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Barriers and Solutions to Conducting Large International, Interdisciplinary Research Projects

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Abstract Global environmental problems such as climate change are not bounded by national borders or scientific disciplines, and therefore require international, interdisciplinary teamwork to develop understandings of their causes and solutions. Interdisciplinary scientific work is difficult enough, but these challenges are often magnified when teams also work across national boundaries. The literature on the challenges of interdisciplinary research is extensive. However, research on international, interdisciplinary teams is nearly non-existent. Our objective is to fill this gap by reporting on results from a study of a large interdisciplinary, international National Science Foundation Partnerships for International Research and Education (NSF-PIRE) research project across the Americas. We administered a structured questionnaire to team members about challenges they faced while working together across disciplines and outside of their home countries in Argentina, Brazil, and Mexico. Analysis of the responses indicated five major types of barriers to conducting interdisciplinary, international research: integration, language, fieldwork logistics, personnel and relationships, and time commitment. We discuss the causes and recommended solutions to the most common barriers. Our findings can help other interdisciplinary, international research teams anticipate challenges, and develop effective solutions to minimize the negative impacts of these barriers to their research.

Keywords Latin America · Socioecological systems · Sustainability · Teamwork

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Introduction

Recognition of the global connection and interrelatedness of environmental problems such as climate change is an important issue. Conducting interdisciplinary research projects composed of people from multiple countries, disciplines, countries, and cultures is becoming more common in the attempt to address these complex environmental problems (Halvorsen et al. 2016; Knowlton et al. 2014). While researchers face many challenges to conducting interdisciplinary research domestically, these same challenges are often exacerbated and new challenges arise when there is also an international component, with people from different countries conducting fieldwork together. Oftentimes, funding agencies require a minimum numbers of

countries are involved in funded projects or specific geographic coverage is met, both of which create challenges for researchers. Our objective here is to expand on the extant literature on the challenges inherent in conducting interdisciplinary research to include an international perspective. Our main research questions are: (1) What are the challenges or barriers that interdisciplinary, international research teams face and do the barriers vary by country? and (2) How can these barriers be overcome? We use a case study from a large interdisciplinary, international research project on the sustainability of bioenergy plantations across the Americas to answer these questions. We first present a literature review on the challenges of interdisciplinary research, give country-specific context for each country in which we worked and then report the results of a survey completed by our team members on the challenges of interdisciplinary, international research. Finally, we conclude with concrete suggestions on how to overcome the challenges we identified.

Literature Review

Interdisciplinary Research

Interdisciplinary research is one among several types of research that employ the tools and perspectives of more than one discipline. Interdisciplinary research fosters linkages between disparate disciplines while some aspects of each discrete discipline are still recognizable and left intact (Strober 2006). For example, researchers may integrate methods by mixing methods from various disciplines or create a shared language to approach a common problem, which can lead to a more holistic approach to problem-solving than a single discipline would allow (Buizer et al. 2015; Hickey and Nitschke 2005). Multidisciplinary, or cross-disciplinary, research involves researchers from more than one discipline who do not attempt to interconnect and integrate their research methods (Hickey and Nitschke 2005; Strober 2006). Transdisciplinary research is unique in that academic researchers work with non-academics who are involved with the research topic or communities where fieldwork is taking place (Buizer et al. 2015; Hadorn et al. 2006). This type of research takes into account their opinions and goals and attempts to understand problems using local knowledge from the bottom up (Hadorn et al. 2006). This paper focuses on interdisciplinary research.

Barriers to Interdisciplinary Research

The challenges of interdisciplinary research teamwork are well documented (e.g., Barlow et al. 2011; Gardner et al. 2013; Morse et al. 2007; Ross 1984; Strober 2006). These challenges, or barriers, can include building an effective research team, finding a common vocabulary for communication across fields, identifying a framework around which to build the research, integrating diverse methods and perspectives, and working within resource constraints.

The difficulties in building an interdisciplinary research team include finding personnel and research team members who have shared goals, experience working together, and good interpersonal skills (Dieguez et al. 2015; Halvorsen et al. 2016; Ross 1984), disproportionate research responsibilities among all disciplines involved (Lang et al. 2012), and asymmetries between students and senior researchers (Dieguez et al. 2015). Each academic discipline has its own overt or subtle traditions to which researchers within that discipline adhere (Gardner et al. 2013). Differing expectations about protocols, treatment of subjects, ownership of and access to data, publication protocols, or basic etiquette can also be challenging when working with people from different disciplines (Bosch and Titus 2009; National Research Council 2008).

