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Current Opinion in Environmental Sustainability

Biological research stations as central nodes in promoting North–South collaborative networks for teaching and research

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Addressing global environmental problems requires collaborative international arrangements that incorporate the strengths of multiple partners with cultural, infrastructural, educational, and economic differences to produce more robust research and improved environmental outcomes. This can be especially important for research in the tropics given the ecological importance and economic and social constraints. However, significant economic, social and institutional barriers exist towards establishing effective collaborative networks, especially between North–South partners. In this paper, we integrate best practices from the collaboration and social networking literatures to examine a teaching and research partnership between American and Costa Rican institutions. This case demonstrates the potential for research stations to serve as central nodes in establishing collaborative networks involving researchers, government, and community organizations.

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Current Opinion in Environmental Sustainability 2019, **39**:31–38

This review comes from a themed issue on **Open issue**

Edited by **Eduardo Brondizio**, **Professor Opha Pauline Dube** and **William Solecki**

Received: 14 December 2018; Accepted: 14 June 2019

https://doi.org/10.1016/j.cosust.2019.06.007

Introduction

Biological research stations play a vital role in addressing some of the most critical environmental problems, including climate change, biodiversity loss, and deforestation. However many stations, especially in the tropics, are threatened by funding cuts and lack of public support [1–3]. To address these challenges, biological research stations will need to strengthen links between research, education, and outreach activities and integrate societal concerns [2]. Expanding collaboration among potential academic, governmental and community stakeholders could enable research stations to generate the support necessary to meet these varied objectives.

International collaborations in research and teaching are high impact practices that can benefit each partner and enhance research and conservation outcomes [4–7]. Although the most productive collaborations tend to occur among scholars from developed nations [8], North–South partnerships have the potential to improve research outcomes by integrating the funding and scientific expertise of the Northern partner with the local and specialized knowledge and contacts of the Southern partner [9•,10], enhancing mutual learning [7], integrating diverse sets of knowledge [11], improving research capacity [4], increasing research productivity and impact [9•,12], establishing long-term strategic partnerships [13] and integrating Southern partners into the global knowledge network [11]. The capacity building functions of North–South partnerships are especially crucial for addressing critical issues that exist primarily in the South, such as tropical forest conservation [14], which depends largely on knowledge gained from biological research stations. As information is crucial to generating effective conservation strategies [15], the effectiveness of partnership networks in conservation research can have a direct impact on conservation outcomes.

In this paper, we integrate the literature on collaboration and social networks to examine an education and research partnership involving American and Costa Rican institutions that builds on best practices to expand and strengthen a network involving students, professionals and community partners. In our analysis, we discuss the development, accomplishments and limitations of this network and use them to provide recommendations for future North–South socio-ecological research. This case study expands the focus of the literature on collaboration to examine the central role of biological research stations in North–South collaborative networks for teaching and research.

Relevance of collaborative networks to environmental outcomes

Collaborative approaches are increasingly being promoted to improve environmental and natural resource governance [11,9•,6,16••,17,18]. As collaboration among stakeholders is widely seen as essential to improve conservation outcomes [19•,20], collaboration among researchers has the potential to improve knowledge creation and produce outputs of greater quality than would be possible individually [21,5]. Adams [8] describes this as the 'fourth age of research.' where knowledge production is increasingly shifting towards international research collaboration [9•]. However, these potential benefits are not inevitable under all collaborative arrangements [19•,6,22]. Collaborating is time consuming [23•,19•] and North–South partnerships are frequently dominated by and skewed towards the interests of the Northern partner [24] which can limit the extent of meaningful collaboration and beneficial knowledge exchange. Cultural and linguistic distance [9•], diverse interests and capabilities [25–27], limited funding [10,28], and high transaction costs [12] can also undermine North–South collaborations. Studies of successful collaborative partnerships highlight networks that include successful capacity building, knowledge exchange, and reciprocal interaction throughout the various project stages [19•,29,13] and incorporate repeated in-person interactions to enhance communication and build trust [30•,31,10].

