

Maderas Rainforest Conservancy: A One Health approach to conservation

Laura M. Bolt^{1,2}  | LaRoy S. E. Brandt^{2,3}  | Renee L. Molina² | Amy L. Schreier^{2,4} 

¹Department of Anthropology, University of Waterloo, Waterloo, Ontario, Canada

²The Maderas Rainforest Conservancy, Miami, Florida, USA

³Department of Biology, Lincoln Memorial University, Harrogate, Tennessee, USA

⁴Department of Biology, Regis University, Denver, Colorado, USA

Correspondence

Laura M. Bolt, Department of Anthropology, University of Waterloo, Waterloo, ON N2L 3G1, Canada.

Email: laurabolt@gmail.com

Abstract

Maderas Rainforest Conservancy (MRC) was incorporated as a conservation non-profit organization in 2008, and manages two sites where biological field courses have been offered since the 1990s: La Suerte Biological Research Station in Costa Rica, and Ometepe Biological Research Station in Nicaragua. MRC employs a One Health approach to conservation education, and can serve as a model for other biological field sites. The Nicaraguan Molina family, who owns the sites, partnered with primatologist Paul Garber in 1994 to develop a primate field course aimed at introducing university students to field research. Through using their land to further conservation education and research, the Molina family has preserved the forest and engaged the local communities near their sites. Eight graduate theses and 46 refereed publications have been completed since 2010 based on research undertaken at MRC sites. While primate field courses have been offered at least once annually since 1994 and remain popular, a range of other ecological courses are now additionally offered. MRC operates from a One Health perspective, engaging in forest restoration and ecological monitoring projects, and has gradually expanded community outreach initiatives. MRC now conducts regular medical and veterinary missions in the communities surrounding the research stations which provide health care to local people and limit the population growth of domestic animals, thereby increasing the survival of wild animals. MRC is also active in ESL-teaching and conservation education, and funds Proyecto Jade, which empowers local women to make and sell organic jewelry. Through these programs, MRC works to help the local communities live more sustainably with the environment around them. MRC's support of research, commitment to education, medical and veterinary missions, and outreach initiatives to the local community all work together for the well-being of both the people and the environment, thus exemplifying the One Health perspective.

KEYWORDS

biological field school, community outreach, Costa Rica, Nicaragua, One Health, veterinary mission

1 | INTRODUCTION

One Health is the concept that the health of humans; wild and domestic animals; and natural ecosystems are intrinsically connected (Deem et al., 2018). To maintain the well-being of each, we must attend to the health of all. One Health has natural application to biological field schools, which are typically situated in world regions of high biodiversity (i.e., the tropics) and low human income (Whitesell et al., 2002). In many such locations, human and environmental priorities conflict (McNeely, 1994), making it especially important to consider human needs when determining how to best preserve biodiversity in the natural world. Biological research stations are therefore ideal centers from which to apply holistic approaches to conservation work. The One Health concept is exemplified by the multi-faceted initiatives of the Maderas Rainforest Conservancy (MRC), a conservation nonprofit organization that maintains biological field stations in La Suerte, Costa Rica (La Suerte Biological Research Station [LSBRS]) and Ometepe, Nicaragua (Ometepe Biological Research Station [OBRS]). MRC serves as a model for how One Health principles can be applied to conservation and education-focused initiatives.

2 | MISSION OF MRC

MRC was incorporated as a conservation nonprofit organization in 2008 by Director Renee Molina with assistance from primatologist Andrew Halloran. The mission of MRC is threefold: (1) to protect the biodiversity of tropical forests in Central America, (2) to promote conservation education through offering biological field courses to undergraduate and graduate students, (3) to establish relationships with local communities by joining with them in preserving natural ecosystems (Halloran, 2013; Figure 1). MRC has fulfilled their first objective by managing tropical forests at sites in Costa Rica (i.e., LSBRS) and Nicaragua (i.e., OBRS) (Molina, 2015). Any deforested areas at the sites have been gradually replanted with trees protected from further clearing, while the animals found therein are shielded from illegal hunting and capture (Molina, 2015). MRC fulfills their second objective by offering a wide range of biological field courses (Table 1), with course topics built around the natural history and ecology of each site: the tropical lowland rainforest in Costa Rica, and the tropical dry forest in Nicaragua (Garber et al., 2010). Since 2010, MRC has taught students from all over the world, and especially from the United States (Table 2). MRC fulfills their third objective by partnering with, employing, and serving the local people around their sites in Costa Rica and Nicaragua, thus helping local communities while gaining strong allies in the preservation of local tropical forests. Since their incorporation in 2008, MRC has gradually expanded their involvement with local communities, offering education, employment, and veterinary and medical care to nearby residents (Molina, 2015). In particular, these expanding community initiatives exemplify MRC's commitment to a One Health approach to biological conservation. MRC fulfills their objectives at LSBRS in

Costa Rica, and OBRS in Nicaragua. While both sites were incorporated as the nonprofit organization MRC in 2008, the Molina family began their conservation and education work at their field sites many years before.

3 | HISTORY OF MRC

3.1 | LSBRS

The Nicaraguan Molina family purchased a 7 km² cattle ranch near Cariari, Costa Rica in 1987 (Garber et al., 2010), called Finca La Suerte. This farm contained over 3 km² of primary and secondary tropical rainforest, as well as many deforested areas, and the La Suerte River ran through the site (Garber et al., 2010). Finca La Suerte was situated in Costa Rica's "banana belt," an area in north-east Costa Rica that had undergone large-scale deforestation since the 1970s as a result of corporate agriculture by international banana corporations (Garber et al., 2010). Such deforestation meant that Finca La Suerte represented one of increasingly few forest fragments in the region. The local population lived in the nearby La Primavera village (population 400), a settlement that was artificially created in the 1980s to house banana plantation workers (Garber et al., 2010). In 1994, property values in the area had risen to the degree that the Molina family sold half of Finca La Suerte to pay off the mortgage on the other half, meaning that the LSBRS site shrank in size to 3.3 km² overall, a size it maintains to present day.

Also in 1994, after operating Finca La Suerte as a cattle ranch for a few years, the owners Rene and Lillian Molina, along with their son Alvaro Molina, contacted primatologist Paul Garber to evaluate the possibility of developing the land surrounding their cattle ranch into a biological reserve that would offer biological field courses to international students and could serve as a field site for researchers (Garber et al., 2010; McKinnon, 2011). Three species of monkey are found at LSBRS: mantled howler (*Alouatta palliata*), white-faced capuchin (*Cebus imitator*), and Central American spider monkeys (*Ateles geoffroyi*) (Pruetz & Leason, 2002), making it an ideal site for a primate field school. The patriarch of the family, Rene Molina (1933–2013), was a visionary who wanted to preserve the remaining forest at Finca La Suerte and promote habitat reforestation and rejuvenation through sustainable education programs (Garber et al., 2010; Molina, 2015).