While shared vocabulary, theories, and methods can enhance and streamline disciplinary research, trying to combine disciplinary traditions in interdisciplinary research can create more acute challenges (Barlow et al. 2011; Strober 2006; Romero-Lankao et al. 2013). Interdisciplinary researchers have main communication challenges at two levels: to communicate internally and with a broader audience (Gardner et al. 2013; Strober 2006; Romero-Lankao et al. 2013). Clear communication is necessary for the process of building the research team, successfully executing the proposed research, which can be especially challenging in the initial stages of a project when these new modes of communication are being developed, and also later when presenting results coherently to a broader audience (Morse et al. 2007). The more disparate each discipline's tradition is from another, the more difficult it is to find common ground when defining problems and developing a research plan (Brown et al. 2015; Lang et al. 2012; Morse et al. 2007). Negotiating different disciplinary norms and integrating methods adds to the complexity of interdisciplinary research (Bosch and Titus 2009; Morse et al. 2007; National Research Council 2008; Strober 2006).

Integration of diverse research programs also extends beyond conceptual challenges when multiple researchers from different disciplines try to coordinate the logistics of carrying out interdisciplinary fieldwork (Morse et al. 2007; Romero-Lankao et al. 2013). Research is often limited by the volume of resources, mainly time and money, available. Interdisciplinary research may be hampered by the need for more time and more money than is necessary for a similar single, disciplinary project (De Torres 2013; Dieguez et al. 2015; Morse et al. 2007; Ross 1984). Moreover, short term funding is often not adequate for the long-term planning and

execution of interdisciplinary research projects (De Torres 2013). Some of these challenges are actually embraced by researchers and used to bolster existing relationships, depending on the context (Morse et al. 2007).

Barriers to Conducting Research Abroad

While researchers face many challenges to conducting interdisciplinary research domestically, international research offers a variety of specific challenges and oftentimes the challenges facing domestic interdisciplinary teams are magnified or exacerbated when working with people from other countries or when placed in an international context. Other problems posed by research conducted abroad are not related to the challenges of interdisciplinary research. The barriers to conducting international research include: a lack of familiarity with the local language or culture, dealing with fieldwork logistics, problems caused by suspicion and political situations, resource needs, and bureaucracy issues.

Misunderstandings within research teams can take many forms, stemming from different expectations, norms, priorities, and values across cultures (Barrett and Cason 1997; Di Castri 1976; Ross 1984). These misunderstandings can be exacerbated when placed in an international context. Culture as a barrier to international research may manifest itself in the philosophical differences between research paradigms in different cultures or it may crop up as misunderstandings in everyday life (Gardner et al. 2013; Romero-Lankao et al. 2013). There are often differing expectations of workloads, sensitivity to deadlines, levels of supervision, and mentoring among teams made up of people from different cultures (Bosch and Titus 2009; National Research Council 2008). Furthermore, a lack of familiarity with a local language or culture in developing countries can lead to problems translating research materials or in communicating research needs to local communities (Lang et al. 2012; Ross 1984; Romero-Lankao et al. 2013).

In international teams, collaborators in more developed countries are often seen as holding more power because they generally have access to large grants for this type of research (Romero-Lankao et al. 2013). If the principal investigators do not include their international collaborators in an equal and open way during the development stages of the research, asymmetries of power and less-functional teams will result. International research teams also face the challenge of having to conduct many meetings, planning sessions and other correspondence among team members via phone, email, or video conferencing rather than in person, which can lead to misunderstandings, slower progress, and lack of coordination and consistency (Goddard et al. 2006). Good interdisciplinary research depends on quality fieldwork and data collection, which takes more time than is usually expected or planned (Ross 1984).