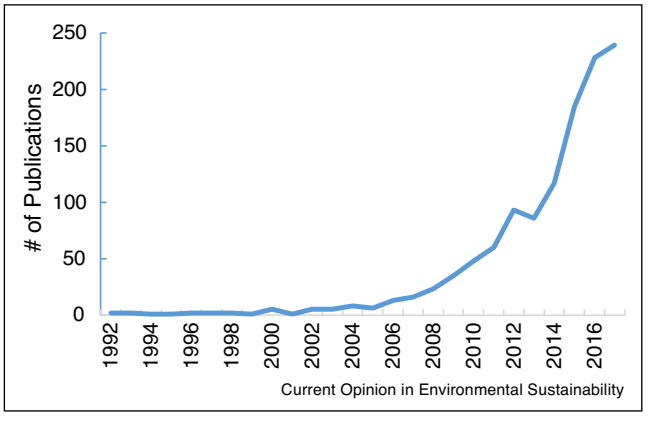
Social networks, 'the structures and types of interactions between actors in a group' [25], enable learning among different stakeholders to address complex problems. Effective networks are increasingly seen as essential to science as they enhance information exchange, build trust, and increase social capital [9•,32,33]. Networks can promote innovation, make expensive facilities available to participants, and lead to increased scholarly productivity [5]. Strong networks that include scholars and stakeholders also increase the likelihood that the knowledge will be applied in practice [23•]. Scholars have analyzed social networks substantially over the past decade and many have focused on the characteristics, position, and interest of individual stakeholders in the collaborative network and the nature of collaboration between the stakeholders [26,16••]. As relationships between partners are essential for knowledge diffusion [34], examining aspects of social networking systems such as how the strength of ties between collaborators facilitates information exchange and knowledge transfer can thus be crucial towards assessing network success [35•,36,37].

Although Crona and Bodin [38] noted the paucity of scholarship applying social network analysis (SNA) to address questions related to natural resources over a decade ago, this has recently become an increasingly prevalent approach with 60% of the articles on this topic written in the past five years (Figure 1). Scholars have used SNA to examine a range of environmental challenges including groundwater management [35•], forestry [39], invasive species [30•,40], bioplastics [41], sustainability [19•], land use planning [42], fisheries [32], watershed governance [29], coastal governance [25], and payments for ecosystem services [23•]. These studies have demonstrated that networks that provide opportunities for knowledge exchange, reciprocal interaction and trust more effectively facilitate collaboration between stakeholders. Actors that occupy central positions are better suited to promote these linkages. These findings have generated significant insights into how relationships between stakeholders influence environmental and natural resource management; however, they have largely lacked a focus on how researchers collaborate to examine environmental issues with no relevant articles looking at the importance of research stations. Although Abrahams *et al.* [30•] do examine how researchers shape collaborative networks to study invasive species, as with the previously referenced studies of research collaboration, they employ co-authorship as a proxy for collaboration.

Biological research stations as central nodes of collaborative networks

SNA examines how nodes are linked in a social network. Nodes, such as individuals, groups or organizations, can serve as both a unit as well as an actor in the network. Scholars employing SNA have identified that actors that are more centrally located are more effective at generating trust and diffusing knowledge [40,32]. *Betweenness centrality* identifies actors who sit between many actors in a network and are therefore able to broker relationships. *Degree centrality* refers to the number of direct ties a

Figure 1



Web of science search on December 3, 2018 for 'social network analysis* AND natural resource management* OR conservation* OR natural resources* OR sustainability*' = 1432 hits. The search for social network analysis* AND natural resource management* OR conservation* OR natural resources* OR sustainability* AND research station* OR biological station* is not depicted since this yielded no relevant publications.

node has which indicates trust [32]. Boundary spanners occupy central positions and are able to connect different actors that would otherwise not be connected [16••]. As trust and knowledge are crucial for effective collaboration [19•,29,13], actors with high degrees of betweenness and degree centrality will more effectively be able to facilitate collaboration.

Figure 2 depicts how research stations, by enhancing the opportunities for connecting governmental agencies, non-governmental organizations, tourists, students, and researchers, can serve as boundary spanners demonstrating high levels of betweenness centrality and degree centrality to promote networks of conservation. Researchers and students come to the station from domestic and international institutions to produce conservation-relevant knowledge that is disseminated through global academic publications and potentially to local conservation and community networks. These last two linkages are possible, although not guaranteed, as the stations can be physically remote and the outputs intellectually remote if the knowledge gained generates only scholarly publications. However, involving local researchers, students, and community members in the generation of knowledge and communicating the results to governmental and private organizations greatly magnifies its usefulness for conservation. In addition, if the station also attracts and educates tourists, then this knowledge is linked to the ecotourism network, further expanding its reach.