The newly founded LSBRS began offering field courses in 1994, with Paul Garber designing and leading a 3.5-week primate field course aimed at introducing university students to the rigors of primatological field research. This course has been consistently taught several times annually since 1994 and continues to be the most frequent course offering at MRC today (Table 1). Many field school students have gone on to earn PhDs in primatology or related subjects (Garber et al., 2010), including approximately 70 students since 2010 (Table 2).

Rene and Alvaro Molina continued to operate LSBRS as a research and education site, while gradually reducing the number of

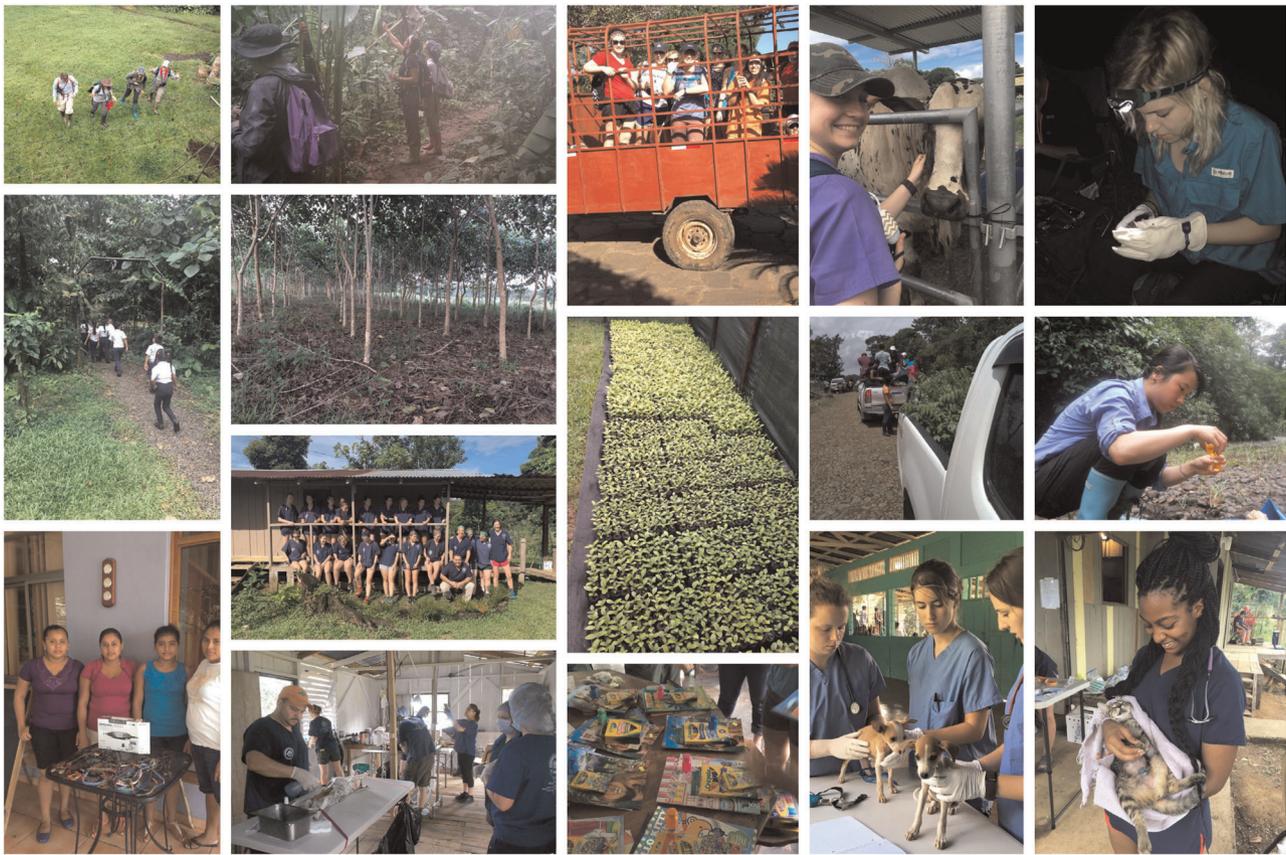


FIGURE 1 Images of MRC activities. Far left top, primate field school students returning from a morning conducting field surveys; far left middle, local elementary school students on educational hike at LSBRS; far left bottom, Proyecto Jade women's artisanal group at OBRS; middle left top, primate field school students spotting monkeys; middle left second down, replanted teak (*Tectona grandis*) forest at LSBRS; middle left third down, 2019 veterinary field mission students at LSBRS; middle left bottom, LSBRS veterinary mission surgery; middle top, 2018 veterinary mission students at OBRS on transportation to visit farmers; middle center, gmelina (*Gmelina arborea*) seedlings awaiting planting; middle bottom, school supplies being prepared for distribution to visiting elementary school students at LSBRS; middle right top, a veterinary mission student assisting with the cattle wellness check; middle right center, tree planting crew staged and ready to begin work; middle right bottom, veterinary mission students conducting wellness checks at OBRS; far right top, a bat ecology student examining a bat at OBRS; far right middle, a rainforest ecology student conducting water quality tests at LSBRS; far right bottom, a veterinary mission student with a cat recovering from anesthesia. LSBRS, La Suerte Biological Research Station; MRC, Maderas Rainforest Conservancy; OBRS, Ometepe Biological Research Station

TABLE 1 Biological field courses offered at Maderas Rainforest Conservancy sites since 2010

| Course name | Site offered | Number of times offered since 2010 |
|---|----------------|------------------------------------|
| Advanced Primate Behavior & Ecology | LSBRS | 3 |
| Botany | LSBRS | 2 |
| Comparative Skeletal Anatomy & Function | OBRS | 3 |
| Herpetology | LSBRS | 1 |
| Neotropical Bat Ecology | LSBRS and OBRS | 10 |
| Photography for the Field Biologist | LSBRS | 6 |
| Primate Behavior & Ecology | LSBRS and OBRS | 26 |
| Rainforest Ecology | LSBRS and OBRS | 5 |
| Veterinary Field Training Mission | LSBRS and OBRS | 25 |

Abbreviations: LSBRS, La Suerte Biological Research Station; OBRS, Ometepe Biological Research Station.