Initial mistrust among members of international research teams is common, and often stems from dissimilarities of practice and asymmetries of power (Dieguez et al. 2015; National Research Council 2008; Palmer et al. 2016). Also, it is often found that researchers, especially foreigners, are viewed as outsiders by the local people with whom they are trying to communicate, which can create mistrust and misunderstandings (Morse et al. 2007). Locals may be suspicious of outsiders, have mistaken expectations about what research projects are providing, and suspicious about how collected data is used (Barrett and Cason 1997; Di Castri 1976; Ross 1984). All of these barriers can lead to biased data or withheld information. Moreover, the political environment can present additional challenges, either through biased or hesitant respondents and inaccessibility to key informants (Barrett and Cason 1997; Ross 1984).

There are many challenges to conducting research abroad, especially when working in a developing country. Fieldwork in a different country poses the typical challenges, such as accessing the necessary data (e.g., maps or sample frames) or equipment, traveling in rented vehicles on poor roads, and finding the proper personnel or technical assistance (Barrett and Cason 1997; Ross 1984). Conducting international fieldwork is often resource intensive. The amount of time, money, and resources needed before, during, and after fieldwork takes place is often underestimated, especially in countries where bureaucratic processes can stall research for long periods of time (Freshwater et al. 2006; Ross 1984). It often takes more time and resources to obtain a visa to work in the United States than it does to enter and work in countries such as Argentina, Mexico, or Uruguay. Budget constraints for international projects are greater than for national projects, mainly due to the costs of travel for face-to-face meetings and research (Goddard et al. 2006; Romero-Lankao et al. 2013). The amount of time spent making local contacts, introducing the researchers to field technicians or local communities and gaining access to field sites is also time and resource intensive (Gardner et al. 2013). These resources are unlikely to be expended in all field sites for the duration of the project; resources are likely to be spread thin to maximize their utility (Ross 1984).

Literature Gap

The extant literature on barriers to conducting either interdisciplinary research or international research lacks an in-depth examination of the intersection of the two. It is our objective to fill this gap by not only discussing the challenges faced by interdisciplinary researchers and the challenges they face when working abroad, but by demonstrating which barriers are experienced when

conducting interdisciplinary research abroad. Doing so will shed light on problems that future interdisciplinary, international project teams might face, as these types of projects become more commonplace (Halvorsen et al. 2016; Knowlton et al. 2014).

Case Study Background

The results presented in this paper stem from a project funded by the National Science Foundation's Partnerships in International Research and Education grant (henceforth NSF-PIRE) with a focus on addressing the socioecological sustainability of bioenergy development across the Americas. To address this research topic, our team included more than 100 social, natural, and engineering scientists and students from these countries actively working together over 5 years. In-depth socio-ecological and engineering investigations have been integrated during each phase of the project. Thus, we believe our team is uniquely qualified to address the challenges and opportunities of interdisciplinary, international research.

To accomplish our research agenda, our project was organized in two ways: by country in which the researchers work and by discipline. First, each country, or case study, had a leader whose primary role was to assist and coordinate research within the country for a joint team of social and natural scientists. Second, we developed sub-teams based on disciplinary expertize, including a social science and policy team, an ecosystem team, and a metrics team (see Table 1); researchers from our case study countries comprised these sub-teams. Disciplinary teams also had a leader or co-leader. Much of the coordination efforts were accomplished remotely via email or video conferences, but each year of the project there were also researchers from each country conducting fieldwork in the case study countries—with some researchers working in more than one country—and annual in-person team meetings that rotated among case study countries.

Methods

Stemming from personal experience working on the large interdisciplinary, international NSF-PIRE research project spanning six countries, we developed a structured survey (presented as a self-administered questionnaire) about the challenges that project members face while both working outside their home country and interdisciplinarally. The NSF-PIRE survey administrators, two authors of this paper, worked in case study countries outside the US and were involved in interdisciplinary fieldwork. The questionnaire protocol was divided into seven sections: one section asked whether the respondent was a scientist or student and what main discipline they belonged to (but did not ask about gender or country of origin) and the other sections asked about working in the case study countries (each country was represented in its own section). There were three questions that researchers were asked: Do you conduct PIRE research in [country]?; If you conduct NSF-PIRE research in that country, based on your team experiences there, what have been the biggest challenges to conducting interdisciplinary research?; and based on your NSF-PIRE team experiences in that country, please describe the biggest challenges you've encountered in the country. Each respondent answered all applicable questions for each NSF-PIRE case study country in which they conducted research. We administered the survey in person to all NSF-PIRE team members at an annual meeting in June 2015 (~65 people attended). Questionnaire responses were anonymous.

