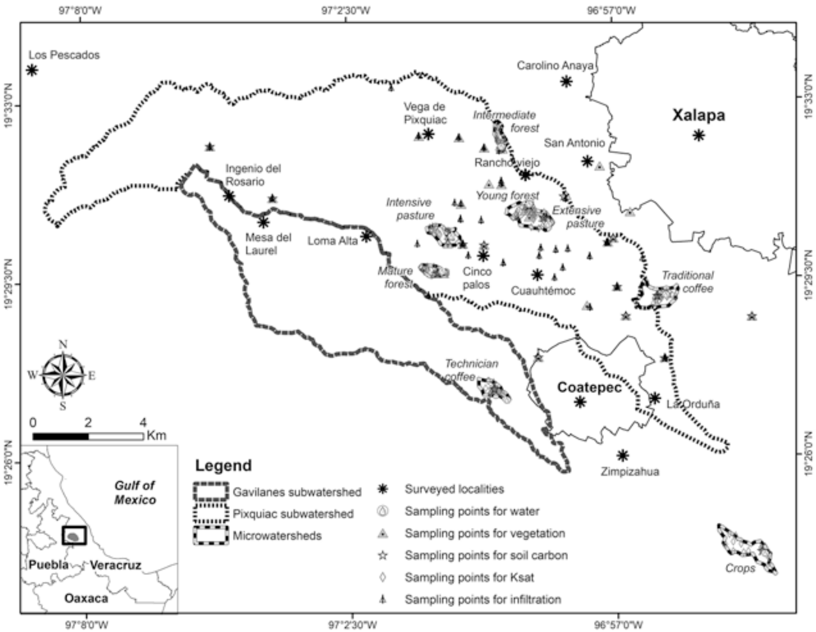

Fig. 2.2 Map of data collection sites in Veracruz, Mexico (*Source* Map made by Jose Von Thaden Ugalde using ArcMap 10.4.1)

(Fig. 2.4). This model highlights how the PHS program was originally designed as a linear construct, wherein participation of upstream landowners (e.g., water providers) would result in greater protection of forest cover and more sustainable land use practices, which ultimately would lead to improved provisioning of hydrologic services for downstream water users (e.g., blue solid arrows). However, due to the inherent complexities of CNH system dynamics, PHS policies typically lead to interactions and feedbacks between the socioeconomic and biophysical systems that were not intended by the program administrators or by the program participants (e.g., dashed green lines). To improve the design of PHS programs to better achieve watershed sustainability goals, knowledge about the underlying mechanisms that determine these complex relationships and the trade-offs between ecosystem service provisioning and socioeconomic costs and benefits is critical.

Fig. 2.3 **a** Cloud forest in Veracruz; **b** Ejido in the Gavilanes watershed (*Source* Photographs by Erin Pischke)

The focus of Mexico's PHS program on conserving (or restoring) forest cover is due to the perceived role of forests in enhancing watershed sustainability through increased water supply, erosion control, nutrient regulation, water purification, and flood protection (Burkhard et al.

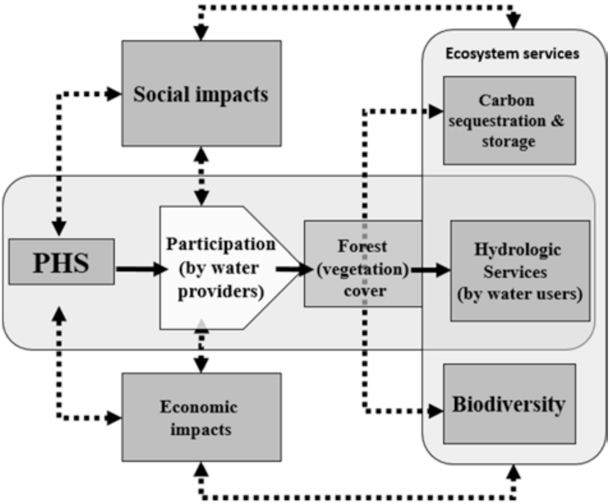

Fig. 2.4 Conceptual model of PHS programs in Mexico. Blue arrows represent the expected linear relationship between Mexico's PHS program and its impacts on program participants, forest cover, and hydrologic services. Green dashed arrows indicate the more complex (often indirect and unintended) linkages and feedbacks that emerge between PHS programs and the social, economic, and biophysical systems (*Source* Figure created by the authors) (Color figure online)

2012; Walker et al. 2009). Due to the steep topography and high rainfall in the Veracruz study region, flood and erosion mitigation as well as accessible, reliable, and clean drinking water are specifically targeted in the PHS program. While using forest cover as a proxy can be effective in providing general information about the quality and abundance of hydrological services, it does not capture the complex, often non-linear, relationships between vegetative cover, land use, and their impacts on hydrology and diverse hydrological services (Bruijnzeel 2004; Muñoz-Piña et al. 2008). For example, in this CNH system it has been shown that less forest cover leads to greater peak flow and lower seasonal base flows, reducing the total annual water availability (Asbjornsen et al. 2017; Bruijnzeel 2004; Muñoz-Villers et al. 2012; Muñoz-Villers and McDonnell 2013; Wilcox et al. 2008). In cloud forests, these effects are amplified because these environments are typically found in foggy, wet, and often windy conditions where ecological and hydrological functioning implies high rainfall, cloud water interception, and low evaporative losses (Bruijnzeel et al. 2011; Holwerda et al. 2010; Jarvis and Mulligan 2011). However, these relationships are not always linear and some are unexpected. For example, many young secondary forests can provide hydrological benefits similar to mature forests (Muñoz-Villers et al. 2012). In addition, reforestation can reduce water availability to lower-lying regions (Trabucco et al. 2008). Finally, not all cloud forests exhibit higher water production than non-cloud forests (Munoz-Villers et al. 2015). Capturing these intricate trade-offs between hydrological services and land cover is thus critical for accurate quantification of the net effects of land cover on watershed sustainability, which is instrumental for improving PHS program targeting and performance (Mokondoko et al. 2018).