TABLE 2 Student enrollment demographics in Maderas Rainforest Conservancy (MRC) courses since 2010

| | |
|---|---|
| Number of students who have participated in MRC courses since 2010 | 494 |
| Nationalities of students who have participated in MRC courses since 2010 | 85.5% American, 5.9% Canadian, 2.1% Italian, 1.8% Costa Rican, 1.0% British, 1.0% French, 0.7% German, 0.4% Australian, 0.4% Chinese, 0.4% Mexican, 0.4% Nicaraguan, 0.4% Swedish |
| Percentage of students who have completed a master's degree in a related subject after participating in an MRC course | 19.9% |
| Percentage of students who have completed a doctorate in a related subject after participating in an MRC course | 14.8% |
| Percentage of students who have enrolled in medical or veterinary training after participating in an MRC course | 9.6% |

cattle present, until by 2004, all cattle were gone, and LSBRS was self-sustaining through field school tuition, researcher fees, and governmental protection contracts (Garber et al., 2010; Molina, 2015). LSBRS has held a forest contract with the Costa Rican government since 2004, preserving 2.2 km² of LSBRS forest (which is 3.3 km² in total) through an agreement with Fondo Nacional de Financiamiento Forestal (FONAFIFO) and Ministerio de Ambiente y Energia (MINAE/ASIRAE), which prevents the alteration or removal of any forest products from the protected portion of the site (e.g., fallen trees cannot be removed). The remaining 1.1 km² is not subject to the same restrictions, meaning that the Molina family can cut new forest trails for use by students or researchers and/or build new student accommodation or roads in the remainder of the site, if needed (Molina, 2015). Rene and Alvaro Molina stepped down from the day-to-day administration of the field sites in 2007, making way for Rene's daughter Renee Molina to take over operations and oversee the incorporation of MRC as a nonprofit organization in 2008. Renee Molina continues as director of MRC to the present day, and has initiated most of MRC's outreach activities, including both medical and veterinary initiatives (Molina, 2015). MRC has thus increasingly exemplified a One Health approach to biological conservation since its inception as a nonprofit organization.

3.2 | OBRS

In 1996, the Molina family purchased a plantain field in San Ramon, Ometepe Island, Nicaragua. This area was part of the tropical dry forest surrounding the inactive Maderas volcano (from which MRC gets its name—Maderas means “wooded” in Spanish), and is home to mantled howler monkeys and white-faced capuchin monkeys (Bezanson et al., 2008). Ometepe Island is a well-traveled tourist destination, with main attractions including the San Ramon waterfall (Cascada de San Ramon), which is very close to OBRS. Ometepe Island also houses a substantial local population, with OBRS located nearest the village of San Ramon (population 3000). Ometepe faces different conservation challenges than LSBRS, with most deforestation coming from local farmers using slash-and-burn agriculture to

clear trees to plant crops to support their families (Garber et al., 2010; Molina, 2015). Consequently, the Molina family felt that they could make more of a lasting impact on the overall conservation of the Ometepe region, which had not yet been largely deforested, through their land purchase and conservation activism (Molina, 2015). The Molina family continued to purchase more land in and surrounding San Ramon and founded OBRS in 1997, which began offering primate field courses in 1999 following the same model as at LSBRS (Garber et al., 2010; Molina, 2015). OBRS was similarly established by Rene and Alvaro Molina in collaboration with Paul Garber, with Andrew Halloran later joining with the incorporation of MRC as a nonprofit. Edgar Molina, another son of Rene Molina, began acting as on-site manager in 2012 and continues to administer the site to present day.

4 | EDUCATION AND RESEARCH AT MRC

4.1 | Field courses at MRC

Since the first primate field school was offered in 1994, more than a thousand students have completed the primate field course alone (Garber et al., 2010; McKinnon, 2011). Both LSBRS and OBRS have widely expanded their course offerings beyond primatology since their inceptions as field sites, and currently offer a variety of biological field courses (Table 1). Since 2010, around 500 students have completed MRC courses (Table 2). In addition to the ongoing biological field courses offered through MRC, LSBRS and OBRS additionally host field courses that are administered and taught by individual high schools and universities worldwide, across a broad range of topics including primatology, botany, rainforest ecology, and conservation biology (Molina, 2015). LSBRS has been hosting courses led by other institutions since 1994, and OBRS since 1999, with LSBRS and OBRS acting as a host sites and MRC as a facilitation agency, organizing in-country transport and providing food and housing for students and instructors from various institutions when they visit (Molina, 2015). To date, several thousand students in total

have been educated by courses led by MRC and/or hosted by the LSBRS and OBRS sites (Huetteman, 2015d).

Through studying and living at field stations, students gain experiential knowledge of the biodiversity and ecosystems of each Neotropical region, thus transforming field school graduates into informed advocates who understand the vital importance of conserving threatened regions worldwide (Halloran, 2013). Qualitative student reflections from the MRC primate field school indicate that after a month in the rainforest, students truly understand the fundamentals of primate behavior as well as the research process (McKinnon, 2011; Schreier, unpublished data). They leave the course empowered, becoming an expert in some aspect of these animals' lives, and having been immersed in nature. In a qualitative course evaluation, one student reflected, "I remember the feeling of freedom from everyday life, electronics, everything. It gave me the feeling of self-empowerment" (Schreier, unpublished data). Another student described participating in an MRC field school as "challenging and one of the most rewarding experiences" (Schreier, unpublished data). Preliminary data on educational outcomes show that students who complete MRC biological field schools tend to become more focused on their coursework and more active participants in their education (Brandt, unpublished data), thus leading to more ambitious educational and career goals. A notable percentage of MRC students go on to complete graduate degrees in biology or a related subject, or enroll in medical or veterinary school (Table 2), attesting to the educational impact of their field experience.

Conservation through education continues to be a primary objective of MRC, with field school tuition providing the main source of income for all site maintenance, salaries, and day-to-day operations (Molina, 2015). MRC has consistently offered one or two scholarships annually for primate field school participation through the American Society of Primatologists, and has also waived fees or found other sources of funding to support habitat country primatologists who apply to complete the primate field school (Garber et al., 2010). The ecological education of international students provides a primary means of support for MRC, but also furthers the objectives of a One Health perspective. Through bringing students to the LSBRS and OBRS sites and allowing them to gain experiential understanding of the interconnections between the land, the animals, and the people, a holistic One Health worldview is fostered in the next generation.

4.2 | Biological research at MRC

Before 2010, several master's theses and doctoral dissertations and approximately 20 refereed publications were produced by researchers at LSBRS or OBRS (Garber et al., 2010). Since 2010, field research at LSBRS and OBRS has continued, with a number of long-term projects using the MRC sites seasonally and annually. Scientific publications since 2010 include four master's theses, four doctoral dissertations, 12 book chapters, and 34 refereed journal articles (Table 3). This active use of LSBRS and OBRS as research sites helps

further MRC's conservation mission, since pure research is needed to inform conservation action plans (McIntosh et al., 2018) and to promote awareness of how humans are altering habitat, particularly in already-fragmented tropical regions, like the areas surrounding LSBRS and OBRS. Research findings are also key to better understanding the health of plants, animals, and their environment, thus allowing local medical and veterinary initiatives to be contextualized within current ecological health findings for the LSBRS and OBRS sites. Finally, researcher site fees help fund MRC operations, thus providing an additional source of support for general operating costs at MRC as well as supporting conservation and outreach initiatives.