Attendees were surveyed at the beginning of a morning meeting when all meeting attendees were present and had time during coffee breaks and in between meeting presentations to complete the survey. We collected completed surveys at lunchtime. A total of 29 surveys were returned, for a response rate of 45% from people who conduct research in NSF-PIRE case study countries. Responses from natural and social science researchers who work in Argentina, Brazil, and Mexico were included in the analysis because the each of the respondents conducted fieldwork outside their home countries and experienced the challenges of working abroad; therefore, 15 surveys, from five natural scientists, and 10 from social scientists, were included in our analysis.

Authors Pischke and Knowlton independently reviewed and inductively coded the returned surveys by reading through all responses and generating a list of key patterns of barriers that emerged (Ritchie et al. 1994). Those two lists were combined into one list of 11 patterns (Ritchie et al. 1994). They came to an agreement on use of the 11 themes attributed to the survey responses to ensure intercoder

Table 1 Number of NSF-PIRE project participants by sub-team and country

Disciplinary team	Argentina	Brazil	Canada	Mexico	United States	Uruguay	Total
Ecological	6	5	6	11	15	1	44
Metrics and indicators	0	6	1	4	20	2	33
Socioeconomic/Policy	0	3	2	7	12	0	24
Total	6	14	9	22	47	3	

reliability (Bernard 2006). Afterward, they collated the results based on patterns that emerged across all data and then calculated the number of responses by pattern and by country and presented the percentages for each. They also grouped each of the patterns into one of three categories based on the responses given. Each pattern was categorized as either representing an interdisciplinary barrier, an international barrier, or a one that represented interdisciplinary and international barriers.

Results

In this section, we present findings about conducting interdisciplinary research in multiple countries outside the United States. In our NSF-PIRE research project, many of the researchers (both US and other nationalities) worked in more than one foreign country (outside their home country) and had to adapt to new contexts for each new field season in a different country. We present here survey results from researchers who worked in Argentina, Brazil, and Mexico (each researcher may have worked in more than one country), which provided some topics for discussion in light of the existing literature. Based on our coding results we determined that 11 different types of barriers were discussed in the survey responses: budget and money, bureaucracy, communication, consistency and coordination, danger and safety, different cultural traditions, integration, language, fieldwork logistics, personnel and relationships, and time commitment. Each of these barriers falls into one of three categories: they can be either an interdisciplinary barrier, barrier to conducting research abroad, or a barrier to conducting interdisciplinary research abroad (Tables 2–4).

Concerns about danger and safety were not common in responses from any of the three countries. Fewer than a third of responses from researchers working in Brazil and Mexico related to this barrier, and none from researchers working in Argentina. There were also very few responses in relation to different cultural traditions being a barrier to research in any of the case study countries. Language was somewhat commonly mentioned as a barrier faced by researchers working in Argentina and Mexico, but was mentioned more frequently in Brazil.

The fieldwork logistics barrier was in the top three most commonly listed by respondents and was mentioned by more than half of respondents for Argentina and Mexico. This was the only theme in Mexico that more than half of the respondents mentioned. Half or nearly half of all respondents working in Argentina, Brazil, and Mexico listed personnel and relationships as important barriers to conducting research The time commitment barrier was mentioned by half of the responses related to conducting research in Argentina and Brazil, while only about a quarter of responses from Mexico mentioned this theme. While responses in Argentina and Brazil relating to integration as a barrier accounted for half or more than half of the total responses, there were fewer responses about this barrier with respect to conducting fieldwork in Mexico. In Argentina, the most important barriers described by more than half of the survey respondents were integration, fieldwork logistics, personnel and relationships, and time commitment. In Brazil, the most important barriers listed in more than half of the responses were integration, language, and personnel and relationships. In Mexico, only one barrier, fieldwork logistics, was listed by more than half of the respondents.