In addition to the hydrological services that forests provide, there are other ecosystem services that are affected by changes in land cover. In the national PHS program, additional focus was placed on carbon sequestration[1] and biodiversity preservation including natural forest cover and agroforestry systems like shade coffee. Forests generally capture and store more carbon than non-forest ecosystems, while clearing of forests for agricultural conversion releases large amounts of carbon (Pan et al. 2011). Biodiversity is a critical, albeit less tangible and quantifiable ecosystem service provided by different land use/land cover types. High levels of biodiversity have been shown to enhance ecosystem resilience and stability (Tilman et al. 1997), while species diversity influences both carbon sequestration and storage (Bunker et al. 2005), nutrient cycling, and vegetation water use (Asbjornsen et al. 2011). Nevertheless, trade-offs exist between ecosystem services and local knowledge of ecosystem function and service provisioning is often lacking. There is consequently growing interest in the policy arena for strategies that combine or "bundle" ecosystem services in some contexts while disaggregating or "stacking" them in others, with the goal of

[1]Carbon was only included in the PHS program from 2004 to 2006 but then eliminated in preparation for a separate payment for ecosystem services program through REDD+.

balancing ecosystem service trade-offs and the willingness of user groups to pay for them (Mokondoko et al. 2016; Raudsepp-Hearne et al. 2010; Robertson et al. 2014).

The preservation of this suite of ecosystem services is intended to have positive effects on several human components of the CNH system. In theory, payment for ecosystem services programs should improve economic status through poverty alleviation (McAfee and Shapiro 2010; Muñoz-Piña et al. 2008; Perevochtchikova et al. 2012). This could occur directly, through large payments, or indirectly, through improved ecosystems that incentivize the poor to undertake new livelihood strategies that generate additional or increased income streams (Wunder 2008). However, combining socioeconomic goals with efforts to ensure ecosystem provisioning has been challenging in practice and may negatively impact program effectiveness (Alix-Garcia et al. 2015; Börner et al. 2017; Calvet-Mir et al. 2015). The type and quantity of the compensation utilized as well as perceptions of the program will likely dictate the ability of a PHS program to generate net socioeconomic benefits.

Changes in socioeconomic conditions should in theory feedback to influence an individual's or a community's perceptions and behaviors in ways that promote greater forest conservation (Alix-Garcia et al. 2012; Grieg-Gran et al. 2005). However, benefits from PHS programs may be somewhat limited in Mexico due to inadequate payment amounts based on opportunity costs calculated from national averages. There is also the longstanding culture of subsidies used by policymakers to periodically redirect land use decisions in rural areas, which landowners may assume will occur again in the future (Manson et al. 2013; Muñoz-Piña et al. 2008). Further, the social contexts within the communities may affect the success of the program. Within our study region, much of the land is under ejido (i.e., collective) ownership (Bray et al. 2006), and thus, PHS programs must be approved and managed by the entire community. This creates added complexity, as decisions about precisely how, where, and to whom payments are made must involve some degree of collective process, potentially compromising the influence of the PHS program.

Another important consideration that adds complexity and is often overlooked in PHS design is that participation in payment for ecosystem services programs may have indirect effects on stewardship behavior. For example, fostering greater environmental awareness and the adoption of best management practices may have long-lasting effects on ecosystem service provisioning (Deng et al. 2016; Grillos 2017; Moros et al. 2019). Such non-economic motivations can impact participant retention as well as the continuation of stewardship behaviors after the cessation of payments.

All of these complexities must be addressed when designing the structure and implementation of PHS programs and are reflected in the multiple feedback arrows in the conceptual model (Fig. 2.4). When functioning effectively, PHS programs should incentivize individuals or communities to preserve forests, improving the ecosystem services provisioned by those forests, which feed back to improve socioeconomic livelihoods for those individuals or communities. Ultimately, these positive feedbacks increase motivation by upstream and downstream watershed residents to contribute to the PHS program via enrollment or payments, respectively, indicating the potential for positive reinforcement among the different CNH system components.

2.4 Approach to Collaboration Across Boundaries

Our research team employed a transdisciplinary collaborative approach with an interdisciplinary research team to elucidate the complex linkages between Mexico's PHS program, and the dynamics of coupled social-ecohydrological systems. Our interdisciplinary research team consisted of approximately 35 people, including 20 research scientists and 12 university students and post-doctoral researchers from universities in Mexico and the United States, as well as several community and NGO representatives from Veracruz. This number has fluctuated over the years. Our team was interdisciplinary because we intended to integrate the theories and methods of multiple scientific disciplines. Our research was transdisciplinary in that it was premised on crossing geographic, disciplinary and social group boundaries in order to incorporate a wider range of scientific, professional and cultural voices into the research process (Bernstein 2015).

