Bijagual River Watershed, Costa Rica: Improving Watershed Health and Engaging Local Communities in Monitoring and Outreach

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Abstract

The Bijagual Center for Environmental Education and Conservation (BCEEC) owns and operates the Bijagual Ecological Reserve (BER) in Sarapiquí, Costa Rica. In order to assist the BER to engage community members in reforestation efforts as well as monitor the outcomes of these efforts, this report summarizes environmental attitudes and interests in the region, provides geospatial analysis to support the BER in identifying land use patterns and areas to target for reforestation and provides materials for a water quality monitoring program and educational interpretive signage system. The body of the report is divided into four sections: social research, geospatial analysis, stream sampling/water quality monitoring, and signage. Each of these four sections include an introduction, methods, results and recommendations as appropriate.

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Section 1: Introduction

The Bijagual Ecological Reserve (BER or Reserve) is a 286 hectare field station centrally located within the approximately 50 km^2 Bijagual River watershed in southwestern Sarapiquí County, Costa Rica (see Figure 1.1). The Reserve is the managed by the Bijagual Center for Environmental Education and Conservation (BCEEC) a non-profit 501(c)(3) organization dedicated to conservation, research, and education (Bijagual Ecological Reserve, 2016). With money from a Costa Rica-US debt-for-nature swap program, the BCEEC, is working with landowners to improve water quality and connect forest patches by encouraging reforestation and forest protection along riparian corridors on private property within the Bijagual River watershed. At the same time, the BCEEC hopes to increase awareness of the importance of regenerating secondary forest on privately owned land.

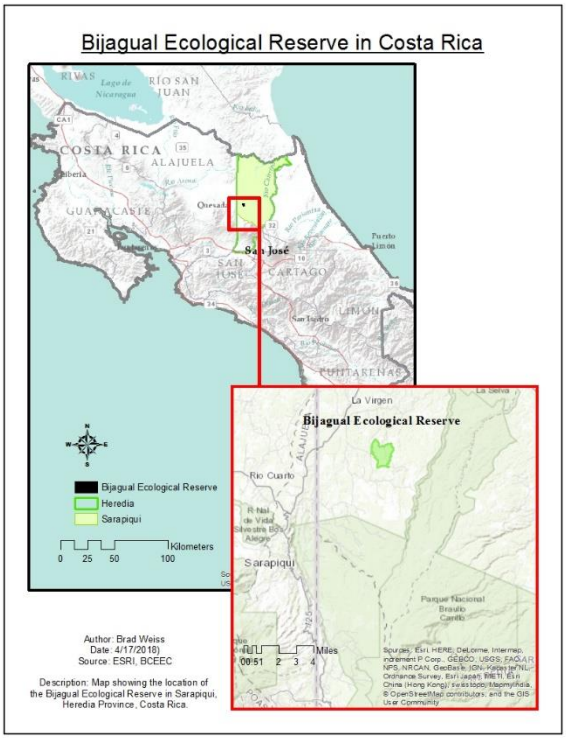

Figure 1.1: The Bijagual Ecological Reserve is located in Sarapiquí, Heredia Province, Costa Rica.

This project supported the BCEEC in their efforts by completing the following objectives:

- Utilize social science research methods to identify people in the region who would be interested in reforesting, and understand current areas of environmental concern among people in the region;
- Create current land-cover maps to assist with the site-selection phase of future reforestation efforts, as well as establish optimal stream monitoring locations;
- Provide a mechanism for citizen engagement and assessment of the effectiveness of reforestation on improving water quality by developing a citizen-science stream monitoring program to; and
- Develop a plan for an interpretive trail to enhance knowledge of the importance of the Reserve's ecosystems.

The report that follows discusses the methods, results, recommendations, and the deliverable products related to each of the four objectives described above.

Regional Context

Costa Rica is divided into five provinces, which are further subdivided into counties. Sarapiquí is a rural county located in Heredia Province, in the north-central portion of the country. Despite the towns of Puerto Viejo, La Virgen, Las Horquetas, Llanuras del Gaspar, and Cureña, only 18.1% of Sarapiquí's population was considered "urban" as of 2011, compared to 72.8% of the country's overall population

(Instituto Nacional de Estadísticos y Censos (INEC), 2018). However, Sarapiquí is experiencing rapid population growth. As of the 2000 census, 46,258 people lived in Sarapiquí. Just 11 years later, the population of Sarapiquí had reached 64,488 people (INEC, 2014A), an increase of 39%. By 2025, the population of Sarapiquí is projected to reach 94,600 – over double the number of people who lived there just 25 years earlier (INEC, 2014B). The Sarapiquí region has experienced many transformations over the years, largely as a result of human behavior in the area. The primary livelihoods in Sarapiquí have traditionally been agriculture and livestock farming, both of which rely on clearing primary forests.

Deforestation Explained

Population growth, the profitability of 'export only' agriculture, and shortages of arable land led to widespread deforestation in Costa Rica throughout the past half-century (Perfecto and Vandermeer, 2005; Rudel et al. 2009). Specifically, the book *Breakfast of Biodiversity* (Perfecto and Vandermeer, 2005) describes the six general steps that led to widespread deforestation as it related to large-scale intensive agriculture focused on a 'hot' commodity.

The first step is simply the identification by capitalists of a potentially profitable expansion in production of a certain agricultural product. Next, these investors must find land to purchase (or transactions of dubious legality) and then clear the rainforest for agricultural expansion. Third, labor must be imported into the region to support the expansion. Once the profitability of the investment declines due to market saturation, large proportions of the workforce must be laid off to ensure the operation's survival. These newly unemployed workers need to farm for subsistence until they can find a new source of income. Finally, the only land these unemployed workers can access without a significant threat of eviction is in the forest, leading to the removal of additional rainforest. This process illustrates the fact that deforestation is not always directly related to large scale agricultural operations, but can also be indirect effect of these industry practices. Figure 1.2 (from *Breakfast for Biodiversity)* illustrates how dramatically the land in Sarapiquí and beyond has been altered by deforestation.

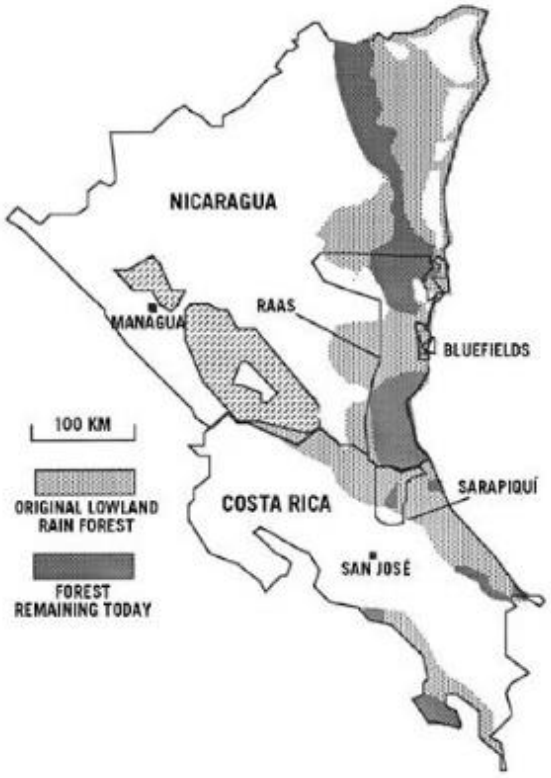

Figure 1.2: Map showing the former at current extent of rainforests in Costa Rica and Nicaragua (Vandermeer and Perfecto, 2005).

Costa Rica "Turns a New Leaf"

However, more recently the country has been portrayed as a world leader in conservation, with over a fifth of Costa Rican land falling under some category of protection (Lambin 2011). In fact, in 1996, Costa Rica put in place a countrywide ban on deforestation, and implemented programs that would pay private landowners for complying with certain conservation related mandates (Morse et al. 2009). Despite its newfound environmentalist status, Vandermeer and Perfecto (2005) point out the failure of traditional rainforest conservation practices in Costa Rica that focuses on establishing reserves, as well

as large scale agriculture's history of negligence towards environmental goals (specifically, the banana industry).

In contrast to traditional large-scale agriculture in Costa Rica, a new economy based on "nature-oriented" tourism has emerged, and Sarapiquí has benefited from this shift due to its proximity to popular rafting areas and ample forests. Due to the richness of nearby forest preserves and national parks, the region is recognized as an important area for biodiversity (World Meteorological Organization, 2017). This sets up conflict of interest between industries that rely on large parcels of arable (deforested) land, and those that thrive when this land is pristine and protected.