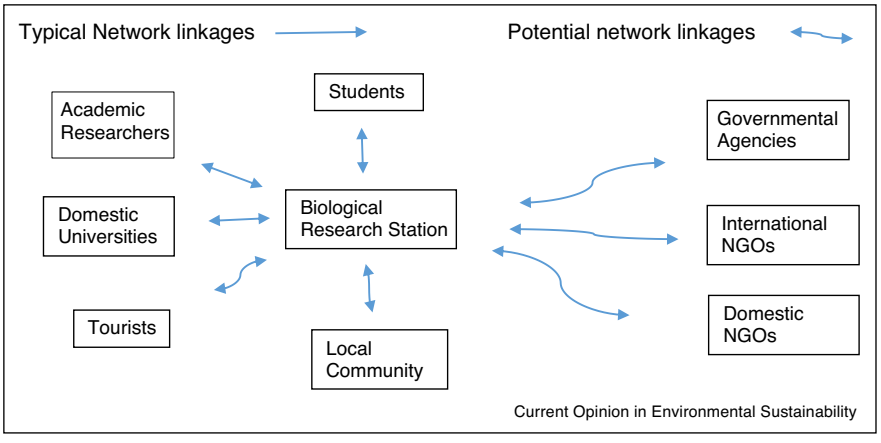
To examine a research station as the center of a collaborative network, we revise a SNA approach adopted by Nita *et al.* [17] which identifies two foci of study: the project as the collaboration venue and the project's partners. This approach has been used successfully to examine a range of different environmental and conservation initiatives. However, unlike these studies that define the venue as the project, we identify the venue of collaboration as the institution of the research station. Research stations can serve as 'nodes of interaction' which facilitate interaction between local and domestic researchers, conservation organizations and governmental agencies, and, potentially, even if rarely in practice, tourists and local community members. As increasing social capital can be viewed as increasing ties that would otherwise not be available [5], it follows that the approach that more effectively facilitates collaboration between the different actors will increase social capital and lead to improved research and related conservation outcomes.

Most studies of social networks in conservation settings have employed co-authorship of publications to measure e collaboration [24,8]. Although useful and easily quantifiable, co-authorship is at best a partial indicator of collaboration as it conceals the extent and means by which the different authors worked together [33,43]. Moreover, few studies examine the personal relationships between collaborators and the process of collaboration [43]. Here, we follow the recommendations of Jeong *et al.* [12] to examine a more complete range of collaborative activities than simply publications.

Case study: St. Edward's University – Indiana University – Organization for Tropical Studies Biological Station Network

To explore the potential of biological research stations to serve as central nodes in effective collaborative networks, we examined a partnership between U.S. and Costa Rican institutions which encompasses both international education and research experiences. The primary organizations involved are St. Edward's University and Indiana University in the United States and the Organization for Tropical Studies (OTS) in Costa Rica. St. Edward's University (SEU) is a private, liberal arts university in

Figure 2



Conceptual model depicting a biological research station as the central node in a social network. The central position demonstrates strong betweenness centrality while the numerous linkages demonstrate degree centrality.

Austin, Texas, with 3730 undergraduate students and almost 1000 graduate students. Indiana University Bloomington (IU) is a research institution located in Bloomington, Indiana, with 32 991 undergraduate students and 9000 graduate students. OTS is a consortium of almost 60 academic and non-academic research institutions that operates three biological field stations in Costa Rica and one in South Africa and offers field courses that have trained over 8000 students and generated over 5000 scholarly publications. In our analysis, we will briefly describe the development of the partnership and accomplishments and limitations of this network.

Nature of collaboration and relationships within core biological station network

As with most collaborations that begin informally [10,12], this partnership developed gradually with the depth and breadth of collaboration increasing at each stage. In 2012, SEU began a program to train undergraduates on sustainable development. The program involved a Spring semester course followed by an eight-day study tour of Costa Rica which included a visit to the OTS La Selva Biological Station for guided forest hikes and a citizen science activity on the importance of tropical forests to carbon sequestration. Incorporating training in research and a lesson in conservation into the ecotourism experience helped OTS communicate the research goals of the station to undergraduate students and non-academics. After three years of visiting La Selva with the study tour, SEU faculty developed a master's level summer field research course at La Selva and Las Cruces Biological Stations with SEU faculty teaching the course with assistance from OTS scientists.