To meet our objectives, we developed and implemented an interdisciplinary approach via sub-teams. Although the project PI is an ecologist, the sub-teams were led by researchers having expertise in different disciplines related to the overall project. Specifically, we organized our team into six sub-teams, each of which was led by a co-PI: socioeconomic, landscape analysis, biophysical, community-based watershed monitoring, model integration, and participatory workshops.

Although originally the plan was to identify a single study system for data collection, over time, it became evident that the scales needed to address different social and biophysical science questions were inherently and fundamentally different. Thus, compromises were needed to allow for each of the sub-teams to meet its specific objectives through disciplinary research focused on key indicators. These indicators were identified by the entire team at an early stage of project implementation (see Asbjornsen et al. 2011 for details) and provided a guiding framework for obtaining the data needed to develop the integrated model of PHS-CNH dynamics. The indicators were selected based on our hypotheses about which attributes with the social and biophysical systems should be most sensitive to the PHS program and thus best capture the interactions and feedbacks within our coupled natural-human system conceptual model (Fig. 2.4). Below, we briefly describe the methods used by each sub-team.

2.4.1 Socioeconomic Methods

To conduct the socioeconomic components of the research, we used qualitative interviewing and quantitative survey methods. The scale of this component was at the community (ejido) level, with interview and survey data collected at the household level in the two micro watersheds, as well as in "downstream" communities (e.g., in the cities of Coatepec and Xalapa; see Fig. 2.5).

(a)

(b)

Fig. 2.5 **a** Conducting surveys in the watershed; **b** Conducting surveys in the watershed (*Source* Photographs by Erin Pischke)

2.4.2 Landscape Analysis

A combination of geographic information systems (GIS) and remote sensing technologies, supported by ground verification when necessary, were used to create land cover/land use maps from Landsat and SPOT imagery of our study areas.

2.4.3 Biophysical Methods

Measurements of biophysical properties related to the hydrological biodiversity and carbon ecosystem services were collected in the field and then combined with the landscape analysis to develop spatial maps of watershed characteristics and to support the hydrological modeling (Fig. 2.6). The maps showed land cover/land use throughout the study areas as well as changes over time.

2.4.4 Community-Based Watershed Monitoring

We collaborated with an established non-governmental organization in the region, Global Water Watch (GWW) Mexico, to recruit volunteers to monitor precipitation and water flow in the Gavilanes and Pixquiac watersheds. With the help of GWW-Mexico, we recruited 35 volunteers for ongoing monitoring. We surveyed them prior to training, one week after, and six months after training to determine the profile of potential volunteers, the factors that contribute to their longevity and changes in their perceptions.

2.4.5 Model Integration

We are currently working on integrating the data collected for each of the different components within our conceptual model (Fig. 2.4) to enable the simulation of different PHS program scenarios. For example, these scenarios may involve changing the payment amount, targeting payments based on different criteria, whether biophysical

Fig. 2.6 **a**–**d** Biophysical data collection in the watershed (*Source* Photographs by Z. Carter Berry)

(e.g., landscape positions with high hydrologic recharge zones; deforestation risk) or socioeconomic (e.g., poverty alleviation; opportunity costs). The objective of this integrated coupled natural-human system model is to assess the impacts of different scenarios on key biophysical outcomes (i.e., trade-offs among different ecosystem services) and socio-economic benefits and unintended consequences, as a basis for informing and improving payments for hydrological services program design.

2.4.6 Participatory Workshops

We will conduct a participatory workshop that involves local stakeholders in role-play simulations to evaluate scenarios and trade-offs in ecosystem services. The scenarios in the workshop will integrate social and biophysical data gathered in the project and present the models to PHS program stakeholders.

2.5 Team Organization

The initial team composition for this study was defined according to the areas of expertise needed to address the project objectives within the biophysical sciences (e.g., hydrology, soil science, ecology, watershed modeling), social sciences (economics, sociology) and landscape analysis (geospatial analysis and modeling). Another key objective was to create a team that would be capable of working together across boundaries and function as an integrated entity that was more than just the sum of the individual participants (Strober 2006). In particular, we sought collaborators who were willing to invest the necessary time and energy to communicate across disciplinary boundaries and who had a genuine interest in understanding differing perspectives. This required a commitment to listening, patience, respect, teamwork, and balancing of diverse opinions and ideas (Buizer et al. 2015; Hickey and Nitschke 2005). This meant that individuals who tended to seek confrontation and conflict rather than compromise and consensus were not considered for our team, despite strong scientific qualifications. This criterion was a particularly difficult filter to apply when recruiting new team members, and the learning curve at times was quite steep.

Approximately half of the original team consisted of researchers with whom the co-PIs had worked previously, while others were identified to fill particular needs within the team. In most cases we relied heavily on existing networks of collaborators and recommendations by other team members. Additionally, an effort was made early on to establish and share our common team vision with prospective new members joining the team at different stages of the project, as this was considered critical in minimizing unnecessary misunderstandings and unrealistic expectations.

Given the international nature of our project, another critical aspect to forming our team was identifying collaborators at Mexican universities within each of the disciplines related to the research. We were fortunate to have a strong project leader at our Mexican host institution, who was critical to identifying, recruiting, and engaging local biophysical science researchers, as well as recruiting—and securing local funding to support—Mexican graduate students. We were successful in recruiting research collaborators and their students in the social sciences from both our local host institution and another university in Mexico City who were an excellent fit with our project. This experience underscored the overriding importance of persistence and having a clear team vision, as well as, in one case, recognizing that common research interests and a long-term commitment outweigh geographic proximity and convenience.