Discussion

While many of the articles referenced in our literature review focus on the inherent challenges to conducting interdisciplinary research in a domestic context (or without acknowledging the context at all), we argue that these same challenges are often exacerbated in international contexts and that new challenges arise when conducting interdisciplinary research internationally. In this section, we discuss in detail five of the major barriers identified in our survey (responses equal to or greater than 50% of total responses), their causes in relation to the NSF-PIRE project

Table 2 Percentages and total numbers (in parentheses) of responses to survey questions about the barriers of working on interdisciplinary research, by barrier and country

Interdisciplinary barrier	Description	Argentina % ($N = 8$)	Brazil % ($N = 6$)	Mexico % ($N = 13$)
Integration	Trouble integrating experimental design, fieldwork plans and data collection; obstacles to sharing and combining information across sub-teams and across disciplines; attachment to one's own discipline; challenges aligning research questions and foci across disciplines	**63 (5)**	**50 (3)**	**38 (5)**

Bold font signifies responses that are equal to or greater than 50% of total responses

Table 3 Percentages and total numbers (in parentheses) of responses to survey questions about the barriers of working on conducting research abroad, by barrier and country

International barrier	Description	Argentina % ($N = 8$)	Brazil % ($N = 6$)	Mexico % ($N = 13$)
Budget and money	Constraints to transferring or converting currency between countries or researchers; limits to accessing and spending funds abroad	25 (2)	33 (2)	0 (0)
Bureaucracy	Difficulty in procuring insurance, permits, or visas to work abroad; challenges navigating unfamiliar bureaucratic systems; difficulty gaining permission to work in rural areas or on private lands; challenges in obtaining access to foreign officials or company representatives	38 (3)	17 (1)	8 (1)
Danger and safety	Feeling unsafe navigating unfamiliar roads and traffic conditions; uncertainty associated with levels of personal safety and safety of students in cities and rural areas	0 (0)	17 (1)	15 (2)
Different cultural traditions	Feeling "out of place" while conducting field work or unaware of cultural norms; navigating different expectations for when daily activities should occur (eating, working); miscalculating how some research topics may be interpreted or misunderstood	13 (1)	17 (1)	15 (2)
Language	Difficulty in speaking and working in a second language; challenges understanding different accents, dialects, or slang when working in the field	25 (2)	**50 (3)**	31 (4)
Fieldwork logistics	Challenges obtaining housing, transportation and supplies abroad; traveling long distances to and between field sites; challenges lining up different sub-teams' intermittent periods of fieldwork in space and time	**50 (4)**	17 (1)	**77 (10)**

Bold font signifies responses that are equal to or greater than 50% of total responses

Table 4 Percentages and total numbers (in parentheses) of responses to survey questions about the barriers of working on interdisciplinary research projects abroad, by barrier and country

Interdisciplinary and international barrier	Description	Argentina % ($N = 8$)	Brazil % ($N = 6$)	Mexico % ($N = 13$)
Communication	Miscommunication about research focus and fieldwork plans; misunderstanding who is working with whom; challenges communicating disciplinary concepts; difficulty understanding the societal context or history of field sites abroad; misunderstanding of researchers' objectives by community members or collaborators in field sites; lack of communication across all members of sub-teams and disciplines	13 (1)	33 (2)	31 (4)
Consistency and coordination	Difficulty coordinating research among disciplines and sub-teams before fieldwork began; little or no overlap in the field because of different field site locations or field seasons; loss of consistency in experimental design and methods; challenges defining questions, concepts, and subjects consistently	25 (2)	17 (1)	31 (4)
Personnel and relationships	Trouble finding research contacts abroad; disciplinary isolation; researchers' dependency on others for research needs in general and in the field; strains on interpersonal relationships when working in large groups during the extended timeline of the research	**50 (4)**	**50 (3)**	46 (6)
Time commitment	Frustration with slow progress preparing for and conducting interdisciplinary research abroad; large time commitment required to combine disciplinary data and write interdisciplinary papers	**50 (4)**	17 (1)	23 (3)

Bold font signifies responses that are equal to or greater than 50% of total responses

and, finally, share general recommendations for overcoming all the identified barriers.