This collaboration with OTS to design and teach the graduate field course provided the impetus for a research proposal submitted to the National Science Foundation (NSF) International Research Experience for Students (IRES) program to fund an interdisciplinary research project based at the two OTS stations. After one of the faculty moved to Indiana University, the core of the network grew to include a research institution (IU), a teaching institution (SEU), an international research organization (OTS), and two biological research stations. This program, currently in its third year, funds graduate or advanced undergraduate students to design individual research projects in the U.S. under supervision of SEU and IU faculty and then spend ten weeks conducting their research in Costa Rica under supervision of OTS scientists. This arrangement enabled through the trust developed during the field courses and the direction of OTS staff helped reduce the domination of the American institutions. After a brief introduction from IU faculty at the research station, the students rely on OTS during their ten-week study, other than occasional video conferences with their American advisors.

Each of the three projects in Costa Rica has resulted in different types of relationships between the student participants, American faculty, and Costa Rican hosts. The undergraduate study tour involved course delivery to students by American faculty and student training in research methods by Costa Rican scientists. The graduate field course involved both of these relationships, as well as advising of student research by American faculty and Costa Rican scientists, student training in research methods by American faculty, development of scientific capacity including sharing of equipment between American faculty, Costa Rican scientists, and students, and the development of itineraries and logistical arrangements conducted through Costa Rican staff and American faculty collaboration. The NSF project involved all of these relationships except course delivery to students by American faculty and student training in research methods by Costa Rican scientists, but included the unique relationships of Costa Rican scientists training in new equipment and social research methods by American faculty and coauthorship of presentations and manuscripts by American faculty, students, and Costa Rican scientists not seen in the other two programs. Examining these relationships highlights the central role in the network of the biological station enabling it to make local connections that cannot be done by the Northern partners directly, such as identifying research sites surrounding the station, negotiating permissions to conduct research at farms in the local community, arranging meetings with landowners and government officials, handling research permits, making reservations, and hiring field assistants or translators.

Outcomes of collaboration and quantification of biological station network

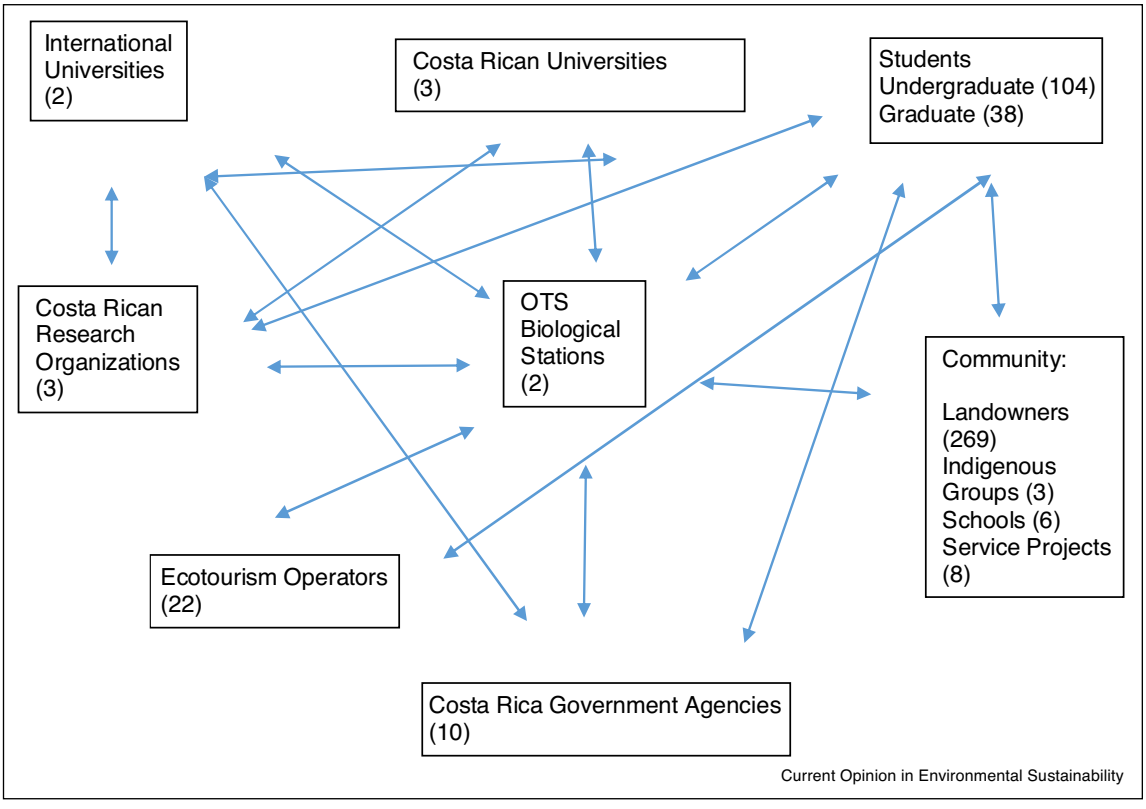
This ongoing collaboration has had significant beneficial outcomes for the involved students, professionals and institutions that would not be possible without the network centered on the research station, students, professionals, and institutions. Approximately 150 students have participated in the three programs, including over half representing populations traditionally underserved in STEM fields. Three of the participants later received Fulbright awards. Both the undergraduate study tour and graduate field course involved community service projects enabling the students to interact directly with community members. In addition, the involvement of OTS staff in facilitating these projects increased their interactions outside of the station with the local community. For the faculty and researchers from the three partner institutions, a primary benefit has been the awarding of NSF funding, at least in part due to their previous collaborations. Outcomes of this collaboration include 16 students (12 from populations underrepresented in STEM) gaining international field research experience, three coauthored manuscripts, twelve presentations at academic conferences, eight master's theses, two undergraduate honor's thesis projects and contributions towards five doctoral research projects.