5 | ECOLOGICAL AND ENVIRONMENTAL INITIATIVES

5.1 | Forest restoration project

At LSBRS, native trees including *Pentaclethra macroloba*, *Pterocarpus officinalis*, *Zygia logifolia*, *Dipteryx panamensis*, *Hieronyma alchorneoides*, *Cupressus lusitanica*, and *Cedrela odorata* have been actively replanted alongside fast-growing teak (*Tectona grandis*) and gmelina (*Gmelina arborea*) seedlings since 1997 in former areas of cattle pasture, to create corridors between forests (Garber et al., 2010; Molina, 2015). Teak seedlings have grown 3.5 cm/year on average with <1% mortality rate, while gmelina seedlings have grown 2.25 cm/year with around a 5% mortality rate (Brandt, unpublished data). To date, close to 50,000 trees have been replanted at LSBRS (Brandt & Singleton, 2018). Most of these trees were planted as part of a Costa Rican government-subsidized reforestation project through FONAFIFO's carbon credit and gasoline tax initiative, but student visitors also typically assist in replanting, with many biological field courses planting one tree per student (Molina, 2015). The LSBRS replanting effort fixes carbon, which helps harness CO₂ from the atmosphere and slows the process of global warming (Weigmann, 2019), thus mitigating the process of climate change and furthering MRC's conservation mission.

Over the last decade, numerous seedlings of additional native tree species from adjacent forests have also grown in replanted areas, attesting to increased seed dispersal by vertebrate species moving freely through the newly forested regions (Brandt, unpublished data). MRC's replanting effort has thus noticeably increased forest habitat, expanding biodiversity and animal ranges at LSBRS (Brandt & Singleton, 2018). For example, before 2010, the large-bodied and arboreal Central American spider monkey formerly ranged only in the northern portion of the LSBRS forest (i.e., the "Large Forest"), which was the only area of the site with continuous canopy and large trees (Garber et al., 2010; Pruetz & Leason, 2002). Spider monkeys now range throughout the entire LSBRS forest fragment, including the trees bordering the student and researcher housing area (Bolt et al., 2018; Bolt, Schreier, et al., 2020).

At OBRS, MRC works with local landowners to reduce slash-and-burn land clearing, and since 2010 has provided the resources to develop living fences, which create corridors for animals between small patches of

TABLE 3 Scientific publications since 2010 on research conducted at MRC sites

| Citation | Subject | Field site | Type of publication |
|--------------------------------|------------------------------|----------------------|-------------------------------|
| Álvarez (2019) | Botany | OBRS | Master's thesis |
| Amato et al. (2016) | Primatology | LSBRS and OBRS | Journal article |
| Amato et al. (2019) | Primatology | OBRS | Journal article |
| Baltensperger and Brown (2015) | Mammalian behavioral ecology | LSBRS | Book chapter in edited volume |
| Barrickman et al. (2015) | Primatology | LSBRS | Journal article |
| Bezanson (2012) | Primatology | LSBRS | Journal article |
| Bezanson et al. (2012) | Primatology | LSBRS | Journal article |
| Bezanson et al. (2013) | Primatology | LSBRS | Journal article |
| Bingman et al. (2017) | Entomology | LSBRS | Journal article |
| Bolt et al. (2018) | Primatology | LSBRS | Journal article |
| Bolt et al. (2019) | Primatology | LSBRS | Journal article |
| Bolt, Russell, et al. (2020) | Primatology | LSBRS | Journal article |
| Bolt, Schreier, et al. (2020) | Primatology | LSBRS | Journal article |
| Bolt, Cavanaugh, et al. (2021) | Primatology | LSBRS | Journal article |
| Bolt, Russell, et al. (2021) | Primatology | LSBRS | Journal article |
| Brandt and Singleton (2018) | Mammalian behavioral ecology | LSBRS | Journal article |
| Chinchilla et al. (2010) | Primatology | LSBRS | Journal article |
| Davis et al. (2012) | Entomology | OBRS | Journal article |
| Dunham et al. (2019) | Primatology | LSBRS | Journal article |
| González-Maya et al. (2011) | Herpetology | LSBRS | Journal article |
| Halloran and Mancz (2015) | Primatology | OBRS | Book chapter in edited volume |
| Hebets et al. (2014) | Entomology | LSBRS | Journal article |
| Huettman (2015a) | Botany | LSBRS | Book chapter in edited volume |
| Huettman (2015b) | Animal biodiversity | LSBRS | Book chapter in edited volume |
| Huettman (2015c) | Ornithology | LSBRS | Book chapter in edited volume |
| Illes (2010) | Primatology | OBRS | Doctoral dissertation |
| Jordan et al. (2014) | Bat ecology | OBRS | Journal article |
| Madden et al. (2014) | Primatology | LSBRS | Journal article |
| Madden et al. (2015) | Primatology | LSBRS | Journal article |
| Mallott (2016) | Primatology | LSBRS | Doctoral dissertation |
| Mallott et al. (2017) | Primatology | LSBRS | Journal article |
| Mallott and Amato (2018) | Primatology | LSBRS | Journal article |
| Mallott, Amato, et al. (2018) | Primatology | LSBRS | Journal article |
| Mallott, Garber, et al. (2018) | Primatology | LSBRS | Journal article |

| Citation | Subject | Field site | Type of publication |
|----------------------------------|-----------------------|----------------|-------------------------------|
| Mallott et al. (2019) | Primatology | LSBRS | Journal article |
| Matsushita et al. (2014) | Primatology | OBRS | Journal article |
| Nemitz and Huetttman (2015) | Animal biodiversity | LSBRS | Book chapter in edited volume |
| Occhibove et al. (2015) | Primatology | LSBRS | Book chapter in edited volume |
| Pruetz and Davis (2018) | Primatology | LSBRS | Journal article |
| Raguet-Schofield (2010) | Primatology | OBRS | Doctoral dissertation |
| Raguet-Schofield and Pavé (2015) | Primatology | OBRS | Book chapter in edited volume |
| Rivera-Cáceres (2015) | Ornithology | LSBRS | Journal article |
| Rivera-Cáceres (2017) | Ornithology | LSBRS | Doctoral dissertation |
| Rivera-Cáceres et al. (2018) | Ornithology | LSBRS | Journal article |
| Russell (2018) | Environmental science | LSBRS | Master's thesis |
| Schmid et al. (2015) | Environmental science | LSBRS and OBRS | Book chapter in edited volume |
| Schreier et al. (2021) | Primatology | LSBRS | Journal article |
| Sheehan (2018) | Primatology | LSBRS | Master's thesis |
| Skylstad and Huetttman (2015) | Herpetology | LSBRS | Book chapter in edited volume |
| Spangler (2015) | Herpetology | LSBRS | Book chapter in edited volume |
| Urbani (2019) | Primatology | LSBRS | Book chapter in edited volume |
| Urbani et al. (2020) | Primatology | OBRS | Journal article |
| Wheeler (2013) | Primatology | OBRS | Master's thesis |
| Wiegmann et al. (2020) | Entomology | LSBRS | Journal article |

Abbreviations: LSBRS, La Suerte Biological Research Station; MRC, Maderas Rainforest Conservancy; OBRS, Ometepe Biological Research Station.

forest (Garber et al., 2010; Molina, 2015). Much of the land on Ometepe Island is a patchwork of locally-owned small forest fragments and agricultural fields, and many local property owners surround their land with wooden and barbed wire fences to indicate their property line. MRC provides native trees to these landowners to replace the wooden posts of their fences (Garber et al., 2010), thus creating rows of living trees that act as fences. These living fence corridors provide crucial navigation pathways for many birds and mammals to migrate between food sources and habitat patches, allowing them to move between closely situated fragments and promoting their genetic health.