Whereas we initially organized our team into three sub-teams (i.e., biophysical, socioeconomic, landscape analysis), we later incorporated the other three sub-teams (i.e., community-based watershed monitoring, model integration, and participatory workshops) as the project evolved and new needs emerged. It is worth noting that these three new sub-teams were inherently interdisciplinary and required explicit integration of researchers, methodologies, and data throughout their entire implementation process.

Given the highly interdisciplinary and international nature of the research, early on we adopted a model of shared responsibility for project leadership. Overall project coordination and communication was shared by the counterpart lead-PIs from Mexico and the United States. Each sub-team also had a lead United States and Mexican researcher, which was important in enabling sub-teams to make progress toward their disciplinary research objectives and activities, while also providing a mechanism for maintaining communication across sub-teams to ensure coordination and integration. As the project evolved, this model of shared leadership became even more important as new project components emerged that required different skill sets and also because the project was sufficiently large (and participants' or scientists' commitments were already stretched), that sharing these leadership responsibilities allowed us to be more efficient and effective with limited time and budgets.

Another important challenge to spanning boundaries for the research was the need to forge strong partnerships with diverse local and national stakeholders involved in Mexico's PHS program. We incorporated a transdisciplinary aspect to the project by inviting these non-scientific partners (e.g., NGO staff members) to work with us to address the research questions we posed (Buizer et al. 2015; Hirsch Hadorn et al. 2006). To accomplish this, we relied heavily on our local Mexican collaborators to identify partner organizations and facilitate engagement by their representatives within the project. As part of our transdisciplinary approach, we followed Jahn et al.'s (2012) transdisciplinary research typology. To initiate this process, we organized several meetings during the project development stage and extended open invitations to relevant organizations and individuals, during which we shared our overall project vision and solicited their input, ideas and suggestions (Jahn et al. 2012). A key challenge we experienced was how to sustain their active involvement throughout the lifetime of the project, which may be partly attributed to our leadership structure, which was not strictly bottom-up as recommended by some transdisciplinary research scholars (Hirsch Hadorn et al. 2006). We attempted to compensate for this by specifically seeking their input and participation whenever particular issues or activities emerged where their interests and expertise were especially relevant.

The development of the citizen science, community-based watershed monitoring program also provided an important venue for sustained engagement by diverse local stakeholders during the latter part of the project. This approach was critical in ensuring the support and engagement among the PHS program community at both local and national scales. This, in turn, was crucial in enabling many of the research activities. We further anticipate that sustained stakeholder engagement will be instrumental during the final stage of the project, when we plan to communicate the results to watershed stakeholders through a series of participatory meetings and workshops in ways that will maximize the potential for future impacts on PHS program design and watershed sustainability.

2.6 Challenges of Collaborating Across Boundaries

Several challenges emerged during the project that were, in part, introduced by the interdisciplinary and transdisciplinary nature of the research, can be broadly summarized into the following categories: (1) team organization; (2) fully engaging local stakeholders; (3) integration of different disciplines; (4) matching spatial scales; (5) language and communication; and (6) field site logistics. These challenges have proven to be persistent and at times presented barriers to maintaining progress toward developing an integrated CNH–PHS model. Below, we discuss each of these challenges in greater detail and provide examples of how these challenges were addressed.

2.6.1 Team Organization

We faced real challenges in identifying suitable collaborators to fill some of the areas of expertise in our project's sub-teams, which we attributed to a variety of factors, many of which were beyond our control. A potential reason for the challenges we faced in recruiting local collaborators reflected the apparent differences across academic cultures, with the Mexican research community possibly having more limited experience with interdisciplinary research. However, several of our project co-PIs had worked previously with several of our Mexican collaborators, which played a critical role in our ability to more quickly build trust and effectively initiate the research, recruit new collaborators and students and ultimately, to the success of the project. Our Mexican research colleagues and NGO counterparts were able to make connections to other potential collaborators on the ground, visit the proposed study areas, and introduce researchers to the PHS program decision-makers and managers before the project started. Those who were based in Mexico—including the US researchers who were temporarily located in Mexico—were able to hold regular in-person meetings with institutional representatives, such as university professors and NGOs, who were providing in-country support or personnel. These frequent meetings helped keep the team informed about changes happening on the ground, build relationships, and obtain access to important databases, as well as show that we were invested in the area and help insure that project results will inform future policy decisions. Additionally, the students of our Mexican colleagues were able to address a number of additional lines of research not contemplated in the original proposal. In exchange, the project funded the field activities of local collaborators and their students and provided the opportunity to participate in published results.

A unique challenge faced by the students and post-docs was that some of them were involved in the beginning but then moved on from the project before it was complete, while others joined the project at later stages. This created a situation whereby the team at times struggled to pass on the institutional memory of earlier participants. For some students, the lack of institutional memory was compounded by the interdisciplinary challenge of fully understanding and relating to project components outside their own discipline. Participation by students in interdisciplinary seminars offered by teams of project researchers greatly helped to address this issue. These seminars allowed new students to hear about the project from many perspectives in conversations that framed the role that each research discipline played within the project. Of equal importance, the students were able to spend extended time asking questions with investigators on the project in small breakout groups. These small group interactions allowed students to engage with the aspects of the project they were struggling to understand and seek out the right individuals from the team that could best answer their questions. However, one challenge was that not all students were able to participate in these seminars, limiting their ability to establish the connections described here. Additionally, most students participated in the annual full team meetings, which lasted for three to five days and provided substantial opportunities for students to participate in both large team discussions about overall project integration.