The Case for Riparian Buffers

Many studies have addressed the concerns of deforestation and land use change in tropical regions. With regard to land-use change, converting rainforest for use in industrial-scale agriculture and livestock production causes an increase in nutrient inputs into the local ecosystem, specifically nitrogen and phosphorus in various forms. Unlike temperate regions, which are often phosphorus limited, tropical fresh waters are usually nitrogen limited, and therefore an increase in available nitrogen will cause an increase in primary productivity (Downing et al. 1999). This increase in primary productivity can drastically alter the structure of biological communities, and often not for the better. The United States has already experienced the negative effects of such disturbances in areas like western Lake Erie, where large-scale agricultural activities and their associated non-point source runoff have at times created harmful algal blooms (Smith, King, and Williams, 2015). However, subtle changes to an ecosystem also can occur as a result of increased nutrient inputs, which is why monitoring freshwater systems experiencing altered nutrient regimes is of great importance (Connolly & Pearson, 2013). One possible solution for reducing non-point surface runoff is to strategically replant forest stands in riparian areas most likely to encounter elevated nutrient loading. Reforestation reduces the sediment load carried in nearby streams (Ouyang, Leininger, & Morana, 2013) by reducing surface water velocity and the amount of sediment entering the watershed, mitigating for the effects of increased nutrient inputs and accelerated erosion in the watershed and especially along stream banks. Riparian buffers can be more effective when designed and installed as part of an assessment of the river network as a whole.

Section 2: Social Science Research

In order for the Bijagual Ecological Reserve to successfully implement environmental projects in the Bijagual River watershed and surrounding areas, those involved must strive to understand the environmental concerns and priorities of the people who reside there. Additionally, having interaction with the community through social outreach projects can help identify landowners within the watershed who would be interested in engaging in environmental projects such as reforestation of riparian zones. The social research component of this project therefore aimed to identify people in Bijagual River watershed interested in reforestation and citizen science projects, as well as to understand environmental issues impacting people in the region more generally.

Past research in Costa Rica examining environmental attitudes revealed that, when asked what they thought were the "three greatest environmental problems facing society," survey respondents most frequently answered "deforestation, garbage, and water and air pollution" (Holl, Daily, & Erlich, 1995, p. 1551). However, this data reflected the concerns of people across socio-economically diverse neighborhoods in the capital city of San Jose, and may not be consistent with the concerns of rural communities and other communities outside of the capital. Both ability and willingness of landowners to engage in reforestation projects varies, with those owning larger tracts of land (and also having other sources of income in addition to agriculture) more likely to participate in incentivized reforestation (Thacher, Lee & Schelhas, 1997). Further, conservation of land in general is viewed in multiple ways. For example, in a qualitative study of attitudes toward national parks in Costa Rica, interviewees expressed frustration that people without land could not access the land conserved by national parks for their own livelihoods. Others felt that, conservation of forested areas was beneficial and worth the potential downsides (Schelhas and Pfeffer, 2005).

In order to meet the research goals of identifying participants for reforestation and citizen science projects, and to understand environmental attitudes more generally, a mixed-method, two-part research strategy was employed. The first step involved in-person interviews, with the goal of identifying people who lived along the Bijagual River or its tributaries and who would be interested in citizen science activities. The second step involved a survey in which respondents were asked to respond to a series of questions about their environmental attitudes and behaviors.

The data gathered by this project was used to develop recommendations for the Bijagual Ecological Reserve as it continues its conservation and education efforts. According to Steg and Vlek (2009), interventions are needed to enhance pro-environmental behaviors. Interventions can be considered to fall into two different categories: informational and structural. Informational interventions are "aimed at changing perceptions, motivations, knowledge, and norms, without actually changing the external context in which choices are made" (Steg & Vlek 2009, p. 313). Structural interventions, in contrast, are "changes in the circumstances under which behavioural [sic] choices are made … so as to increase individual opportunities to act pro-environmentally and to make pro-environmental behaviour [sic] choices relatively more attractive" (Steg & Vlek 2009, p. 313). Both types of interventions could be used in the Bijagual River Watershed region. This report will include suggestions of interventions to increase pro-environmental behaviors in the region.

Deliverables

As discussed with the client, the deliverable products generated from this portion of the project include:

1. A list of people in the Bijagual River watershed interested in participating in reforestation efforts and citizen science projects (for confidentiality purposes, this list was emailed to the client on December 12, 2017 and is not contained within this report); and
2. A summary of environmental attitudes and concerns, contained herein.

Methods

Interview Methods

In order to identify landowners/residents whose parcels were adjacent to rivers and other bodies of water within the Bijagual River watershed, and who among them would be interested in participating in reforestation and citizen science activities, the research team completed a series of interviews. The method of face-to-face interviews were completed because they allow for in-depth and probing follow up questions that assisted the researcher in understanding underlying values and beliefs held by people in the watershed. Face-to-face interviews are also recognized to have higher response rates than many other forms of data collection, which make them an ideal way to collect data, especially when the population size is relatively small (Kelley, Clark, Brown, & Sitzia, 2003).

To collect data, the research team traversed all major roads within the watershed boundaries and stopped at each visible property to request an interview. The primary researcher for this portion of the project, Audrey Pallmeyer, was accompanied by 2 - 3 Costa Rican researchers (Bernal Paniagua, Enrique Salicetti, and Jeanette Paniagua), of the Organization of Tropical Studies (OTS, or La Organización de Estudios Tropicales, OET, in Spanish). These Costa Rican researchers served as cultural bridges -- introducing the project to potential respondents, assisting with translation support as needed, and navigating steep roads.

Interviews were conducted in Spanish, and detailed notes were taken at the time of each interview. The Interview Guide (in English and Spanish) can be found in Appendix A. At the end of each day of data collection, field notes summarizing the interview content were compiled. Interviews were not recorded. Interview questions were reviewed by the University of Michigan Institutional Review Board and granted exempt status (HUM00128080). Interviews were conducted on June 26th - 30th, 2017, and July 3rd - 4th, 2017.

Survey Methods

Due to the limited time available for field research, it was not possible to collect more interview data. However, staff from the BER were interested in obtaining more information about the main concerns that residents of the region had related to the environment. Additionally, they were specifically interested in recycling behaviors of people in the region. Therefore, in addition to the interview data that was obtained through this project, the Bijagual Ecological Reserve requested that the research team create a survey regarding environmental concerns and recycling behaviors. Survey research, though often resulting in smaller response rates than in person interviews, allows for data to be collected in a standardized manner. It also allows for a relatively high amount of data to be collected in a limited timeframe (Kelley, Clark, Brown, and Sitzia, 2003). The data obtained through this survey were used to help the Bijagual Ecological Reserve and its partners (such as La Selva Biological Station) understand general environmental behaviors and attitudes in order to develop future programming.

In order to assess current environmental attitudes near the Bijagual River watershed region, an in-person written survey was administered for visitors at La Selva Biological Station (Estación Biológica La

Selva) during the 11th Annual Environmental Fair (La Feria Ambiental Anual). (See Appendix B for advertisement for this event.) Unfortunately, La Selva is not located within the Bijagual River watershed. However, it is proximal to the Bijagual River watershed. As the Bijagual Ecological Reserve does not have regular events at which data collection could occur on its premises, and La Selva's Environmental Fair attracts visitors from nearby communities, this event was determined to be a reasonable site for surveying. The survey was just one component of the Environmental Fair, which also included guided tours of the station and free admission to La Selva Biological Station, as well as opportunities to purchase local goods and explore scientific and artistic displays. La Selva offered rides to and from several locations throughout the area.

Paul Foster surveyed people at La Selva on November 12th, 2017 from 8:30 a.m. to 4:30 p.m. In order to recruit participants, Mr. Foster asked passersby if they would like to participate in a survey. If they said yes, they were given a paper survey on a clipboard. Upon completion, survey respondents were given an informed consent form with contact information for members of the research team. The survey guide was granted exempt status by the University of Michigan Institutional Review Board under HUM00128080.

The survey was divided into four sections. The first section captured basic demographic information, including age of respondent, land ownership status, and community from which they came. The second section asked for respondents' level of agreement to a number of statements intended to gauge environmental attitudes. The third section assessed recycling behaviors, and the fourth section asked for respondents to answer several open-ended questions regarding their perceptions of environmental issues in their community. (See Appendix C for the survey in Spanish and English.) For the purposes of this report, responses to the open-ended questions were translated from Spanish into English by Audrey Pallmeyer. Translations were verified by Helen Gutiérrez, a student at the University of Michigan School for Environment and Sustainability.

Results and Discussion

Interview Results

Overall, 36 interviews were completed in the Bijagual River watershed, with a total of 40 total interviewees: 15 female subjects and 25 male subjects, including four couples. As couples were interviewed together, their responses will be reported together as well, so the total number of interviews will be reported as 36. Of the 36 interviews, 25 were with the property owners, 10 were with property caretakers (or people who lived with the caretakers) of the property, and one worked and lived at the National Park where his interview occurred.

Despite the fact that all the interviewees lived within the Bijagual River watershed, only seven respondents said that their properties were adjacent to or contained part of the Bijagual River, or that they were not sure but believed so. Several other interviewees remarked that their properties were near the Bijagual River, contained other small springs or creeks that they thought connected to the Bijagual River, or bordered the Sarapiquí River, another nearby river.