5.2 | Ecological monitoring and consultation

As one branch of the One Health triad, the health of the environment can have substantial direct and indirect effects on the

health of humans and animals (Deem et al., 2018). Monitoring environmental health is therefore a crucial precursor for making predictions about the tenacity of environmental influences on human and animal health. As no standardized, accepted method to quantify environmental health exists, it is beneficial to use a number of proxy measurements that are anecdotally accepted as correlates to environmental health. As such, the monitoring of natural processes and biodiversity is important in tracking a landscape's ecological health, and MRC keeps track of abiotic and biotic markers in the LSBRS forest site in an effort to understand and maintain a healthy forest habitat. In addition to regularly updating a species lists of animal and plant species to catalog overall biodiversity (Brandt, available upon request; Huetttman, 2015b), MRC also monitors rates of succession and forest expansion. For example, excluding the replanted areas, natural expansion of existing forests by 0.05 km² has reduced

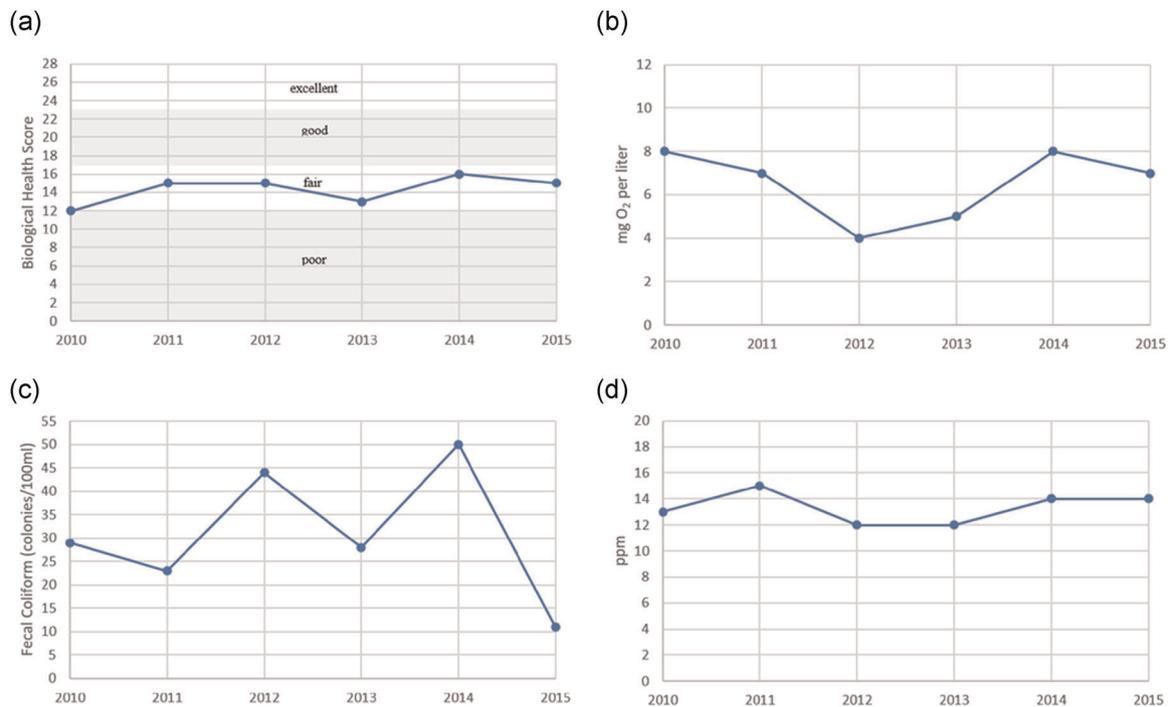


FIGURE 2 Representative water quality data for the La Suerte River. Data are presented for four of the nine water quality parameters monitored in the La Suerte River as it passes through LSBRS from 2010 to 2015. (a) Marco-invertebrate Health Index is based on the diversity of aquatic macro-invertebrates and their relative sensitivities to various pollutants. (b) Biological oxygen demand was determined using a 100 ml water sample from each location and extrapolated to a liter equivalent. (c) Fecal coliform counts are based serial dilutions of a 100 ml water sample to a 10% concentration of the original sample. (d) Nitrates were measured using a Hach™ nitrate field kit. The Macro-invertebrate Health Index indicates a stable score within the “fair” health range. LSBRS, La Suerte Biological Research Station

historical cattle pastures by 12% since 2005 (Brandt, unpublished data; Molina, 2015).

These landscape changes have also resulted in population increases for forest-dwelling insects, birds, and numerous vertebrate species at LSBRS. Studies of insect communities across the various habitats at LSBRS have shown that as the historical cattle pastures yield to the expanding forests, the insect communities increasingly comprise forest-dwelling insects (Brandt, unpublished data). Similarly, avian communities are becoming dominated by forest-dwelling bird species, with fewer bird species present that prefer open fields or pastures than in past years (Huetteman, 2015c). For example, birds preferring open spaces like the groove-billed ani (*Crotophaga sulcirostris*) and Great kiskadee (*Pitangus sulphuratus*) were commonly seen at LSBRS in 2008, with approximately 15–20 kiskadees regularly visible at the site (Brandt, unpublished data; Huetteman, 2015c). As of 2018, fewer than five individual kiskadees were commonly observed (Brandt, unpublished data). Instead, an increased number of forest-dwelling birds are visible at LSBRS. In 2005, the keel-billed toucan (*Ramphastos sulfuratus*) was a rare sight and did not consistently occupy the area (Brandt, unpublished data), while in 2008, it was more regularly observed (Huetteman, 2015c), and by 2018, at least four identifiable breeding pairs consistently occupied the site (Brandt, unpublished data). Similarly, sightings of other forest-dwelling bird species such as the slaty-tailed trogon (*Trogon massena*) and rufous motmot (*Baryphthengus martii*) occurred rarely before

2008 (Huetteman, 2015c), but were daily occurrences in 2018, with multiple pairs of each species residing permanently in the forests at LSBRS (Brandt, unpublished data). These changes in bird species found at LSBRS attest to the improving ecological health of its forest habitats.