2.6.2 Fully Engaging Local Stakeholders

Involving local stakeholders in a meaningful way, while also respecting their time and resource limitations, was a recurring challenge. Developing relationships and trust with these stakeholders required significant time and interaction. Finding local collaborators interested in coleading research committees was difficult, in part due to a lack of funding for local participants. While efforts were made to involve local stakeholders throughout, the funding was pursued predominantly through US-based channels. The increased need for funding from US institutions to help pay for equipment or other resources to support the research in Mexico, some of which was not budgeted for in the original proposal, limited the extent to which everyone on the project could fully participate in all meetings and research-related activities in Mexico.

Another challenge to maintaining project momentum was that many of the US-based researchers who were actively involved in data collection were only able to be in the field in Mexico for short time periods, which may have hindered the continuity of data collection and limited the strength of connections that could be formed with local stakeholders. Furthermore, nearly all of the data-collecting researchers were graduate students who eventually ran out of funding or graduated, in some cases disrupting relationships that had been built over time with stakeholders.

More challenging perhaps was the lack of opportunities to coproduce knowledge together with NGOs and municipal governments. This was partly due to the lack of resources and overcommitted staff within these organizations, which made it difficult to allocate staff to participate in the research. Moreover, the mission of organizations that work in PHS program implementation does not necessarily consider including the role or influence of knowledge as a prominent priority. This problem was exacerbated by the rapid turnover in the staff of municipal governments that operate PHS programs in 2017. This will be a challenge in transferring results to a new cohort of decision-makers at the state and national level that occurred as a result of state and national elections in July 2018. Another complicating factor associated with the changing leadership was the culture of new decision-makers rejecting programs promoted by previous administrations, which also undermines long-term planning essential to the success of PHS programs.

2.6.3 Integration of Disciplines

Our project was hampered by the very characteristics that inspire multicultural, interdisciplinary approaches. Strong ties to one's discipline and cultural differences among Mexican and US scientists shaped the framing of project objectives in ways that hindered progress. Our team began this project by publishing a paper highlighting the absence of integrated monitoring and evaluation practices for PHS programs, pointing to the failure of evaluation efforts to integrate physical, social, and governance measures (Asbjornsen et al. 2015). Despite recognizing the challenges upfront, our team experienced many difficulties to effectively integrate across disciplines, which each carry their unique theoretical proclivities and other intellectual commitments. We witnessed firsthand the difficulties involved in breaking down academic silos that often served important institutional functions and thus could not simply be abandoned. Different theories and models are used by different disciplines, and the practice of producing specific innovations that advance a particular field can distance one discipline from another, especially when they seek to deepen the sophistication and specificity of the discipline's theory. Consequently, some disciplinary disagreements emerged. For example, there was a misconception that socioeconomic data are less expensive and easier to collect than biophysical data.

At the onset of the project, a central theme of our team meetings was to identify integrated social and biophysical questions and methods. However, it later became apparent that splitting into smaller subgroups was necessary to improve productivity, even at the possible expense of integration. Researchers who have worked on large collaborative teams will appreciate the "inverse meeting size" theorem: the greater the number of people involved in a meeting, the less you can expect to accomplish. Team leaders attempted to account for this issue by organizing a range of different types of meetings, depending on the meeting objectives and the individuals directly involved in the decision-making process, including biweekly to monthly full team video conferences, annual full team in-person meetings, and smaller sub-team and small group teleconferences. Nevertheless, we did experience a tendency to place a greater focus on planning each research component on its own, rather than emphasizing the integration across research components. This challenge can be traced back to the need to balance the focus of sub-teams upon their disciplinary research agendas with achieving broader project goals involving integration. Ultimately, a rich and diverse set of metrics was collected by the team as a whole, ranging from soil hydraulic conductivity to environmental governance networks. But combining different types of measures in an integrated evaluation framework and then modeling future outcomes presents a persistent challenge.

While the project was inter- and transdisciplinary in theory, much of the data was obtained by disciplinary sub-teams of researchers with minimal interaction across teams, making it more multidisciplinary in practice. Although we recognized the need to produce an interdisciplinary rather than multidisciplinary approach to monitoring and evaluation of the PHS program, we did not develop a clear map to facilitate integration at the project's onset. One consequence of the lack of a clear road map is that the task of integration has been an evolving process informed by team learning and growth, rather than guided by a preestablished template. Whether such a template would even have been possible is an interesting question for debate. Only after each sub-team had gained more clarity about their own research focus was it able to begin developing a vision for how the different project components fit within a larger integrated research plan.

Finally, because of the painful work of bridging gaps and the evolution of team integration, interdisciplinary projects are naturally prone to mission creep. Sub-teams and sub-projects, such as the citizen science water monitoring, may increase productivity and impact. However, they can also cause the project to grow simultaneously in different directions. For example, the citizen science project was designed to provide decision-makers involved with the PHS program with information on water flow, while simultaneously improving public perceptions of PHS programs to motivate positive behaviors. On the one hand, this provided a fortuitous opportunity to substantially expand the scope of the citizen science activity that was part of the original project, as by enhancing the ability to examine more closely the motivations of participation of volunteers and impacts on their perceptions of PHS programs. On the other hand, fully taking advantage of these new opportunities required engagement by a larger number of researchers and more resources from the main project. Another consequence of this leveraging across the two projects is that one of the initial goals of the new citizen science project—providing decision-makers with useful information—was not fully accomplished, in part because the contributions of the citizen science activity to the larger project goals were not communicated well at the beginning.