Reforestation

When asked if they would be interested in participating in reforestation programs, answers were highly variable. Nearly half (47.2%, or 17 respondents) respondents stated that they were not interested in taking part in reforestation programs. Of these 17 "no" responses, 70.5% (n=12) did not specify why

they did not want to reforest their properties. An additional 17.6% of this group (n=3) said they did not want to reforest because they already had reforested parts of their land, 5.8% (n=1) stated that their land was primary forest (it had never been logged) an another 5.8% (n=1) felt that formal reforestation programs were "manipulative and too bureaucratic," stating that they often failed to provide the payouts that participants are promised. This respondent suggested that if a reforestation program existed that paid living wages, he would be interested in participating – though he was not optimistic that such a program existed or would be created.

In contrast to those who were not interested in reforestation, 13.8% of respondents (n=5) said that they were interested in reforesting, regardless of incentives (though two respondents noted that they would only be interested if someone else did the actual planting), and 36.1% (n=13) stated that they might be interested in reforesting. Of those thirteen respondents, several noted that they had already reforested parts of their land or left it as primary forest. Other interviewees were caretakers of the property where they lived, and were unsure whether or not the owner would be open to reforesting. The remaining interviewees were interested depending on the types of incentives available to them if they did so. The final respondent (n=1) was an employee of a national park, and therefore could not engage in reforestation activities on the private-land scale.

Citizen Science

Interview respondents were asked about their interest in participating in citizen science activities. These activities were described by the research team as both participating in data collection and having their properties be used as sites for data collection. Although the primary goal of the Bijagual Ecological Reserve was to identify persons who would be interested in engaging with citizen science activities related to stream monitoring (as will be described later in this report), this interview was used as an opportunity to ask interviewees about their interest in a number of different types of citizen science activities. Interviewees were asked if they would be interested in doing activities related to aquatic invertebrates (as part of a water quality monitoring project), activities with plants, activities with mammals such as monkeys and pacas, activities with terrestrial insects (including ants), activities with birds, and "other activities". Overall, there was a high level of interest in participating in some way in citizen science activities (see Table 2.1). There were sixteen respondents (45.7%) who said they would be interested in participating in citizen science activities. Of those, only two were interested in just one type of citizen science (both interested in stream sampling for aquatic invertebrates). The remaining 14 "yes" respondents were interested in any or all types of citizen science activities. There were 11 respondents (31.4%) who were not interested in participating (including the respondent who worked at the National Park), and nine who were not sure because they were not the owners of the property.

Interested in Citizen Science Activities?	Percent of Respondents	Number of Respondents
Yes; any/all types	38.9%	14
Yes, aquatic invertebrates	5.6%	2
No	30.6%	11
Not sure	25.0%	9

Table 2.1: Interest in citizen science activities.

General Environmental Attitudes

In general, respondents described a sense of concern for the environment. Just one respondent noted that they did not have any concerns about the environment or environmental issues in her community.

The remaining respondents all described ways that they care for the environment or are concerned about it.

The primary issues that arose were protecting animals, protecting springs of water, and providing comfort to humans. Respondents believed that it was important to leave forest intact because of the role forests play in protecting animals and providing homes for animals (n=7). Several respondents expressed concern about protecting "las fuentes de agua" (the springs) on their properties (n=2). In order to protect springs, several respondents noted that they left the area near the springs on their property forested rather than cutting down the trees in proximity to the springs, or using that land for agriculture. Further, forests were recognized as an effective natural way to keep temperatures lower on individual properties, as a result of the shade that they provide (n=1).

Agricultural issues came up repeatedly in the interviews. Several respondents reported that they use organic fertilizer sources and compost on their own land because they were better for their family's health than chemical fertilizers (n=2). Another noted a general preference toward organic fertilizers (or possibly using beneficial microorganisms at some point in the future), but acknowledged that they sometimes used chemicals for the weeds close to the path. A different respondent preferred not to use chemical fertilizers, but noted that they were not the owner, and the owner wanted them to use chemicals (n=2). Several respondents believed that the chemicals used by some of the industries in the area (milk production and pineapple plantations) caused negative environmental impacts.

Overall, respondents described their relationship with nature in very intimate ways. One interviewee described a love and appreciation for the beauty provided by nature. Another interviewee said "*El bosque es un jardín… es como el pulmón del mundo*" (The forest is a garden...it's like the earth's lung). In this way, they viewed the environment as an essential, life-giving force. Another remarked that caring for the environment was essential because they wanted their grandchildren to have somewhere to go that would have "aire bueno" (good air).

Interestingly, although they were not explicitly asked to talk about the various types of ecosystem services that they receive from the natural areas in their region, the comments that respondents made were closely aligned with the ecosystem services as they are defined by the Millennium Ecosystem Assessment (2005). According to the Assessment, "Ecosystem services are the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth" (Millennium Ecosystem Assessment, 2005). Concerns about sources of water fit into the category of "provisioning services." Temperature control fits into the category of "regulating services" and the aesthetic beauty of nature is a cultural ecosystem service.

Survey Results

Demographics

Overall, 35 people completed surveys at the Feria Ambiental (Environmental Fair). Respondents ranged in age from 18 to 95, with a mean age of 37.8 and a median age of 31. Although the survey did not ask for gender, 32 out of 35 respondents listed their names, which was coded male or female. Using the coded names as a proxy for gender, 20 of the respondents were coded as female, and 12 were coded as

male (with 3 coded as gender unknown). The majority (25 out of 35) respondents responded that they (or their families) were the owners of the property where they live.

Environmental Attitudes (Self-Reported)

When asked "Do you think that most people in your community are interested in taking care of the environment?" the majority (60%, n=21) respondents answered "no," while 28.6% (n=10) responded yes, and 11.4% (n=4) responded that they didn't know. In contrast, when answering about their own environmental attitudes and behaviors, respondents showed their own concern for taking care of the environment. Respondents were asked to respond with their level of agreement to three statements. The results demonstrate high levels of pro-environmental attitudes among respondents. For all three questions, the majority of respondents indicated pro-environmental attitudes. The breakdown of responses can be seen in Figure 2.1 below.

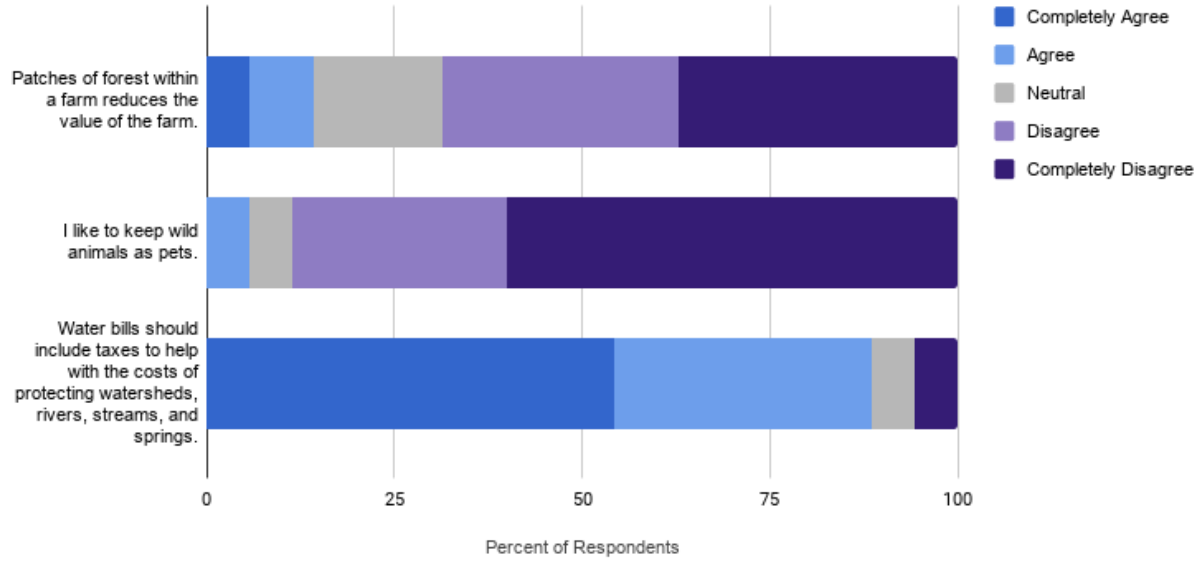

Figure 2.1: Percent of respondents in agreement with statements related to the environment.

Comparing the "Level of Agreement" Questions

In order for these different "level of agreement" questions to be compared to each other, the responses were coded 1 - 5, with 1 representing the least pro-environmental response and 5 representing the most pro-environmental response, as demonstrated in Table 2.2. (The survey also allowed for respondents to select "I don't know or I don't understand." As no respondents selected this option for any of the questions, it is not included in Table 2.2).