Integration

Integration in interdisciplinary research teams is perhaps the greatest challenge researchers face, as has been discussed extensively in the literature (Barrett and Cason 1997; Gardner et al. 2013; Knowlton et al. 2014; Morse et al. 2007; Palmer et al. 2016; Romero-Lankao et al. 2013; Strober 2006). Integration was seen as one of the greatest interdisciplinary challenges in by researchers on the NSF-PIRE project. Respondents stated that they needed more time for discussion about specific research issues and field sites, which was not possible in part because the social and natural scientists completed their fieldwork at different times. Other respondents identified integration of data as a difficult barrier and pointed to the need to identify software that is capable of integrating data from multiple disciplines. Many respondents wished that the team had had more detailed plans of exactly how the information from different disciplines and countries would be integrated from the very beginning, before the fieldwork started, as found in Barlow et al. (2011) and Morse et al. (2007). Other respondents commented that there was not enough cross-disciplinary collaboration on the ground and that they were concerned that research participants were not being compensated or recognized for their time, as discussed by the National Research Council (2008) and Palmer et al. (2016). Respondents said that there were not enough meetings to specifically address how to integrate socioeconomic and ecosystem teams' research, so that many researchers just ended up working on their own disciplinary questions since they were most comfortable with the methods used.

Beyond the literature about the difficulty of integrating methods (Gardner et al. 2013; Strober 2006; Romero-Lankao et al. 2013), we also found other challenges to integration in our survey results. The social and natural science teams had trouble lining up their field seasons temporally, and so working together closely to integrate questions, communities, and methods was difficult. Respondents also identified integration as a significant barrier in Brazil because of language difficulties as well as issues similar to those in Argentina in trying to coordinate important variables, field sites, and timelines between disciplines.

Furthermore, our survey results, or lack of survey responses from people who did not attend the NSF-PIRE meeting where the survey was administered or from people who attended the meeting but did not complete a survey, could exemplify the challenges associated with integrating across disciplines. Throughout the years the project has been funded, some researchers stopped participating for various reasons. For those who were not comfortable working across disciplines, working abroad, or did not fit in with the larger group of researchers, integration within the larger project may have been a deciding factor in their decision to no longer participate in the project.

Language

Understanding the language of collaborators is obviously fundamental to successfully working together. Language barriers are often present in international teams no matter where they conduct their research (Barrett and Cason 1997; Ross 1984). The NSF-PIRE project, with researchers whose native languages ranged from Portuguese to Spanish to English, was no exception. The differences in the prevalence of language as a barrier in the three case study countries points to the differences in the initial level of Spanish or Portuguese language skills that researchers possessed when beginning to conduct fieldwork abroad in each country.

Fieldwork Logistics

The challenges of working on an international research project are made very apparent in the responses about fieldwork logistic challenges in Mexico, which encompassed most of the other barriers mentioned. Not only is it difficult to fully plan for changes in weather or the political climate of a country, but one must also coordinate multiple field seasons and when, where, and how to share resources across disciplinary researchers, as noted by Freshwater et al. (2006) and Ross (1984). As Barrett and Cason (1997) and Ross (1984) found, our survey respondents also mentioned logistical challenges in securing housing and transportation, traveling long distances on rough roads, and seasonal concerns such as who would be available to be interviewed or surveyed or what biophysical measurements could be taken while researchers were in the field.

Fieldwork logistics were a barrier to conducting research in Argentina because of cumbersome bureaucracy, the need to pay for everything in cash, and because the fieldwork was perceived as expensive. In addition, the natural and social science teams shared housing, which proved difficult to coordinate since everyone wanted to be closer to their particular study site. Rental cars were also shared, which was challenging due to the different schedules and locations of the researchers in the field. Bureaucracy was dealt with on both ends of the research, when researchers were in the field abroad, and again when they were at their home institutions. These types of challenges were not found in the existing literature. In Brazil, fieldwork logistics were minimal since research was undertaken within a large oil palm plantation and the company provided housing and

assistance in getting around. In the past it was difficult for foreign researchers to gain access to essential stakeholders because of local suspicions (Barrett and Cason 1997; Di Castri 1976; Ross 1984), but the situation appears to have improved.

Personnel and Relationships

Challenges to conducting our fieldwork involved both international and interdisciplinary aspects. Personnel and relationship barriers in conducting research abroad included having too many people in the field at a time, finding local contacts, and dealing with personal isolation and dependency on local hosts, as discussed in the literature (Dieguez et al. 2015; Halvorsen et al. 2016; Ross 1984). In Mexico, the problems associated with personnel and relationships related to concerns about not recognizing the hard work being done by the local researchers as well as the problems in finding appropriate interviewees and survey respondents, as cited in Dieguez et al. (2015) and Ross (1984).