2.6.4 Mismatched Spatial Scales

One of the greatest challenges of this project has been linking observations sampled by the socioeconomic and biophysical teams into an integrated modeling framework. Our team tried to develop a common study design from the onset, one that married biophysical and socioeconomic research methods, but we decided that it was not possible for multiple reasons. While it would have been ideal to sample for both biophysical and social data in the same regions of the watershed, this proved to be infeasible. It was more difficult than expected to match the scale of biophysical measures to the scale of qualitative socioeconomic measures, especially since there was little spatial overlap of where the two teams worked and collected data within the study's two micro-watersheds. Social scientists conducted interviews and surveys of people living in villages, but biophysical scientists collected measurements of plots and watersheds located outside the boundaries defined by human settlements.

Even within the same disciplinary sub-teams, there were different understandings about where data collection would take place. This often stemmed from the need for repeated sampling, which is very demanding. Some researchers needed many replicate measurements within a few hundred meters of each other to address their research questions, while others required replication across the entire study watershed. We therefore faced significant challenges with developing approaches to obtain the data required to generalize results about PHS program dynamics and ecosystem services provisioning across all indicators and at larger spatial scales.

2.6.5 Communication and Language

Cultural differences are central obstacles to any international collaboration, and these obstacles compound the difficulty of breaking down barriers between disciplines. A shared challenge for all sub-teams concerned changes in the local context and details of PHS policies and management. Despite having knowledgeable local collaborators who were actively engaged at different levels within the PHS program, information gaps still developed between local stakeholders and foreign researchers, particularly regarding the vagaries of the PHS program and its functions.

Another challenge related to language and communication concerns sensitivities to the interests of in-country collaborators. Often, local stakeholders are eager to work with international interdisciplinary teams, but this interest can quickly fade if not adequately nurtured. For example, all of our team calls and most of the meetings were conducted in English because of the presence of US scientists who did not speak Spanish. This may have alienated the Mexicans on our team who did not speak much English and who found it difficult to follow the conversations and decisions. Finding common ground and maintaining momentum requires consistent, and potentially burdensome, efforts at translation to support communication. Cultural differences can thus be bridged, but collaborator time and persistence are essential ingredients needed to overcome such challenges.

2.6.6 Field Site Logistics

Embedded within these issues are the inherent difficulties in conducting fieldwork in remote locations such as our field sites. Basic logistics such as finding vehicles and personnel for fieldwork, accessing private lands and obtaining needed equipment were ongoing challenges. The project collaborators in Mexico facilitated fieldwork as much as possible but could not solve all the challenges. For the first two years, the post-doc served as field coordinator, and was invaluable in the preparation and communication among team members in both countries. However, because the post-doc was hired for specific skills tied to their research, expertise tied to local logistics was lacking. The post-doc ended up having to troubleshoot local problems while simultaneously trying to conduct their own research. For example, if a technical piece of equipment to measure climate data was needed, a researcher in biodiversity or socioeconomic networks can only suggest others who might help, but not provide the equipment on their own. A central coordinator would have been better able to aid in management of timely researcher availability and leveraging of resources and data needs from local organizations.

Some challenges were due to studying a PHS program that is political in nature. This led to many difficulties, including the desire for immediate local impacts that the research project could not meet, changes in PHS program personnel that hindered key relationships with the research team and changes to PHS program rules that undermined our ability to determine the PHS program's effects. The tumultuous political environment resulted in irregular payments and a lack of baseline data, which hampered our ability to measure the net effects of PHS programs. Involving government institutions and NGOs in our research was critical, as our results are most useful for those organizations. However, getting an accurate and clear message to these groups has proved challenging due to the long and arduous process of obtaining detailed, robust data. Resources for research in these non-academic institutions are limited, which constrained their ability to engage during different phases of the research project. It was therefore important for our team to carefully prioritize the project activities for engaging local collaborators.

2.7 Opportunities to Advance Collaborative Science Across Boundaries

A major achievement from our project was the completion of a detailed case study analysis that generated a nuanced understanding of the intricate relationships between PHS policies and the placed-based and context-specific CNH occurring at each of the study sites. Researchers were able to integrate models and conduct a policy evaluation with ecological outcomes to shed light on whether PHS programs lead to detectable improvements in the target outcome, hydrological services, while also evaluating the impacts on and trade-offs with other ecosystem services. Another accomplishment was our ability to identify relationships between land use change, decision-making processes, and diverse ecosystem services. We were also able to document unexpected surprises, such as the relatively low additionality resulting from the PHS program because of the lack of a sufficient financial incentive to influence people's decisions. Few previous analyses have fully quantified to a similar extent the complex linkages between policy tools such as PHS, and both the socioeconomic system and diverse ecosystem services.