Statement	Response and (*Response Coding*)
Patches of forest within a farm reduce the value of the farm.	Completely agree (*1*) Agree (*2*) Neutral (*3*) Disagree (*4*) Completely disagree (*5*)
I like to keep wild animals as pets.	Completely agree (*1*) Agree (*2*) Neutral (*3*) Disagree (*4*) Completely disagree (*5*)
Water bills should include taxes to help with the costs of protecting watersheds, rivers, streams, and springs.	Completely agree (*5*) Agree (*4*) Neutral (*3*) Disagree (*2*) Completely disagree (*1*)

Table 2.2: Coding of "Level of Agreement" questions.

When these three questions are compared to each other, and scored according to the earlier described methodology (the most pro-environmental responses scored “5” and the least pro-environmental responses scored 1”) we see the highest level of pro-environmental attitudes for the question about wild animals (average response of 4.43). Next, the question regarding water bills received an average response of 4.31. Finally, the question regarding patches of forest on farmland received an average response of 3.87, the lowest average response.

Recycling Behaviors

Respondents were asked which of the following materials they recycle: paper, aluminum, metal cans, plastic, scrap metal, or none of the above. The results, as seen in Figure 2.2 reveal that recycling behaviors vary across different materials.

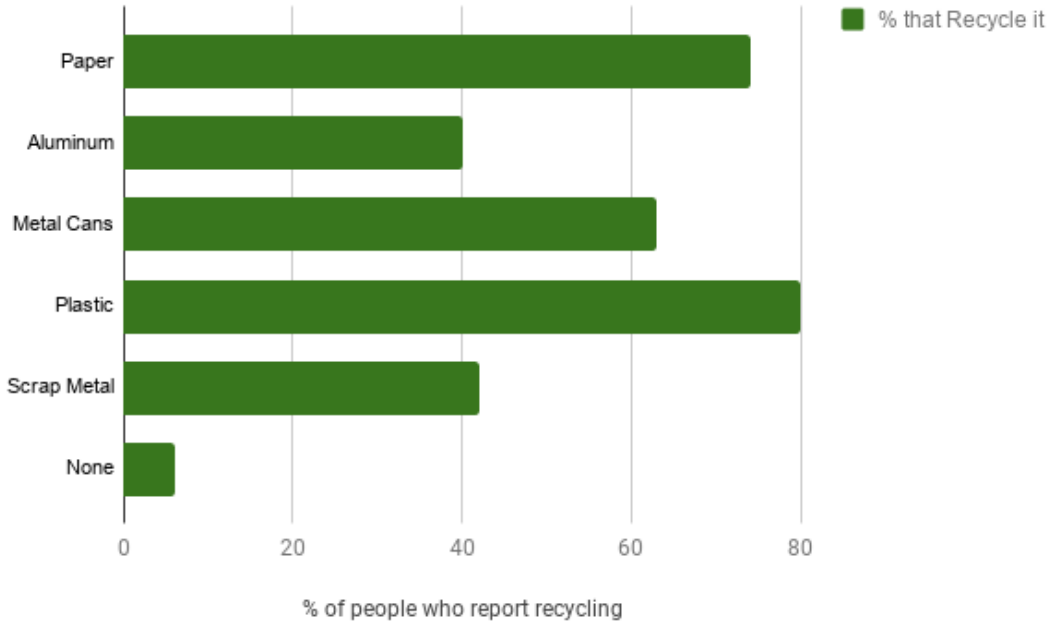

Figure 2.2: Recycling rates of respondents at the La Selva Environmental Fair.

On average, respondents reported recycling nearly three (2.9) types of recyclables. Respondents ranged from not recycling any materials (n=2) to recycling all five types of recyclable materials (n=8). Plastic was the most commonly reported recyclable, and aluminum was the least frequently reported recyclable. In all cases, respondents to our survey reported higher rates of recycling than previous data has suggested. According to a 2016 Costa Rican report titled "National Strategy of Separation, Recovery, and Valorization of Waste" (Estrategia Nacional de Separación, Recuperación, y Valorización de Residuos) (ENSRVR), 41% of Costa Ricans reported that they separate plastic, glass, and aluminum, and 35.8% separate paper. Interestingly, separation rates are higher in rural areas than in urban areas (Gobierno de la República de Costa Rica, 2016, p. 11). Despite the separation of recycling from trash, there are overall high levels of littering throughout the country, with an estimated 30% of the solid waste produced in the country each day ending up in streams, streets, vacant lots, or other public places not intended to serve as garbage receptacles (McDonald, 2010). Although our data reveals that our respondents were recycling at higher rates than reported elsewhere, the fact that littering was noted by so many respondents as the most important environmental issue suggests that there is still much improvement that could be done in this area.

Perceptions of Others' Environmental Attitudes

Interestingly, despite the generally pro-environmental attitudes expressed by respondents, respondents overall did not believe that other community members were interested in taking care of the environment (see Figure 2.3).

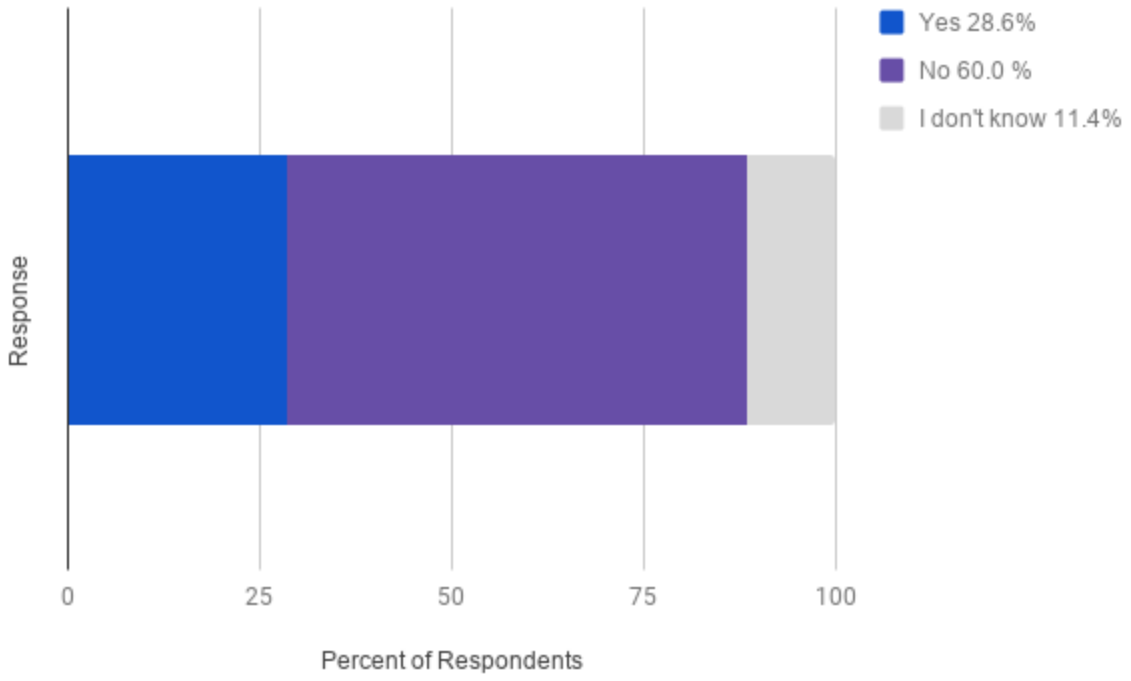

Figure 2.3: Responses to the question, "Do you think the majority of people in your community are interested in caring for the environment?".

Predictors of Environmental Attitudes and Environmental Behaviors

In order to implement interventions that effectively increase environmental attitudes and pro-environmental behavior, it is important "to understand the relationship between demographic variables and environmental attitudes and behaviors" (Zelezny, Chua & Aldrich, 2000, p. 443). In order to determine if there were any correlations between specific variables, the research team utilized a Fisher's Exact Test to assess whether responses to the various closed-ended questions varied by gender, age, and/or belief in the attitudes of others. The significance level used in this report was $p < 0.05$.

Gender

In a 2000 study of environmental attitudes and behaviors, Zelezny, Chua & Aldrich found that women reported higher levels of pro-environmental behaviors than men in Costa Rica. In order to test if respondents to our survey followed this pattern, we tested the relationship between gender and attitudes about patches of forest on farmland, having wild animals as pets, as well as whether water bills should include taxes to help pay the costs of protecting water. Additionally, we looked for variance in whether men and women reported recycling paper, aluminum, glass, plastic, and scrap metal.

In order to run these tests, we excluded the three respondents who did not provide a name, and therefore who we could code their gender. Our null hypothesis in each case was that gender would not impact these variables. Our alternative hypothesis was that responses would vary by gender. Using the 2-sided exact significance results from the Fisher's Exact test, we found that responses did not vary significantly by gender for any of the variables we tested using a significance level of 0.05. Therefore, we were unable to reject our null hypothesis. However, it may be worth noting that in the case of glass we had nearly significant results - with a p-value of 0.053. (95% women reported recycling glass, compared to 50% of men). Additionally, the results of the test analyzing gender and reported rates of scrap metal

recycling were nearly significant, resulting in a p-value of .072, with 61% of women reporting recycling scrap metal compared to 25% of men. These nearly-significant results may relate to the roles men and women play in Costa Rican culture. If women cook more frequently than men, they may come into contact with recyclables more often than men do, and therefore have reason to recycle more frequently as well.