Forest protections have also led to population increases in endangered vertebrate species at LSBRS, including environmental indicator species like the Central American spider monkey (Bolt, Schreier, et al., 2020) and large-bodied mammals like Baird's tapir (*Tapirus bairdii*) (Brandt & Singleton, 2018). Monkey population surveys (detailed in Bolt et al., 2018; Bolt, Schreier, et al., 2020; Pruetz & Leason, 2002) show that the spider monkey population at LSBRS has tripled in size since 1999 and now consists of at least 40 individuals (Bolt, Schreier, et al., 2020; Huetteman, 2015b; Pruetz & Leason, 2002; Schreier & Bolt, unpublished data), while the tapir population at LSBRS shows an even greater size increase. Based on encounter estimates, fewer than two individual tapirs used LSBRS before 2010 (Brandt, unpublished data; Huetteman, 2015b), but an ongoing study using camera traps distributed throughout LSBRS (detailed in Brandt & Singleton, 2018) indicated that an estimated 12–15 individual tapirs were regularly present at LSBRS in 2019 (Brandt, unpublished data). The presence of male, female, and juvenile tapirs in camera trap images suggests that a permanent tapir population is growing at LSBRS (Brandt & Singleton, 2018), demonstrating that the health of the LSBRS forest has improved, since as

large-bodied terrestrial herbivores, tapirs cannot survive in forests that are too heavily fragmented (Schank et al., 2020).

Tropical forests also rely on a healthy water supply, with water quality being of key importance to organisms that live in riparian environments. To further assess the ecological health of LSBRS, MRC monitors water quality in the La Suerte River (Brandt, 2019). The La Suerte River bisects the center of LSBRS on its way to Tortuguero, adjoining numerous communities, forests, and farms, and is utilized by many local residents as a water source for livestock, fishing, and recreation. Wild animals also use the La Suerte River as a source of fresh water. Within LSBRS, research has shown that the habitat adjacent to the riverbanks is critical to the plants and primates (Bolt, Russell, et al., 2020; Bolt, Schreier, et al., 2020), and is likely vital to the entire forest ecosystem. MRC has monitored water quality in the La Suerte River annually since 2010, assessing water flow, pH, conductivity, dissolved oxygen, and macro-invertebrate diversity, as well as the level of nitrates, phosphates, *Escherichia coli*, and other fecal coliform in the river (Figure 2), with data for all nine parameters collected until 2018, although only the data from 2010 to 2015 has been analyzed and is currently available (detailed in Brandt, 2019). As would be expected, some water quality parameters are more variable than others; however, the Macro-invertebrate Health Index indicates a reasonably stable health score within the "fair" health range (Figure 2). By monitoring water quality in the La Suerte River, MRC tracks the health of the wider landscape, well-positioning MRC to make ecological recommendations to conservation and governmental organizations. MRC is currently collaborating with the University of Costa Rica to develop water quality testing methodology that can be reported to the Costa Rican government, particularly as a forest corridor is officially established in the wider region and is planned to pass through and include LSBRS. MRC thus models the One Health concept by studying and promoting the ecological health of their forests.

MRC also provides environmental consultation to a local palm oil plantation, thus showing their commitment to improving the ecological health of habitat adjacent to LSBRS. In the area surrounding LSBRS, some land that was formerly used for cattle ranching has been converted into palm oil plantations. While palm oil plantations generally have lower species richness than tropical forest habitat, they have greater biodiversity and provide more habitat for wildlife than cattle pastures (Knowlton et al., 2019; Koh & Wilcove, 2008), suggesting that their conservation-focused management may increase environmental health in the area. MRC is currently in discussion with a surrounding palm oil plantation to advise them on environmentally sound land management practices and promote biodiversity, thus mitigating some of the damage caused by deforestation. Some of MRC's recommendations include creating waste piles that provide habitat for small birds, mammals, and reptiles, using low-impact pesticides, and using land previously cleared for cattle production rather than clearing forest. By advising a neighboring plantation, MRC helps improve the ecological health of the LSBRS region and demonstrates their commitment to One Health ideals.

6 | MRC'S VETERINARY AND MEDICAL MISSIONS

6.1 | Veterinary missions

Animal health is an important branch of the One Health triad (Deem et al., 2018), and the Molina family began offering veterinary missions in 2007 (Garber et al., 2010; Molina, 2015). The MRC veterinary mission cares for animals including dogs, cats, pigs, horses, cows, and goats, but most typically provides vaccinations, spay/neuter services, and wellness checks for dogs and cats. With a general goal of preserving biodiversity through conservation activism, the Molina family recognized the urgent need to provide general veterinary care for domestic animals to minimize their impact on wild animals and ecosystems. While animals like pigs are often fed well by their owners in Costa Rica and Nicaragua, dogs and cats are expected to hunt and catch their own food from forests, rivers, and lakes (Molina, 2015). This has a devastating effect on wildlife, with dogs who hunt in the forest preying on wild animals including howler monkeys (Raguet-Schofield, 2008). Veterinary missions therefore reduce the strain placed on wild animals, improving the ecological health of the region and comprising a vital part of MRC's One Health efforts.

The veterinary field mission involves local licensed veterinarians supervising graduating and upper-year veterinary school students from the United States, who serve as course instructors and teaching assistants to the undergraduate students enrolled in the veterinary mission. Undergraduate students learn hands-on skills such as suturing, and gain experience that can help them determine whether veterinary science is the right fit for their further education and/or to strengthen their veterinary college application. The MRC veterinary field mission is thus a beneficial learning experience for students as well as a crucial service to the local community.

MRC offered a veterinary program in association with World Vets/Casa Lupita in Granada, Nicaragua for 2 years before offering an independent program starting in 2009 at OBRS (Garber et al., 2010; Molina, 2015). Since then, the veterinary program at OBRS has exponentially expanded; veterinary missions are now offered several times a year with veterinary services provided to many communities across Ometepe Island. This provides consistent and reliable veterinary care to animals throughout the region, and the local residents have grown accustomed to taking their pets for regular assessments. The veterinary mission at OBRS typically services more than 100 local families, including more than 75 dogs and 50 cats on average. Additionally, MRC has facilitated other veterinary missions spearheaded by Nicaraguan veterinarians in communities across Nicaragua.

The first veterinary mission at LSBRS was offered in 2016, and is now offered multiple times a year. The veterinary mission serves the local communities of La Primavera and La Suerte, primarily providing spay/neuter services and general health checks for dogs and cats. Each one typically serves more than 50 local families, including more than 50 dogs and 30 cats. While continuing to offer veterinary

missions to small animals in the community surrounding LSBRS, in 2018, the MRC veterinary field mission expanded to offer more courses: one specialized in large animals (cows and horses) near LSBRS, and one geared at treating dogs and cats in the town of Tortuguero. The Tortuguero veterinary mission has the special focus of helping protect the sea turtle population by controlling the domestic animal population. In the years since the MRC veterinary mission has been ongoing, the mission has sterilized an estimated 600 dogs and cats, thus substantially reducing the local domestic animal population and reducing predation pressure on local wildlife near both OBRS and LSBRS (Garber et al., 2010; Molina, 2015). MRC thus improves the health of surrounding ecosystems by treating domestic animal health, supporting the One Health philosophy.