Personnel and relationships were ranked as interdisciplinary barriers in Argentina for many of the same reasons as in Mexico, and because of conflicts in personality types among team members, just as Romero-Lankao et al. (2013) found in their research. Respondents also mentioned differing expectations about roles, authorship, and what would be provided (e.g., monetarily and in terms of field help) to each team. In Brazil, personnel and relationships were ranked as interdisciplinary barriers due to different expectations of meeting deadlines, individuals constantly changing research plans, as well as the added complexities of working with NGOs and agribusiness personnel, as found by National Research Council (2008) and Palmer et al. (2016).

Time Commitment

The barriers identified by our survey respondents that were associated with the time commitment of conducting interdisciplinary, international research mainly stemmed from individual researchers having difficulty planning to spend weeks doing fieldwork while being full-time students. Many foreign researchers spent significant time in the field in Argentina, as opposed to having local collaborators conduct most of the field data collection as was the case in the other countries. The extra time that it takes to conduct interdisciplinary, international research compared with single discipline or within home country research was found to be a barrier not only in our research, but also in the literature (Morse et al. 2007; Ross 1984). Many scientists do not anticipate the much greater time commitment required to work across disciplines or to set up successful international collaborations and field sites.

Recommended Solutions for Overcoming Barriers to International, Interdisciplinary Research

In this section, we recommend solutions for overcoming barriers to international, interdisciplinary research based on the literature and our experiences with our NSF-PIRE project (see Tables 2–4). Our solutions can be grouped into three broad categories: (1) preparing and training team members in advance of conducting research and fieldwork; (2) conducting trust-building activities; and (3) granting international research partners more autonomy.

Preparation in advance of conducting research and fieldwork can include setting realistic yet flexible expectations (Gardner et al. 2013); conducting a thorough investigation regarding which permits are required well before starting the research (Ross 1984); and learning about both written and unwritten rules and norms (Ross 1984). From our experience, we recommend thoroughly training researchers before fieldwork occurs and creating agreed-upon guidelines for team members; getting to know the local context where research is conducted; and always being accompanied by local people who have local knowledge of the situation and can make appointments over the phone before the fieldwork starts. This type of preparation can promote integration across both countries and disciplines; resolve timing and budgetary problems; minimize cultural and personal misunderstandings; mitigate personal safety issues and language difficulties in the field; and solve consistency, coordination, and communication barriers. One method we used in the NSF-PIRE project was to delegate leaders of each disciplinary team and each country team. These leaders proved very useful in getting teams focused on preparation before fieldwork, maintaining contact and coordination throughout the project, and providing a point-person for questions or problems that arose. We recommend other large teams create similar hierarchies to aid in team communication, consistency, and integration.

Our experiences strongly suggest that fostering trust among researchers on interdisciplinary and international teams can help mitigate or solve communication, time, integration, logistical, and personal relationship barriers to conducting fieldwork. Trust can be built by designing interactive experiences for the team members, getting researchers out of their seats at meetings and into team- and trust-building exercises that have nothing to do with the subject being studied. Establishing trusting and cooperative relationships with local partners is essential for overcoming logistical barriers in-country, as is a flexible and adaptive attitude to problems that arise. Beginning an interdisciplinary, international research project with at least

some researchers who have already worked together is one way to foster a strong sense of ownership and a democratic and trusting network of researchers (Gardner et al. 2013). In the case of the NSF-PIRE project, the majority of the PIs had already worked together on previous smaller projects and thus had developed a sense of trust and mutual commitment. Flexibility, patience, creativity and shared responsibility, and involvement of all researchers should be encouraged, especially in teams composed of diverse groups of people from different disciplinary and cultural backgrounds (Cheruvelil et al. 2014; Di Castri 1976; Morse et al. 2007).