Age

Research on the relationship between age and pro-environmental attitudes and behaviors is unclear. Using recycling behavior as a proxy, some data suggests that older people are more likely to recycle than young people, while some data suggests the opposite is true (Jenkins, 2003; Aadland & Caplan, 2003). In order to test the relationship between age and attitudes about environmental issues and recycling habits, we re-coded respondents into three different age groups: 18 - 35 years old, 36 - 53 years old, and 54 years old or older. Our null hypothesis was that responses to environmental attitudes and recycling habits would not vary by age. Our alternative hypothesis was that responses related to environmental attitudes and recycling habits would vary by age. Again, using a significance level of 0.05, we did not find significant variability in responses according to age, and therefore we failed to reject our null hypothesis.

Perception of Others' Attitudes

Finally, we tested whether respondents would have different environmental attitudes or behaviors depending on whether or not they believed that the majority of people in their community believed it was important to care for the environment. According to Cialdini, et al., descriptive norm "is what is typical or normal"... descriptive norms "[describe what most people do…[and motivates] by providing evidence as to what will likely be effective and adaptive argument" (Cialdini, Reno, & Kallgren, 1990, p. 1015). Cialdini et al. demonstrated that by appealing to descriptive norms they could alter environmental behaviors. Using responses to whether or not participants believed others in their community thought it was important to take care of the environment as our independent variable, we therefore hypothesized as follows: Our null hypothesis was that there would be no difference in responses to environmental attitude or behavior questions based on perceptions of others' behaviors, and our alternative hypothesis was that there would be a difference. Our results were not significant at the 0.05 significance level, so once again we were unable to reject our null hypothesis.

Open Ended Questions

In addition to the closed-ended questions, respondents were also asked a series of open ended questions related to their perceptions of environmental issues in their community. Responses can be seen in Tables 2.3, 2.4 and 2.5.

Theme (*Frequency*)	Code (*Frequency*)	Examples
Garbage/Littering (*n=18*)	Garbage (nonspecific) (*n=6*)	"Solid waste" -- Respondent #5
	Garbage in the Streets (*n=5*)	"Garbage in the streets and rivers" -- Respondent #4
	Garbage in the Rivers (*n=3*)	"Garbage in the rivers" -- Respondent # 14
	Lack of Recycling (*n=2*)	"The garbage of people who aren't aware of recycling and using plastic" -- Respondent # 19
	Burning Garbage (*n=1*)	"Burning garbage and throwing garbage in the rivers" -- Respondent # 6)
	Garbage Dumps (*n=1*)	"Open air (garbage) dumps" -- Respondent #4
Contamination/ Pollution (*n=11*)	Rivers/Water (*n=6*)	"River contamination" -- Respondent # 22
	Air (*n=3*)	"...air pollution" -- Respondent # 23
	Nonspecific (*n=1*)	"Contamination" -- Respondent # 3
	Sewer (*n=1*)	"Contamination in the sewer…" -- Respondent # 1
Agriculture (*n=7*)	Industry Specific (pineapple, milk, swine, or banana production) (*n=4*)	"Contamination from the pineapple plantations in the area" - Respondent # 13
	Pesticides (*n=2*)	"Use of agro-chemicals" -- Respondent #25
	Monoculture (*n=1*)	"Monoculture (farming)" -- Respondent #22
Deforestation (*n=6*)	Deforestation (*n =6*)	"Cutting down of trees" -- Respondent # 23 "Lack of trees" - Respondent # 28
Automobiles (*n=5*)	Exhaust/Fuel (*n=3*)	"fuel from vehicles" -- Respondent # 20 "Vehicle smoke" -- Respondent # 10
	Sound (*n=2*)	"the sound pollution from the trucks parked on the side (of the road)" -- Respondent # 31
Community Knowledge/Engagement (*n=4*)	Lack of Awareness / Community Engagement (*n=4*)	"Lack of interest… lack of community organization" -- Respondent #16
Industry (*n=4*)	Industry (pineapple, milk, swine, or banana production) (*n=4*)	"Contamination from the pineapple plantations in the area" -- Respondent # 13
Agriculture (*n=3*)	Pesticides (*n=2*)	"use of agro-chemicals" -- Respondent # 25
	Monoculture (*n=1*)	"Monoculture (farming)" -- Respondent 22
Other (*n=2*)	Street Animals (*n=1*)	"Street animals" -- Respondent #11
	Urbanization (*n=1*)	"Urbanization" -- Respondent #9

Table 2.3: Responses to the question, "What are the most important environmental problems in your community?".

As can be seen in Table 2.3, there were 35 responses to the open-ended question "What are the most important environmental problems in your community?" The responses reveal that respondents, though they see a variety of environmental issues in their communities, are primarily concerned with issues of garbage and contamination/pollution. Within these two themes, trends can be further identified. For example, within the theme of garbage, most concerns centered around garbage in the streets or in the rivers. This suggests that littering is a major issue in the area.

Respondents were also asked to identify the biggest obstacles to solving the environmental problems they described. As demonstrated in Table 2.4, the major perceived barriers to solving environmental problems identified by respondents related to people and their lack of education around, knowledge of, or interest in environmental issues.

Theme (*Frequency*)	Code (*Frequency*)	Examples
Education (*n=12*)	Public's Lack of Education (*n=10*)	"Lack of education in the (general) population" -- Respondent #15
	Lack of Educational Programs (*n=2*)	"lack of community education programs (where they (learn) by practice or by taking them to the communities)..." -- Respondent # 18
Awareness/Knowledge (*n=9*)	Public's Lack of Awareness / Knowledge (*n=9*)	"The indifference of people to problems and the lack of environmental knowledge" -- Respondent # 30
Interest (*n=9*)	Public's Lack of Interest (*n=4*)	"Lack of interest for the environment" -- Respondent # 3
	Government's Lack of Interest (*n=5*)	"Lack of interest from the authorities" -- Respondent # 6
Motivation (*n=2*)	People's Lack of Will (*n=2*)	"The lack of mobilization by the community" -- Respondent #29
Other (*n=5*)	Abandoning Animals (*n=1*)	"That people should not abandon their animals" -- Respondent # 11
	Business (*n=1*)	"lack of commitment from businesses" -- Respondent # 13
	Consumerism (*n=1*)	"Consumerism" -- Respondent # 9
	Overpopulation (*n=1*)	"Overpopulation" -- Respondent # 3
	Trash (*n=1*)	"That people...do not take out their trash early" -- Respondent # 11

Table 2.4: Responses to the question, "What are the biggest obstacles to solutions for the environmental problems from the previous question?".

Finally, respondents were asked what they do with the waste they do not recycle. The vast majority reported either taking their waste to the dump or having it picked up by the dump truck. Another common response was that their waste biodegraded or was composted (see Table 2.5).

Code (Frequency)	Explanation	Examples
Dump/Truck (*n=26*)	Waste that is not recycled is brought to the municipal dump or picked up by a trash collector	"I deposit it at the municipal dump" -- Respondent #4 "The garbage truck picks it up" -- Respondent # 20
Compost/ Biodegrade (*n=9*)	Waste that biodegrades is composted or used as fertilizer	"Organic waste as a fertilizer for plants" -- Respondent # 34 "The truck picks it up, *or it biodegrades"* -- Respondent # 10

Table 2.5: Responses to the question, "What do you do with the garbage you don't recycle?".

Summary of Results

Overall, respondents were interested in protecting the environment, and saw value in reforestation efforts. A lack of willingness to reforest their own property did not reflect a lack of environmental concern. Although most people who did not want to reforest their properties did not state why they did not want to reforest, others stated that as the caregivers of properties, they did not feel like they could make the decision to do the reforestation themselves, and would need approval from the landowner to reforest. With regards to citizen science, nearly half of respondents were interested in participating in citizen science activities.

Although the majority of respondents had pro-environmental beliefs, they did not believe that environmental concern was important to most people in their communities. Pro-environmental attitudes did not vary significantly by age, gender, or belief in the rest of the community's concern with the environment. Responses to open-ended survey questions suggested that the most important environmental issue to people in the Sarapiquí region is the prevalence of littering and garbage in the streets and rivers. In order to solve this, residents suggested a need for more education to build awareness about environmental issues.