6.2 | Medical missions

The third branch of the One Health triad focuses on human health (Deem et al., 2018). MRC started offering medical missions devoted to human wellness at OBRS in 2017, with the first mission led by nurses from Murray State College, OK, USA, and subsequent missions involving volunteers from many different institutions. Medical missions provide care to residents living near the areas of San Ramon and Tichana on Ometepe Island. Medical missions are led by a team of volunteer doctors and nurses from the United States in partnership with local physicians. Many residents of Ometepe Island need free medical assessment and care, and this MRC mission adds to the well-being of the greater community. More than 200 people are typically treated during each medical mission. Three annual medical missions have been offered at OBRS since its inception, and efforts have been made to organize additional medical missions, including a dental mission. MRC ran their first dental mission in 2019, providing free dental check-ups to communities on Ometepe Island. MRC plans to continue these medical and dental missions on OBRS and has also extended this initiative to Costa Rica, offering similar medical and dental missions at LSBRS. The first medical mission was run at LSBRS in 2018 and offered eye exams and blood pressure, anemia, and glucose testing to over 100 children. Further medical missions were under development at LSBRS in early 2020, but are currently on hold due to the COVID-19 pandemic. MRC's expanding medical outreach initiatives exemplify their commitment to a One Health paradigm.

7 | MRC'S COMMUNITY OUTREACH INITIATIVES

7.1 | English as a second language-teaching and environmental education for local elementary students: Nicaragua

MRC employs a part-time teacher to instruct elementary school students in English as a second language (ESL) and environmental education in San Ramon, Ometepe. By learning English, students are

more likely to continue their education and complete high school, and will also have a better chance of eventually working in the tourism industry in Ometepe (which is a primary industry on Ometepe Island). Previously, students on Ometepe had a high drop-out rate with few students entering or completing high school due to the high rate of teenage pregnancy (Molina, 2015). Since MRC began their educational initiatives in 2009, the high school entrance rate has drastically increased. In 2009, only 3 or 4 students out of 15 elementary school students (20% of students) enrolled in high school, while by 2017, 16 students out of 20 elementary school students (80% of students) enrolled in high school (Molina, unpublished data).

In addition to ESL, students are also taught environmental education to foster empathy for wildlife, including animals like bats which many children are afraid of. Through better understanding a bat's role as a frugivore and seed disperser within a tropical ecosystem (rather than as a bloodsucking "vampire") (Molina, 2015), fear and misperceptions are conquered through education. Students take field trips to OBRS forests to see animals in their natural environment and to learn about their behavioral ecology, and high school students are given the opportunity to plant trees and work on other conservation-focused projects at OBRS. Through these initiatives, children develop respect for nature and learn about the long-term effects of their actions on the natural world, and therefore are encouraged to be good environmental stewards. Overall, an estimated 450 local students have been impacted by MRC's educational initiatives in Nicaragua, thus giving students the tools to improve human, animal, and environmental health in the region.

In addition to education, MRC provides students school uniforms and shoes if needed, as well as supplies like pens, pencils, crayons, and notebooks, and continually donates English and Spanish-language books to enlarge the school library (Molina, 2015). Having a school uniform is a prerequisite for receiving an education in Central America, but presents a financial barrier for many families, so MRC's uniform donations help facilitate continued school participation (Molina, 2015). Additionally, since 2010, MRC has given bicycles to the graduating Grade 6 students with the top grades to facilitate their travel to and from high school. The high school is located in Mérida, a village which is a half hour distance from San Ramon by bicycle. Ongoing bicycle donations help the students feel a sense of pride about their education and encourage them to continue to strive for academic excellence.

7.2 | ESL-teaching and environmental education for local elementary students: Costa Rica

MRC has also hired an instructor to conduct environmental awareness workshops with children in the elementary school at La Primavera, Costa Rica (Molina, 2015). This instructor gives lessons on ecology and conservation in the classroom and also organizes field trips to LSBRS, allowing local students to observe and learn about forest ecology. Since 2018, students from surrounding areas have also visited LSBRS several times a year for morning or

afternoon workshops to learn about local wildlife and to observe rainforest animals in their natural habitats. Local high school students are given the opportunity to plant trees at LSBRS and to help with ecological projects, including designing and building the forthcoming environmental education museum at LSBRS. In addition to education, MRC also provides students in La Primavera with school supplies including school uniforms, pens, pencils, and crayons (Garber et al., 2010), and continually donates books in Spanish and English to augment their school library, particularly books with conservation themes. MRC also leads workshops for adults, giving local residents tools to help them live more sustainably and harmoniously in a tropical forest region. To date, approximately 200 local students have participated in educational outreach programs at LSBRS, thus furthering the One Health approach.

7.3 | Local job creation

At LSBRS, MRC employs three full-time staff year-round: an administrator and two maintenance and security staff, who maintain site infrastructure and patrol the forest. Camera traps throughout LSBRS prevent the need for a full-time ranger (Molina, 2015). During high season (December–January and May–August, when there are many field schools), MRC employs three additional kitchen staff and an additional security guard.

MRC has similarly created a number of jobs on Ometepe Island. In addition to six seasonal staff members—three maintenance workers and three kitchen staff—MRC funds a full-time forest ranger position whose job is to protect the forested properties at OBRS from trespassers and poachers (Molina, 2015). The ranger's persistent presence at the OBRS forested sites prevents deforestation and the harvest of wood and other forest products. The presence of the field schools in Costa Rica and Ometepe also provides wider benefits to the local communities, with local merchants and suppliers continually benefiting from the influx of students and researchers. Additionally, each student who completes a course at LSBRS or OBRS spends an average of \$75–100 USD buying goods, services, and souvenirs from local vendors, thus additionally bolstering local economies (Brandt, unpublished data). This financial support of the areas surrounding LSBRS and OBRS helps improve human quality of life, thus reinforcing MRC's commitment to a One Health approach.

7.4 | Proyecto Jade

In 2014, MRC established Proyecto Jade (aka Taller Jade), a women's empowerment initiative that provides craft training and micro-loans to women living in the local community surrounding OBRS. To begin the initiative, MRC hired a local jewelry designer to instruct women in how to make woven rope necklaces and bracelets in varying designs using yarn and organic objects, such as coffee beans, seeds from the forest, and stones from the banks of Lake Nicaragua. Any local women who wanted to participate were included in Proyecto

Jade, and women were provided with instruction in jewelry design as well as all needed materials to make the jewelry. Jewelry that the women create is then purchased by MRC and sold internationally, to students and researchers visiting OBRS and LSBRS, as well as at academic conferences and through the MRC website (Molina, 2015). Approximately 45 women have been involved in this initiative to date, and MRC invests approximately \$300 USD annually to sustain this ongoing project. Through the Proyecto Jade initiative, women have purchased school uniforms and supplies for their children and improved the overall financial health of their families. By empowering these women, MRC demonstrates their commitment to improving human well-being, thus exemplifying the One Health perspective.