The NSF project and involvement of IU has helped generate the transfer of knowledge and technology as the OTS stations have received new research equipment, including a YSI water quality meter, bat echolocation recognition equipment and software, and a centrifuge. In addition, the extended personal interactions at the stations enabled the faculty and students to train OTS researchers on the new equipment, while OTS researchers trained the student researchers in tropical forest research techniques. By incorporating landowner surveys, the activities of the project have also expanded OTS's traditional focus on ecological research to include social research in the neighboring communities. All three programs have expanded interactions to additional Costa Rican academic institutions including Earth University, Soltis Center for Research and Education, Piro Research Station, and Universidad Técnica Nacional. Each year the student researchers present their findings at OTS open to OTS staff and community members, further facilitating community engagement and knowledge transfer.

The activities generated by the projects are further amplified by the environmental education and outreach programs of the biological stations which promote communication of the results and recommendations to local communities around the station. This expands the network and promotes a better understanding of the implications for local conservation. Moreover, community members and eco-tourists participate in lectures presented by the students at the station, thus providing information to this audience, making connections between all actors, and providing experience for the students on public presentations for diverse audiences. The biological station also facilitates the establishment of environmental and conservation policies when providing recommendations based on scientific research to government agencies.

Using the research stations as bases for the educational and research programs enabled them to serve as boundary spanners facilitating the expansion of this network by connecting tourists, domestic and international scholars, and community members, including those from indigenous reserves. This diversity of actors involved in this network increased the value added to each of the education, research and tourism objectives. Figure 3 depicts the linkages between the biological stations and the other

Figure 3



Social network model depicting relationships developed through the undergraduate study tour, graduate field course, and NSF research project co-managed by St. Edward's University, Indiana University, and the Organization for Tropical Studies with the biological research stations in Costa Rica as the central nodes demonstrating degree centrality and betweenness centrality. () = number of nodes in each category.

Table 1

Number of nodes in the St. Edward's University-Indiana University-Organization for Tropical Studies social network based on each of the three Costa Rican education and research experiences

		Study tour (2013–2017)	Field course (2016–2017)	NSF project (2017–2018)
Academic institutions	International	1	1	2
	Costa Rican	1	3	3
Research stations		1	5	5
Students		102	30	10
Community groups				
	Indigenous groups	2	1	1
	Schools	1	2	3
	Service projects	2	6	0
	Landowners	0	4	265
Ecotourism operators		15	4	12
Government agencies		4	5	7

actors in the network. The location of the research stations at the center of the network, demonstrating betweenness centrality, and the linkages to other actors, including those who otherwise would not be linked, demonstrating degree centrality, support previous studies that have shown those factors to be crucial to developing collaborative networks [40,32] and highlight the importance of the biological research stations in their development.

The type of the academic activity and use of the research station greatly influenced which actors were involved in the social network (Table 1). In general, the undergraduate study tour provided international experiences for the most students, but was limited in developing significant relationships between actors besides ecotourism guides. By contrast, the NSF project provided experiences for the fewest number of students, but these experiences developed the strongest relationships and provided interactions with the greatest number of actors across all categories, especially with landowners in the local community through the social research. The graduate field course provided an intermediate number of students with experiences and a wider range of interactions with Costa Rican academic institutions, but was a shorter, more controlled experience, thus limiting the strength of these relationships.