Recommendations for Future Work

As the BCEEC aims to reforest riparian zones, it is critical for the BER to consider how to incentivize reforestation projects. As revealed by our interviews, 13.8% of respondents (n=5) said that they were interested in reforesting, regardless of incentives (though two respondents noted that they would only be interested if someone else did the actual planting), and 36.1% (n=13) stated that they might be interested in reforesting. Several of these interviewees were not the landowner, and were unsure whether or not the landowner would be open to reforestation. This is meaningful for several reasons. First, it is important to note that some participants did not require any incentives to reforestation. A structural intervention to improve rates of reforestation could include having a team of people that drive around with native seedlings in their truck, and visiting properties in the region. Whenever an individual landowner or caretaker is receptive to having part of the land reforested, the team could immediately start planting or at least demonstrate to the landowner or caretaker the types of trees that they would plant. Additionally, this would provide an opportunity for the landowners to meet and build

trust with the people who would be involved in the planting itself. For those respondents who were caretakers and unsure of the landowner's amenability to reforestation, other interventions might be necessary. For example, an informational intervention may be appropriate in this case. Representatives from the BER could leave informational handouts about the benefits of conservation, and leave them with the caretakers with a request for them to be shared with the landowner. BER representatives could follow up regularly via phone with the caretakers (and landowners, if contact information is available) to continue conversations about the benefits of reforestation. It would also be beneficial to ask landowners who are not interested in reforestation what specific incentives they would require to be interested in it. This would facilitate future reforestation projects.

A second goal of the Bijagual Ecological Reserve is to engage people in citizen science activities. As we saw from our interviews, nearly half (n=16) of interview respondents were interested in participating in citizen science activities. According to Rotman et al. (2009), motivation to engage in citizen science activities in Costa Rica is often related to collectivism, or a desire to engage in behaviors that contribute to "the greater good of society" (p. 115). Other volunteers join citizen science projects in order to gain knowledge about the topics being studied (Rotman et al., 2009). Therefore, citizen science recruitment efforts should emphasize the community benefits involved in improving water quality and provide opportunities for participants to learn from experts in the field. Additional recommendations related to citizen science activities can be found in Section 4 of this report.

Interestingly, although responses to the interviews and surveys revealed that people living in the Bijagual Ecological Reserve and in the surrounding communities believe that there are significant environmental issues impacting them, issues of deforestation were not the primary concern. as well as significant barriers to overcoming these environmental issues. Instead, the primary concern expressed by respondents related to garbage and issues of pollution. This suggests two possible pathways forward for the Bijagual Ecological Reserve, which is currently focused on forest connectivity. It could pursue interventions to educate people about the importance of forest connectivity, and the impacts of deforestation on the flora and fauna of the region.

Alternatively, the Bijagual Ecological Reserve could change its focus to include more of an emphasis on the issues that the community identifies as most important -- primarily garbage or contamination/pollution (or both). If the BER takes this route, in addition to educating people in the region about the importance of proper disposal of garbage, and the benefits of recycling and composting, the Bijagual Ecological Reserve ought to consider structural interventions that address the concerns illustrated by this research. According to Gainforth, Sheals, Atkins, Jackson & Michie, simply having the intention to recycle is not sufficient to ensure that individuals actually do recycle. In addition to having intention to recycle, the recycling receptacles need to be accessible and convenient (2016, p.334). Laziness and lack of accessible "litter bins" on streets can also decrease the likelihood of waste being handled appropriately (Muñoz-Cadena, Lina-Manjarrez, Estrada-Izquierdo, and Ramón-Gallegos, 2012). Therefore, if the Bijagual Ecological Reserve and its partnering organizations want to address the issue of garbage and littering, there are several approaches it might take. Advocating for improved garbage infrastructure such as more frequent garbage pickups and/or more public garbage or receptacles could be effective approaches to reducing the garbage that is found in streets and rivers, by making it easier and therefore more attractive to properly dispose of trash.

As our research revealed the community's perceptions of barriers to addressing environmental issues, it is critical to include community perspectives when considering how to solve problems. Twelve respondents suggested that lack of education was a major barrier to solving environmental issues. Education serves as an informational intervention: increasing people's understanding of environmental issues aims to influence them to act in more pro-environmental ways. Local residents who have visited biological stations in or near their communities more frequently are more likely to have higher levels of environmental knowledge than those who do not (Moorman, 2006). By encouraging local visitors to visit the BER, La Selva and other ecological stations, local community members are likely to become more engaged with environmental issues.

Limitations

There are several limitations to this research. First, we recognize the small sample sizes of both our interview (n=36 interviews with 40 total interview subjects) and survey research (n=35). These sample sizes are insufficient to make generalizations about the population of the Bijagual River Watershed. Secondly, respondents were not randomly selected. Additionally, as our survey took place at the Feria Ambiental (Environmental Fair), it is likely that our respondents are people who already are interested in environmental issues. Therefore, it is possible that if the general public were surveyed, they would demonstrate lower levels of pro-environmental attitudes and behaviors. Third, not all respondents were from the Bijagual River Watershed, so the attitudes demonstrated in the responses to this survey cannot be assumed to be representative of the watershed overall.

Section 3: Geospatial Analysis

The area encompassing the Bijagual watershed has experienced many transformations over the years, largely related to anthropogenic activities in the region. Costa Ricans living in this area typically rely on agriculture for their livelihoods, an activity that can dramatically alter the landscape, especially one as heavily forested as northern Costa Rica. Despite its history of deforestation (described in this paper's introduction), recently, the country has been extolled as a leader in global conservation efforts, placing a countrywide moratorium on deforestation (Morse et al., 2009). However, whether or not Costa Rica's recent policies attempting to protect and improve forested areas have been successful is a difficult question to answer. One of the biggest challenges is the sheer size of the area that would need to be examined to determine the effectiveness of countrywide moratorium on deforestation. Additionally, for reforestation efforts to be successful, careful site selection practices must be followed to ensure that the maximum ecological benefits are extracted from each plot of reforested land (i.e. riparian buffers, ecosystem connectivity, minimal impact on humans and animals, etc.). When examining issues with relatively large spatial extents, remote sensing and other geospatial applications can be very useful to researchers and end-users alike. Remote sensing-based studies can examine a problem within a range of both spatial and temporal scales (depending on the subject) at a fraction of the time and cost it would take to collect a similar dataset without the assistance of satellite or airborne imagery (Foody, 2003). Specific to the Bijagual watershed project, examining current land-cover conditions will help groups currently involved in conservation and reforestation both in planning future reforestation projects and in identifying areas that would be especially sensitive to deforestation. In fact, land cover condition is one of the most important variables related to changes in an ecological system, and remote sensing has been used extensively as a means to monitor land cover changes, especially those related to deforestation (Skole & Turner, 1994; Foody, 2003). Figure 3.1 is a reproduction of a list of remote sensing products that would be potentially useful for forest monitoring (ANZECC, 2000).

Theme/issue	Indicator	Example of the potential remote sensing input
Biodiversity		
Threatening process	Native vegetation clearing	Monitor land cover change
	Aquatic habitat destruction	Monitor land cover change
	Fire regimes	Estimate canopy moisture content, map drought
Loss of biodiversity	Extent of native vegetation	Map land cover
	Extent of aquatic habitats	Map land cover
	Populations of selected species	Map land cover and link to biogeographical models
Conservation and management	Terrestrial protected areas	Map and monitor land cover
	Recovery plans	Monitor land cover, estimate biophysical variables
	Area revegetated	Monitor land cover
Land		
Use and management	Changes in land use	Monitor land cover
Erosion	Potential for erosion	Map land cover, link to disturbance and environmental data

Figure 3.1: Ecological indicators and potential remote sensing products for monitoring them (ANZECC, 2000).

After examining potential geospatial products that would not only be useful to the project client, but could feasibly be completed based on the duration of the project, it was determined that a land cover classification map reflecting current conditions in the watershed would be created for the BCEEC.

Deliverables

As discussed with the client, the deliverable products generated from this portion of the project include:

1. Various reference maps for features within the Bijagual watershed (roads, watershed boundary, bridges, etc.).
2. Maps showing the spatial locations of both GPS and macro invertebrate sampling sites.
3. An expandable set of training polygons for future image classifications.
4. Several supervised land-cover classification maps, using various forms of remotely sensed imagery (Pleiades, Landsat-8, PALSAR).

Methods

The methodologies used to complete the geospatial portion of this project can be divided into two sections: onsite and offsite.

Onsite

In order to conduct a supervised classification of an area, training data needs to be collected from the study site to inform the classification model. Training data can be collected solely from imagery, although training data collected in-situ is preferred due to the certainty that can be associated with its assigned cover type. For this project, training data would be in the form of GPS points collected over a specific cover type (primary forest, row crops, pasture, etc.), which would later be converted into training polygons using ArcMap 10.4. Before arriving in Bijagual, a plan was developed to maximize the effectiveness of data collection activities. To collect location data we used the built-in GPS functionality of a smartphone, specifically that Apple IPhone 7. There were a number of reasons for using the smartphone rather than a portable GPS unit: 1) Due to the amount of canopy cover, it was unlikely that the GPS unit would fare any better than the smartphone, 2) A mobile app developed by ESRI (ArcCollector) could be used on iOS, and would significantly streamline data management, III) There was no ground control station in the area for higher accuracy GPS units (i.e. Trimble), not to mention the sizeable initial costs of purchasing such a unit. An added benefit of using the ArcCollector app is that it allows users to drop GPS points away from their current position, while still maintaining satellite-based accuracy (see Figure 3.2).