Several key features of this project were instrumental in realizing these goals. Our pursuit of a transdisciplinary approach enabled us to engage diverse local stakeholders in the research, which consequently enhanced overall knowledge and understanding of the complex issues surrounding PHS programs. By building the project upon long-term collaborative efforts in the study region, involving not only natural and social science researchers from Mexican universities but also partnerships with local NGOs and municipal governments, we promoted synergies to emerge when common goals were identified. For example, we collaborated with a long-term and large-scale project administered by Fondo Mexicano para la Conervación de la Naturaleza, referred to as the *Conservación de Cuencas Costeras en el Contexto del Cambio Climático* (C6) and supported by Global Environment Facility. This collaboration helped ensure that the transdisciplinary and ecosystem service-based focus of our respective projects obtained broader acceptance, for example, through ecosystem service modeling and stakeholder input to plan activities supported by CONAFOR and the *Instituto de Ecología y Cambio Climático* (INECC) in watersheds around the country. Another example is our collaboration with the organization GWW—Mexico, which had a well-established network of local trainers, volunteers, and sites. This association greatly facilitated our ability to incorporate a new research component with GWW's existing efforts and thereby address common goals of validating measurements, evaluating the impacts of PHS and monitoring on the perceptions of local actors, and communicating findings to stakeholders. In exchange, the results from our project on the importance of monitoring in PHS program evaluations has increased interest in CONAFOR to promote community-based watershed monitoring in PHS programs throughout the country. Finally, collaboration with the municipality of Coatepec and FIDECOAGUA resulted in a unique opportunity to participate in a municipal-wide event called International Water Day, when several of our researchers made presentations on project results to a broad audience of diverse stakeholders. These and other efforts have allowed us to leverage the results of the research well beyond the financial resources initially available. It also allowed us to build trust with local stakeholders, maintain policy relevance despite frequent changes in government decision-makers, and to take advantage of parallel efforts to increase the effectiveness of PHS programs in the region.

The process of engaging diverse local stakeholders as part of this transdisciplinary approach also contributed significantly to advancing knowledge about the study system. For example, the inclusion of local forestry technicians in the research process revealed misunderstandings held by the research team and gaps in the team's knowledge of the PHS program. Without support from the forestry technicians, the researchers would not have been able to fully understand why some rural land managers were able to enroll their forests in the PHS program while others could not. Input from forestry technicians also helped to focus attention on the changes needed to advance knowledge, and challenged previous understandings and expectations of PHS program participants. This experience in turn helped to motivate other stakeholders who were interested in the research findings and willing to collaborate in the different stages of policy implementation, increasing the probability that research results would be applied in practice. This was reflected in the sustained participation of most of the project's stakeholder collaborators, which allowed us to build a common project vision that would respect and value the contributions of the program participants and of a positive team environment. The diversity of stakeholder participants involved not only increased the social relevance of the research but also prompted some researchers to scale up the lessons learned from the project to improve the design and implementation of their more recent research projects.

Project researchers developed several interdisciplinary practices to overcome methodological challenges. At times it was difficult to reach consensus about how to adapt sampling strategies to satisfy sub-team priorities concerning scale in light of project goals. To overcome this challenge, sub-teams employed methodological tools by learning from other sub-teams. For example, socioeconomic researchers learned to use GIS software to integrate socioeconomic measures with data on watershed ecosystem services. Biophysical researchers learned new field techniques to encompass the wide range of ecosystem services measured in the project. These interdisciplinary methodological practices also increased the transdisciplinary relevance of our research. Moreover, we are currently in the process of developing our integrated CNH–PHS model and applying it to assessment of decision-making processes and associated feedbacks through a role-play simulation workshop. The combination of these activities is fundamentally transdisciplinary and represents an interesting experiment in process that we anticipate will greatly enhance our understanding of the challenges and opportunities associated with advancing transdisciplinary science.

Finally, monthly project meetings provided vital opportunities to determine the needs of the different sub-teams and identify synergies required for data integration. These meetings contributed to greater integration of research components and to facilitate agreement on a common language to overcome potential misunderstandings that might arise between participants with different disciplinary backgrounds. Although one of the goals of the monthly meetings was to have robust participation of all researchers, small meetings organized around sub-teams also aimed at the integration of data and proved more effective to achieve progress toward specific disciplinary research goals. During the course of the project, the team's ability to assign clear tasks to specific collaborators to ensure someone was responsible for advancing each component within an agreed upon timeline greatly facilitated overall progress.

2.8 Summary of Key Lessons Learned and Conclusions

Our team has learned valuable lessons on how to cross boundaries to conduct integrative and applied research. In this section, we summarize our lessons learned, which coalesce around nine main ideas: (1) hiring a project manager, (2) meeting regularly, (3) requirements for trans-disciplinary research, (4) project expectations and time management, (5) project integration, (6) language, (7) sub-team communication, (8) time spent in-country, and (9) data management.

- ***Hiring a project manager***: We found that hiring a key local person who had a sound understanding of the project and local context, and could thus serve as project manager, was critical in enabling the research team to proceed effectively in terms of coordinated logistics. Ideally, a project manager spans discipline-specific sub-teams to coordinate diverse research activities across all project components. Finding a post-doc that would commit to stay with the project for the full duration was challenging, given the breadth of knowledge needed and the maturity and experience required to lead. Ideally the project manager would be trained in both human and natural systems, and have experience in crossing other boundaries. The project manager also requires sufficient resources to coordinate field logistics among sub-teams in the study region of another country.

Furthermore, we realized that it is sometimes necessary to have an assistant manager for a complex project like ours. By hiring a manager and a second person, you avoid the risk of putting the whole project at the mercy of one person.