7.5 | Lessons learned: Community building

Successfully engaging the local community in One Health initiatives requires active community building. MRC experienced several false starts with various community outreach endeavors in Costa Rica, likely due to the fact that, until recently, LSBRS staff were not year-round members of the local community and, in fact, most students, faculty, and researchers who visit the field site each year are from other countries. At OBRS, on the other hand, members of the Molina family have resided on site year-round since its inception and are thus embedded in the local community. The location of OBRS on Ometepe—on the main road in San Ramon—also makes it part of the community (e.g., buses pass right by it; local children and adults pass it on their way to and from school, jobs, and shops; visiting the popular San Ramon waterfall requires walking through OBRS). MRC's ESL and environmental education teacher grew up on Ometepe which allowed for a seamless transition into his role as part-time instructor at the local elementary school. MRC's veterinary and medical missions on Ometepe also benefited from the previously established community relationships, with relatively strong participation by the local community from the outset.

In Costa Rica, over the years various LSBRS staff members attempted to initiate education programs at the local elementary school in La Primavera with little success until recently. Unlike at OBRS, LSBRS is not situated along a main road in the village and thus few people regularly travel past it. Furthermore, most LSBRS staff are only present during the winter and summer seasons (when students, faculty, and researchers most commonly visit the site) which made it difficult to develop the relationships with teachers and other school staff that are so crucial for successful community engagement. The current LSBRS administrator, hired in 2018, is from the local village of La Suerte, which has allowed the relationship between LSBRS and community members to flourish. The administrator has been instrumental in building relationships with local elementary and high schools and hosting students in regular visits to LSBRS to enhance their environmental education as well as their pride in the natural resources of their local environment. Likewise, few community members participated in LSBRS' early veterinary missions.

Over time, thanks to the involvement of a local veterinarian and relationship-building with local pet owners and farmers, community members now participate in these missions at very high levels, coming to rely on these services for their animals. In fact, attendance has gotten so high that MRC built a shaded waiting area to better accommodate community members as they wait their turn. These experiences highlight how critical community building is for the success of many One Health initiatives.

8 | MRC AND UNFORESEEN EVENTS: COVID-19

Organizations like MRC need the resources and flexibility to be able to survive unanticipated financial setbacks without interrupting support to ongoing One Health initiatives. If programs are disrupted whenever an unforeseen event occurs, this can negatively affect human, animal, and environmental health. COVID-19, for example, changed the face of many ongoing education and outreach programs internationally in 2020, including those at MRC. Field courses have not been offered at OBRS since 2018 due to the civil unrest in mainland Nicaragua, and have continued to be suspended in 2021 due to COVID-19. At LSBRS, field courses were suspended starting in March 2020 due to COVID-19, and continue to be suspended in 2021. Costa Rica placed all field research on hold from March to June 2020, and instituted bans and/or restrictions on international travel which would affect incoming field course students and instructors. Additionally, consideration of the ethics of fieldwork during COVID-19 also needs to be MRC's highest priority (Reid, 2020). A small veterinary mission led by local veterinarians occurred in early December 2020 to maintain the health of domestic animals surrounding LSBRS, which was desperately needed due to the economic crisis caused by COVID-19 leading to many more stray animals in the region. However, regularly scheduled medical and veterinary missions involving large groups of international students have been suspended.

Meanwhile, financial obligations to support upkeep for MRC sites, personnel, and outreach initiatives continue. During the pandemic as well as during the civil unrest in Nicaragua, MRC has continued to support local staff members, and MRC director Renee Molina feels that MRC has a strong ethical obligation to continue to do so. However, MRC depends largely on field course tuition, researcher fees, and donations to financially support ongoing operations (Molina, 2015), meaning that COVID-19 has caused financial strain. Fortunately, LSBRS has been partially supported by governmental forest protection contracts since 2004, and additionally formed a partnership with FONAFIFO/MINAE in 2015 to allow for the eventual harvesting of sustainable wood from LSBRS when needed, specifically from part of the 1.1 km² of the site that is not protected. Fast-growing tree species were planted from 2015 to 2017 for harvest: 200 m² of gmelina (*G. arborea*) trees (planted in 2015–2016) and 400 m² of teak (*T. grandis*) trees (planted in 2016–2017) (Molina, 2015). The gmelina trees were logged and sold

in 2018 to sustain ongoing operations and the teak will be harvested in 2021, allowing MRC to weather the financial strain caused by COVID-19 and to continue into the future.

9 | THE FUTURE OF MRC: FOREST CORRIDOR CREATION AT LA SUERTE

MRC has long been involved in small-scale projects to promote the creation of living fences between their sites and forests owned by immediate neighbors (Molina, 2015). In 2018, a partnership between MINAE, SINAC, and Programa Nacional de Corredores Biológicos de Costa Rica was announced, involving the creation of a large-scale biological corridor linking Tortuguero National Park with Braulio Carillo National Park (Programa Nacional de Corredores Biológicos de Costa Rica, 2019). This corridor will involve joining numerous small, privately-owned forest fragments near the La Suerte River, including LSBRS, to larger protected forests, thus promoting biodiversity for all regions involved. Through this initiative, the Área de Conservación de Tortuguero will expand and be re-named as Corredor Biológico Suerte-Tortuguero. Once LSBRS is incorporated into this corridor, it will receive additional governmental resources and protections, thus further enabling the goals of MRC's ongoing conservation mission and allowing MRC to continue to invest in the people and animals surrounding their sites.

10 | CONCLUSIONS: MRC AND ONE HEALTH

As a multifaceted conservation nonprofit organization, MRC exemplifies the One Health concept of environmental stewardship and community engagement. From its beginning as a family owned cattle ranch, MRC models how a biological field school founded on private land can grow into a successful One Health initiative. Through preserving forest ecosystems, leading biological education initiatives for both international university students and local elementary students, tending to the health of local people and domestic animals, and creating jobs and community engagement, MRC places high importance on both ecological and human health. From MRC's nascent as a primate field school and primatological research site, it has grown into a multifaceted organization devoted to community service, environmental preservation, and conservation education at all levels. MRC's myriad initiatives work together to exemplify an One Health conservation agenda.

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CONFLICT OF INTERESTS

R. L. M. serves as the director of MRC, L. S. E. B. is a member of the board of directors of MRC, and L. M. B., L. S. E. B., and A. L. S. periodically teach field courses at MRC sites.

ETHICS STATEMENT

Our research was conducted with the permission of the Molina family and met the legal requirements of Costa Rica. Our research adheres to the American Society of Primatologists (ASP) Principles for the Ethical Treatment of nonhuman primates, and the research

described in our paper had ethical approval from the authors' home institutions.

AUTHOR CONTRIBUTIONS

Laura M. Bolt: conceptualization (equal); data curation (equal); visualization (equal); writing original draft (lead); writing review & editing (equal). **LaRoy S. E. Brandt:** conceptualization (equal); data curation (equal); visualization (equal); writing original draft (supporting); writing review & editing (equal). **Amy L. Schreier:** conceptualization (equal); data curation (equal); visualization (equal); writing original draft (supporting); writing review & editing (equal).

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Laura M. Bolt  <https://orcid.org/0000-0002-8275-6543>

LaRoy S. E. Brandt  <https://orcid.org/0000-0002-8488-8646>

Amy L. Schreier  <https://orcid.org/0000-0002-0379-3750>

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