Figure 3.2: Offset functionality of GPS collection point (crop) and actual location of GPS unit.

This ended up being important for in-country data collection, as access to the properties containing the desired land-cover types was not always granted. Due to communication, security, and other factors, point collection were taken remotely. All of the roads in the area were public, so once alongside a cover-type of interest, a point was dropped in ArcCollector and dragged laterally until it was over the desired area. Azimuth direction and distance between the GPS unit and the point being recorded were also logged so that they could be replicated if there was any loss of point data.

Time was also a factor in designing the in-country workflow. Several extraneous GIS products needed to be created for other parts of the project in addition to the collection of training data. Also, basic geospatial infrastructure data did not exist for the study area, and as such needed to be collected (e.g. local road networks, power distribution, road materials, bridge locations, and other points-of-interest). Mobility within the watershed was limited by weather and the related road conditions (some roads could not be accessed during rain, some roads could only be accessed by a specific vehicle, vehicles experienced breakdowns, some bridges in states of disrepair (Figure 3.3), etc.) and therefore specific collection activities were planned based on changing daily conditions.

Figure 3.3: Bridge conditions were highly variable and at times necessitated longer alternative routes.

Watershed Delineation

Another prerequisite for data collection was the creation of a polygon layer that would reflect the spatial confines of the Bijagual watershed. As the project was focused specifically on the Bijagual drainage basin, this layer was needed to ensure GPS collection would only take place within the watershed. A digital elevation model was provided to our team by the La Selva GIS Laboratory. Once the elevation data was acquired, a basic watershed delineation was completed using the Hydrology toolset within ArcGIS (there are many online sources for the proper workflow needed to complete a delineation, though the general steps can be view here: https://support.esri.com/en/technical-article/000012346).

Cover Types

Before collecting ground-truth data, a tentative categorization of land-cover types was made for data organization purposes (the names assigned to these classes changed iteratively during the project, but the actual cover types being represented were essentially the same). Classes were chosen based on the likelihood that they would be remotely detectable by a satellite sensor, as well as their usefulness to the client and other end users. Six classes were eventually selected (Figure 3.4): 1) Primary Forest; 2) Secondary Forest; 3) Plantation (planted timber stands); 4) Pasture; 5) Crops (*Cultivo*); and 6) Scrub (*Charral*). Primary forest represents tracks of forest that have never been cut down. Secondary forest

represents natural regrowth of previously cleared (or selectively logged) areas. The Plantation class represents stands of trees that were planted with the intention of future timber harvesting. Pasture represents grass-covered areas cleared of trees for cattle grazing. Crops are areas planted for various agricultural products, including yucca, ornamentals, citrus trees, black pepper, among others. Scrub (*Charral*) is essentially shrubbery, with grasses and sparse trees, but little or no canopy cover.

Figure 3.4: Examples of land cover classifications. Top Row (Left to Right): primary forest, secondary forest, scrub. Second Row (Left to Right): pasture, plantation, crops.

Once the basic classification schema was defined, data collection could begin. Initially, the collection strategy aim was to collect evenly distributed points from every accessible area within the watershed. As mentioned early, the distribution of the points mirrored the layout of the local road networks (see Figure 3.5), as this was the only way to collect data points without needing permission to access private property. Once this general collection was completed, the data was organized in Microsoft Excel to identify cover-types that were insufficiently represented. Inquiries were made to multiple sources regarding what would be a sufficient number of GPS points for each cover-type, based on the size of the study area (roughly 50 km^2). Though it was indicated that there is no 'magic number' for how many points should be collected over a given area, the feedback received from those sources led to the

adoption of a baseline number of 40 GPS points per cover-type. Once insufficiently represented classes were identified, local knowledge of the watershed was used to focus remaining data collection in areas where underrepresented cover-types were abundant.

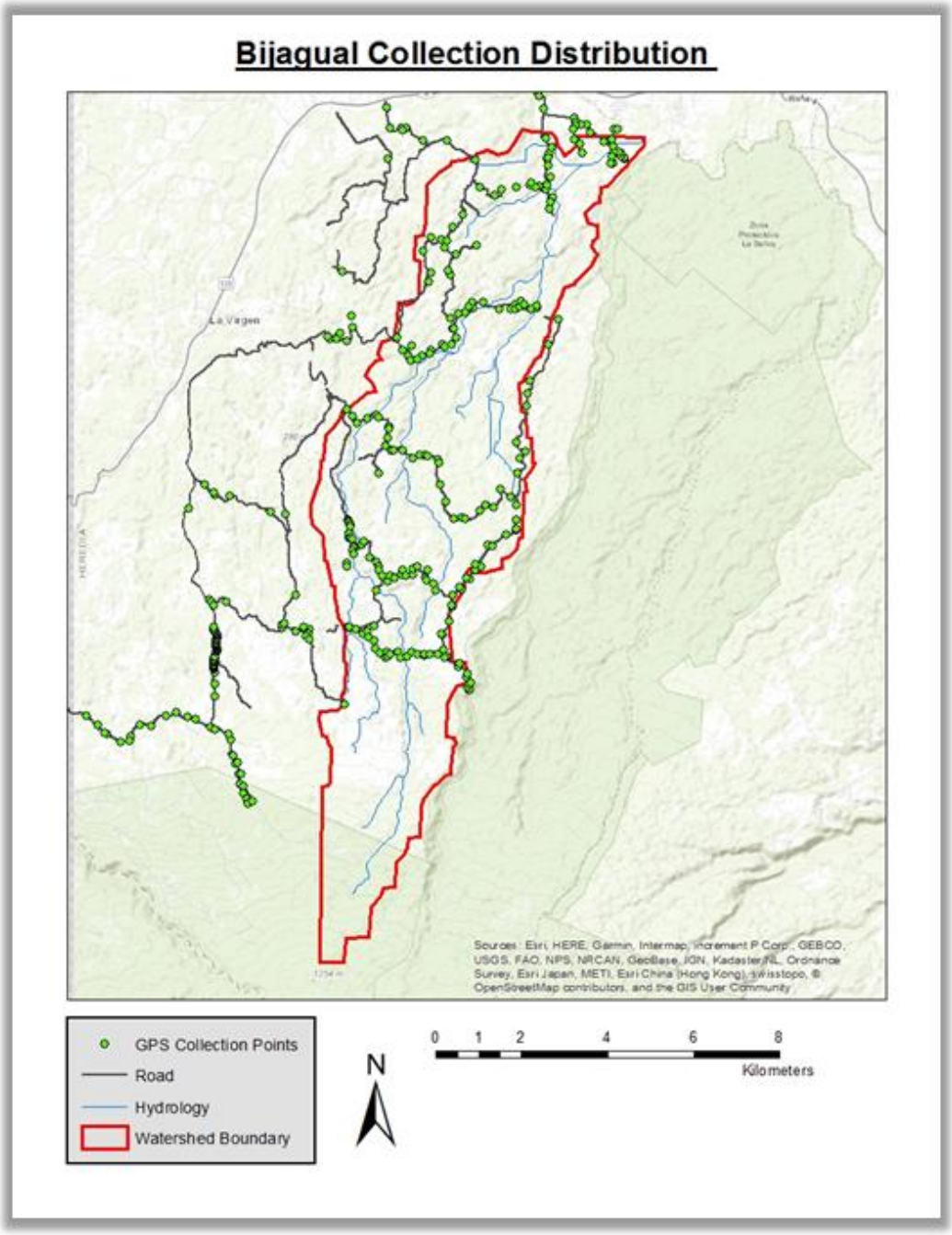

Figure3.5: GPS data distribution in the Bijagual River watershed.

Data Storage

As with any data driven project, careful storage and organization of collected data is crucial to the completion of project goals. An external hard drive was used for data storage and manipulation. However, considering that the field portion of this project was completed in a wet, hot, and rugged

environment, the chances of damaging the external hard-drive were very real. To address this potential issue, the ArcCollector application's 'sync' function was used to back up data using a local Wi-Fi connection (when/where available). At the end of a collection day, a Wi-Fi connection (usually provided by a local hotel or restaurant outside of the reserve) was used to back up the collected data on ESRI's online servers, where an ArcGIS Online account linked to our project was used as a depository. Not only does this decrease the risk associated with relying solely on a physical data storage device, it also made the collected data available anywhere with internet connection.

Offsite

Once summer field collection activities were completed, an initial methodology for post-processing and image analysis was developed with assistance from Shannon Brines, one of the managers of the Environmental Spatial Analysis lab at the University of Michigan School for Environment and Sustainability.