- ***Meeting regularly***: In our experience, regular meetings of both the entire team and various research sub-teams were important for consistent communication among team members. This meant having set times (e.g., weekly or monthly) that team members get together (even if remotely) to discuss study progress, timelines, and challenges for the various project components to advance. Co-PIs on our research project had the foresight to designate funding for annual in-country project-wide meetings. The purposes of those meetings multiplied and gained importance over time. These meetings also served as moments to establish and build trust in relationships among team members.
- ***Requirements for transdisciplinary research***: Our goal was to achieve transdisciplinary science. This involves research that moves beyond academic disciplines to involve non-academic collaborators in the research process to more fully understand a complex issue such as the effectiveness of a PHS program (Buizer et al. 2015; Hirsch Hadorn et al. 2006). We found that to achieve a transdisciplinary understanding, planning for integration of various stakeholders needs to begin at the very start of a project and continue throughout as datasets are developed and shared. For us, the involvement of key stakeholders from the Mexican government and other organizations and groups contributed to the transdisciplinary nature of the research by affecting policy that has impacts on livelihoods and local economies (Jahn et al. 2012).
- ***Project expectations and time management***: Leadership on our project needed to be assertive to ensure tasks were completed in a timely manner. Guidelines on how we conducted meetings, shared information, and published collaboratively were critical to establishing those expectations. Expectations and responsibilities of team members, including leadership on sub-teams, also needed to be defined by leadership at the very beginning of our project. At the same time, leadership also recognized that the project would evolve as new

information became available, the external situation changed, and additional needs and expertise were identified. Thus, project leadership had to be flexible and open to effectively accommodate change.

- ***Project integration***: Thinking and planning more explicitly and intentionally about integration across social and biophysical sciences early on would have helped our project achieve greater integration among components. The research questions are perhaps the most important part of a project to define, so starting with specific, overarching research questions was crucial. Our sub-teams worked together to refine their research questions by combining the specialized requirements for students' disciplinary research needs with the needs of the project's transdisciplinary agenda. Otherwise, younger researchers may have been overwhelmed if trying to span disciplinary and organizational boundaries on their own. In the end, it helped to have people from different sub-teams share at least the general methodologies of other sub-teams and then work together to create a shared understanding of larger research endeavor by everyone involved.

  The attention devoted to other issues during start-up hindered our ability to fully integrate data later for modeling and applications in program evaluation. Drafting a clear plan for data integration at the beginning of the project, including the methods to be used, appropriate spatial scales for sampling and specific research questions to address, with specific responsibilities for each member of the team would have helped to address this challenge. A data management plan that features data integration will also facilitate the incorporation of new team members into the project by enhancing the communication process.
- ***Language***: Barriers to effective communication included working in a non-English speaking country. In Mexico, having a large portion of the team being able to speak and understand, as well as read and write, the Spanish language was imperative to our success. Spanish-speaking team members allowed for the credible interaction with important players from the Mexican government, non-profits and university faculty. The logistics of field sampling and conducting surveys were enhanced by having Spanish-speaking team members

who could directly engage with local people. These team members also allowed the research team to better understand the PHS program from the Mexican perspective, which ultimately led to a better overall understanding of the research context.

- ***Sub-team communication***: Consistent communication between sub-teams was also critical. Face-to-face meetings were invaluable and, ideally, should be attended by all project collaborators, including not only lead researchers but also the broader group of collaborating scientists, students, technicians, and representatives of key stakeholder groups. For the latter, we found that given the substantial time constraints faced by both governmental and civic organizations, organizing a one- or half-day meeting specifically focused on soliciting their input was often the most effective approach in fostering meaningful engagement. Webinar meetings were only effective when well-planned, relatively short and resulted in concrete action items that sub-teams were then held accountable to achieve by a stated deadline. Understanding the motivations of key stakeholders and processes operating at multiple temporal and spatial scales—and how these affected the target variables being measured—was also a key to the project's success.
- ***Time spent in-country***: Our PI and some co-PIs spent considerable time in-country with local experts and stakeholders, so they fully understood the context of the research from the outset. The process of spending significant time up front in the study region building relationships, understanding the local context and engaging scientists and practitioners from a wide range of institutions and disciplines was critical to both our understanding of the local context and to eventually building a broad base of partnerships and cultivating an environment conducive to transdisciplinary science. Collaborating and employing people from the area for significant periods of time to build trust and relationships with people on the ground also lent credibility to our research team, which facilitated the day-to-day implementation of the research activities and generated additional transfers of information in multiple directions.
- ***Data management***: Developing an effective data management plan (including a data repository, meta-data protocols and discussions

about data management early and often) that featured how data from different disciplinary sub-teams would be integrated during the project demanded a substantial amount of time and effort by the team. A key lesson learned was that this process could have been greatly improved by conducting frequent inventories of data collected and data processing (i.e., at least every six months) and carefully reviewing the data with an eye toward identifying possible problems that require attention, as well as ensuring that the potential for effective integration of diverse datasets is being maintained.

In this chapter, we presented the challenges and opportunities that our team faced while conducting transdisciplinary research within a CNH system's context. In the process, we developed approaches to integration, both in terms of the research itself, but also in the way we worked as a team and with stakeholders. The science-policy components of our research have implications for not only advancing fundamental theory about conducting transdisciplinary research but also for impacting decision-making, especially related to PHS programs. We worked across six sub-teams which entailed crossing disciplinary boundaries, but also crossing conceptual, methodological, and language barriers. The various challenges we experienced, the lessons we learned and the recommendations we offer can often be boiled down to devoting time and energy to effective communication. We highlight the importance of clearly stating to project participants and partners from diverse stakeholder groups.

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