Conclusion

This case study has demonstrated the central role that biological research stations can play in developing collaborative networks. Given the importance of collaboration in addressing conservation challenges [11,9•], these findings provide a framework for how such collaboration can emerge as well as how collaboration can be structured to reflect characteristics of successful networks. The extended time at the field stations enabled extended face to face interactions and the building of strong ties [29,44]. Strong ties facilitate information exchange, trust, and the transfer of complex knowledge [16••,36]. The building of trust enabled the NSF students, most of whom had not previously conducted independent international research, to successfully conduct ten-week research projects, knowing that they would have the support they needed. Extending the network to include greater community interaction outside of the research stations reflected the need to extend beyond comfort zones of existing practices for the research institution to have greater influence on conservation [23•,45]. The frequent interactions enabled numerous means of information exchange and knowledge transfer between the different institutions and individuals involved, including research training of students, training and participation in the use of new equipment and social research methods for OTS scientists and staff, and the co-authored papers and presentations. The horizontal network expansion towards other Costa Rican institutions, such as Earth University and Piro Research Station, altered the typical North–South partnership which frequently is geared towards the foreign institution, rather than other domestic institutions.

The incorporation of these best practices, however, does not ensure the viability of the long-term maintenance of this network. Despite the active participation of the OTS counterparts, the field course objectives and NSF funding were largely determined by U.S. institutions. The vagaries of dependence on foreign funding, changing priorities of individual researchers, and fluctuating preferences of international students could limit the collaborative activities. Financial limitations faced by either the American or Costa Rican parties will influence the ability for these activities to be maintained. Despite the repeated interactions, the relatively short time spent at each field station by the American partners and the annual turnover of students disrupts continuity. Changing financial conditions and staff turnover at the field stations could also affect maintaining the contacts necessary to sustain the network. The extension of the network to additional actors will build resilience and enable participating actors to better withstand these constraints. Incorporating multiple activities and maintaining communication remotely

will also help to maintain the contacts necessary to alleviate these limitations.

By supporting the importance of centrality in developing social networks and expanding the networking literature to include biological research stations, the results of this study strengthen understanding of the factors that determine successful collaboration. However, care must be taken when generalizing from this case as Costa Rica is an upper-middle income country with a long history of tropical biology research. Although their institutions have fewer resources than the U.S., they are better equipped and connected than many other Southern nations. Future studies that compare multiple research stations will be able to provide more robust conclusions. In addition to identifying the interactions, studies that examine the extent of interactions and changes over time would enhance understanding of the role of research stations in expanding and maintaining collaborative networks. Finally, examining the effects of these networks on measurable environmental outcomes, such as forest cover, biodiversity, human and wildlife health, and water quality, will allow for development of socio-ecological models useful for evaluating the effectiveness of specific conservation and sustainability practices. Comparative analyses involving multiple field stations that incorporate quantitative data on field station use, research productivity, number of students trained, and community outreach activities will further test the hypothesis presented here that biological field stations serve as central nodes in collaborative networks thereby promoting effective research and teaching which address critical environmental issues. We plan to build on this case study by expanding this network to biological field stations in Panama and Uganda over the coming years.

Role of funding source

Our work in Costa Rica described in this paper has been supported by a National Science Foundation International Research Experience for Students grant #1559223, as well as funds from Indiana University and St. Edward's University. None of these funding sources played any role in the development, design, or writing of this manuscript.

Conflict of interest statement

Peter Beck is Professor of Environmental Science and Policy at St. Edward's University, Rodolfo Quirós is the Head of Research and Education at the Organization for Tropical Studies Las Cruces Biological Station, C. Eric Johnson is Laboratory Manager of the Primate Environmental Endocrinology Laboratory at Indiana University, and Michael Wasserman is Assistant Professor of Anthropology and Human Biology at Indiana University. Although we work for the institutions reviewed in this paper, we attempted to limit any bias in our analysis of the costs and benefits of international biological field stations and their role as central nodes in social networks focused on research and education collaboration.

Acknowledgements

We would like to thank all staff, scientists, and landowners in Costa Rica, especially at the Organization for Tropical Studies, that have been so welcoming over the past five years, as well as the students and staff that have traveled with the undergraduate study tour, graduate field course, and NSF project. We thank NSF IRES #1559223 for funding our research in Costa Rica, along with additional funds from St. Edward's University and Indiana University. We also thank the various government agencies of Costa Rica that have provided permission to conduct the courses and research in the country. Finally, we thank St. Edward's and Indiana University IRB and IACUC boards for approval of our various research projects examining social and ecological effects of conservation incentives.

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