We recommend giving international colleagues more autonomy in interdisciplinary, international research projects. Cheruvelil et al. (2014) point out that having a philosophy that stresses that international partners are integral members of the team and should therefore share in the responsibilities, decision-making, and communications is essential to overcoming cultural barriers. While some of the budgetary and money-related barriers to international research are unavoidable, a possible solution would be to give foreign institutions subcontracts and lump sums of money for them to administer for the research in their own country.

In Table 5, we present our recommended solutions for overcoming barriers to international, interdisciplinary research based on our experience. We give recommendations for the major barriers identified by our survey respondents.

Conclusion

We found five major barriers to conducting interdisciplinary, international research in our NSF-PIRE project countries (Argentina, Brazil and Mexico): integration; language; fieldwork logistics; personnel and relationships; and time commitment. These barriers fit within one of three categories of types of research: interdisciplinary, international or interdisciplinary, and international research. The integration barrier was related to interdisciplinary research, language and fieldwork logistics barriers were relevant to research conducted abroad and the personnel and relationships and time commitment themes were found to be barriers to both, interdisciplinary and international aspects of conducting research. The relative importance of these barriers differed slightly from country to country and between disciplines, but we developed a list of recommendations for preventing or overcoming each barrier based on our experiences and those found in the literature (Table 5).

Although it is important to be aware of all the potential barriers, good interdisciplinary, international research should concentrate on preparing and training team members

Table 5 Recommended specific solutions for overcoming barriers to international, interdisciplinary research

Barrier	Solution category	Specific recommendation
Integration	Preparation	Define focal themes, research questions and spatial and temporal scales jointly before starting research (Di Castri 1976; Morse et al. 2007)
	Preparation; trust	Prioritize face-to-face meetings that focus on interdisciplinary and intercultural training (Goddard et al. 2006; Morse et al. 2007)
	Preparation	Identify outside mentors who can help the team learn integration skills (Morse et al. 2007)
	Preparation; autonomy	Promote flexibility, patience, creativity, and shared responsibility and involvement in the research project (Di Castri 1976; Morse et al. 2007)
Language	Preparation	Require researchers to be at least bilingual, as well as familiar with different cultural settings
Fieldwork logistics	Trust	Establish trusting and cooperative relationships with local partners to overcome logistical barriers in international field sites
	Preparation	Promote flexible and adaptive attitudes for problem solving (Gardner et al. 2013)
Personnel and relationships	Trust	Take advantage of existing interpersonal relationships among researchers who have already worked together (Gardner et al. 2013)
	Preparation	Select team members thoughtfully and carefully, foster team member diversity (gender, ethnicity, religious beliefs, career stage, personality, socioeconomic class, life experiences, viewpoints, skills, problem solving methods) (Cheruvelil et al. 2014; Morse et al. 2007)
	Trust	Teach researchers interpersonal skills, including social sensitivity and emotional engagement (Pentland 2012; Parker and Hackett 2012; Stokols et al. 2008; Woolley et al. 2010)
	Preparation; trust	Build excitement about research goals, foster personal commitment to team members (Cheruvelil et al. 2014)
Time commitment	Preparation; trust	Build trust by discussing issues at length in order to get agreement and mutual understanding between all countries and disciplines
	Preparation	Write memorandums of understanding in which commitments and deadlines are clearly specified
	Autonomy	Recognize and respect timing issues among disparate research groups (Morse et al. 2007)

Solutions fall into three broad categories: (1) Preparation: preparing and training team members in advance of conducting research and fieldwork; (2) Trust: conducting trust-building activities; and (3) Autonomy: granting international research partners more autonomy

in advance of conducting research and fieldwork, conducting trust-building activities, and granting international research partners more autonomy. Further, getting an adequate mix of cultures, disciplines, and languages in order to help the flow of communication and therefore make it easier to overcome the difficulties when they arise. Informal team outings and formal teamwork exercises that build interpersonal skills can also help teams foster strong relationships, establish shared research goals and standards of behavior, and create a shared vision for project management. Our discussion of this case study and results of our survey and literature review can help other interdisciplinary, international research teams anticipate and address challenges in this type of work. Despite the hurdles in conducting interdisciplinary, international research, we have found it to be a rewarding, worthwhile experience. Solving many of the world's most pressing problems will require international teams of experts with the skills to work together successfully. We hope that our recommendations can assist these teams in their formation, planning, and execution of their research.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no competing interests.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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