Image Acquisition

Due to the increased effectiveness imparted by near-infrared (NIR) bands on vegetation classifications, only multispectral images with at least one NIR band were considered. The 30m spatial resolution of the commonly used Landsat-8 imagery did not allow for the fine-scale mapping of spatial features within a smaller study area, and is best implemented when examining larger landscape-scale characteristics (Crnojevic et al., 2014). Eventually, an image from the Pleiades-1 sensor was purchased from Satellite Imaging Corporation. The purchased data included both a 4-band MS image with a 2m spatial resolution, as well as a .5m panchromatic image. Later, due to changes in the off-site workflow design, additional sources of imagery were added to the project, including the original Landsat-8 image (see section on Random Forest Decision-Tree Analysis/Preprocessing).

Classification Technique

Following image acquisition, a classification technique needed to be developed, and associated software selected. Following an evaluation period, a classification model based on random forest decision-trees was selected.

Random Forest Decision-Tree Analysis

Scientists at Michigan Tech Research Institute (where a member of the Bijagual Research Team was interning during the project) had developed a classification technique based on the 'Random Forests' decision-tree method, and had published numerous classification maps using this technique (Bourgeau-Chavez et al., 2013; Bourgeau-Chavez et al., 2015). A machine-learning algorithm, 'Random Forests' creates a series of decision trees (500 in total) by using random subsets of user-specified training data (Bourgeu-Chavez et al., 2015). The output class assigned to a given pixel is determined by how many 'votes' each class gets from the decision trees (i.e. if 350 decision trees decide the pixel is primary forest and the remaining 150 trees are split between secondary forest and plantation, the pixel will be classified as primary forest). For this project, the use of 'Random Forest' was especially appropriate for the following reasons: 1) it eliminates some of the inherent biases that can exist in training data by generating random subsets for each decision tree; 2) it can perform classifications on datasets with limited field verification; 3) it can take advantage of parallel-processing when available; and 4) it is not easily fouled by non-predictive inputs (Bourgeu-Chavez et al., 2015). Additionally, training data that has been field-verified (as was the case for all of the Bijagual training data) is weighted heavier by the model than training data that is not field verified, allowing for the addition of training polygons post field-

collection without diminishing the obvious accuracy advantage possessed by field-verified data. Another useful feature of 'Random Forest' is that it automatically splits training data 80/20 before running, with 80 percent of the data being used by the decision trees, and 20 percent being set aside for validation. After the model runs, it automatically performs an accuracy assessment using the validation data and outputs an excel table into the destination folder, allowing for the easy examination of errors of omission and commission within each class. Furthermore, multiple image layers from different sensors or collection dates could be stacked together in ArcGIS prior to being run through the model. This effectively increased the size of the data pool from which the machine-learning algorithm could pull information, and also allows for the composting of other images to fill in areas of the Pleiades-1 image that were lost to cloud cover and shadows. The MTRI scientists behind the generation of their 'Random Forest' model graciously gave the Bijagual team access to the script, which was then manipulated and ran using several different image stacks in R-Studio.

Image Preprocessing

Before running the imagery through the model, various amounts of preprocessing had to be completed depending on image type. All landsat-8 images had their digital number (DN) values converted to top of atmosphere (TOA) reflectance using a python script proprietary to MTRI. The Pleiades-1 image was not preprocessed for two main reasons: 1) The area of interest (AOI) fit entirely within one image tile, somewhat negating the importance of preprocessing steps (Young et al., 2017); and 2) The client was only interested in relative land-cover classes within the AOI, and was not planning to do any comparative analysis using surface reflectance values. No complex atmospheric corrections were completed beyond what was already mentioned. The reasoning behind this stems from the computational and temporal burden associated with completing this for every image type, as well as claims from multiple literary sources that discounted the increased accuracy of atmospherically corrected images (over TOA or DN) (Masek et al., 2006; Wulder, 2003).

Cloud Masking

Another necessary pre-classification step was masking out clouds and cloud shadows from the Pleiades-1 image. DN values for pixels associated with clouds or cloud shadows were identified using the pixel inspector tool in ArcGIS. The cloud and shadow values were then re-classed as 'no data' values. The mask raster was then converted to a shapefile, so that the mask polygons could be edited by hand, creating a more accurate/effective mask. Once the mask was complete is was converted back into a raster and then 'clipped' from the original image (see Figure 3.6). This was not necessary for the Landsat-8 imagery, as it contained negligible (<10%) data loss due to clouds.

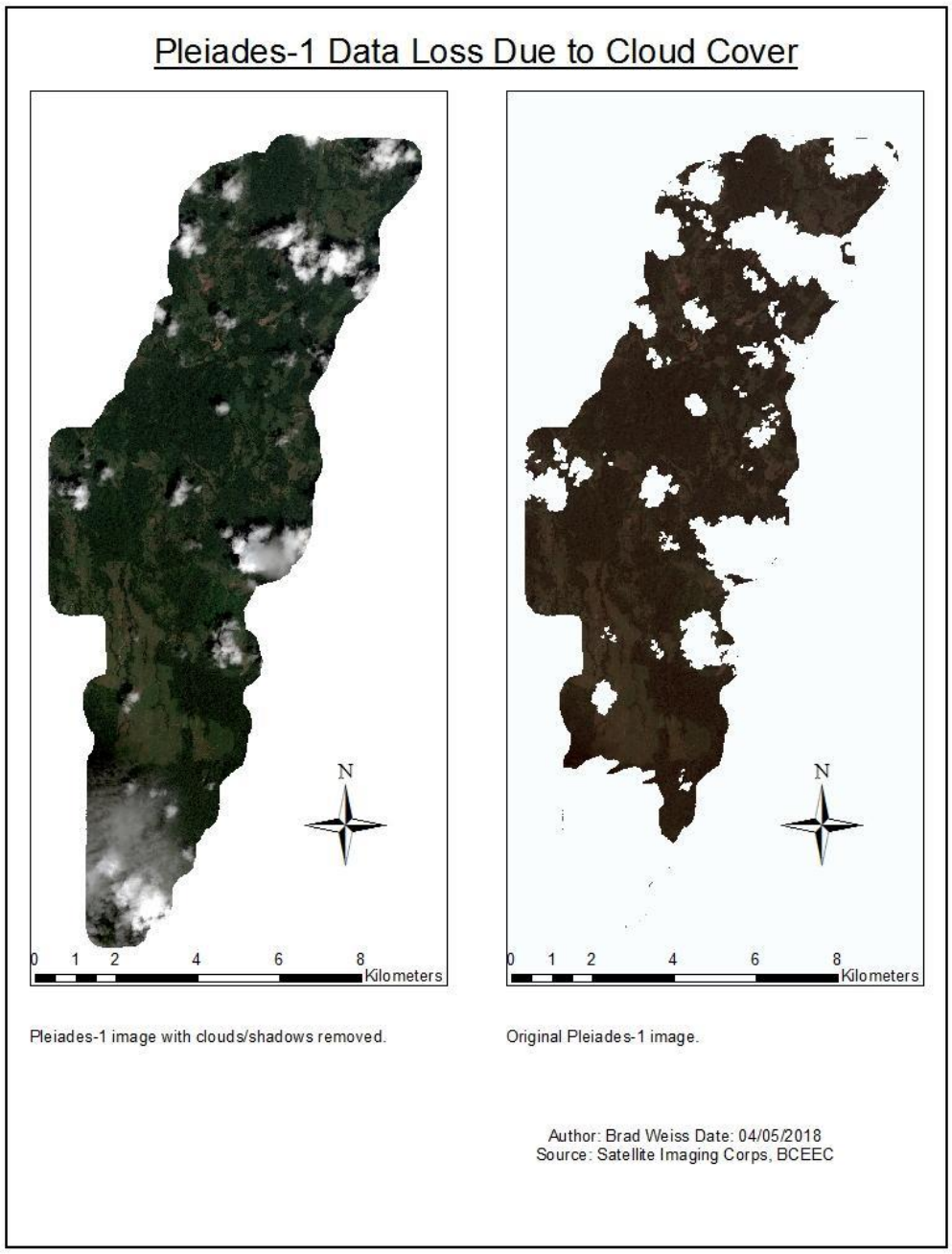

Figure3.6: Cloud mask applied to Pleiades-1 image.

Image Combinations

In order to compare the relative usefulness of different image types used for the classification, various combinations of images were stacked together in ArcGIS before being ran through the model in R-Studio. The coarser dataset (Landsat-8) was resampled to match the 2m resolution of the Pleiades-1 image (the image with the finest spatial resolution). Initially, the two images (Pleiades-1 and Landsat-8) were ran through the model individually, creating a classification based solely on each respective sensor. Then, a layer stack combining the Pleiades-1 and Landsat-8 images was run through the model. The resulting classifications were then compared for relative accuracy.

Results

The following map (Figure 3.7) shows the classification completed with the Landsat-8 imagery.

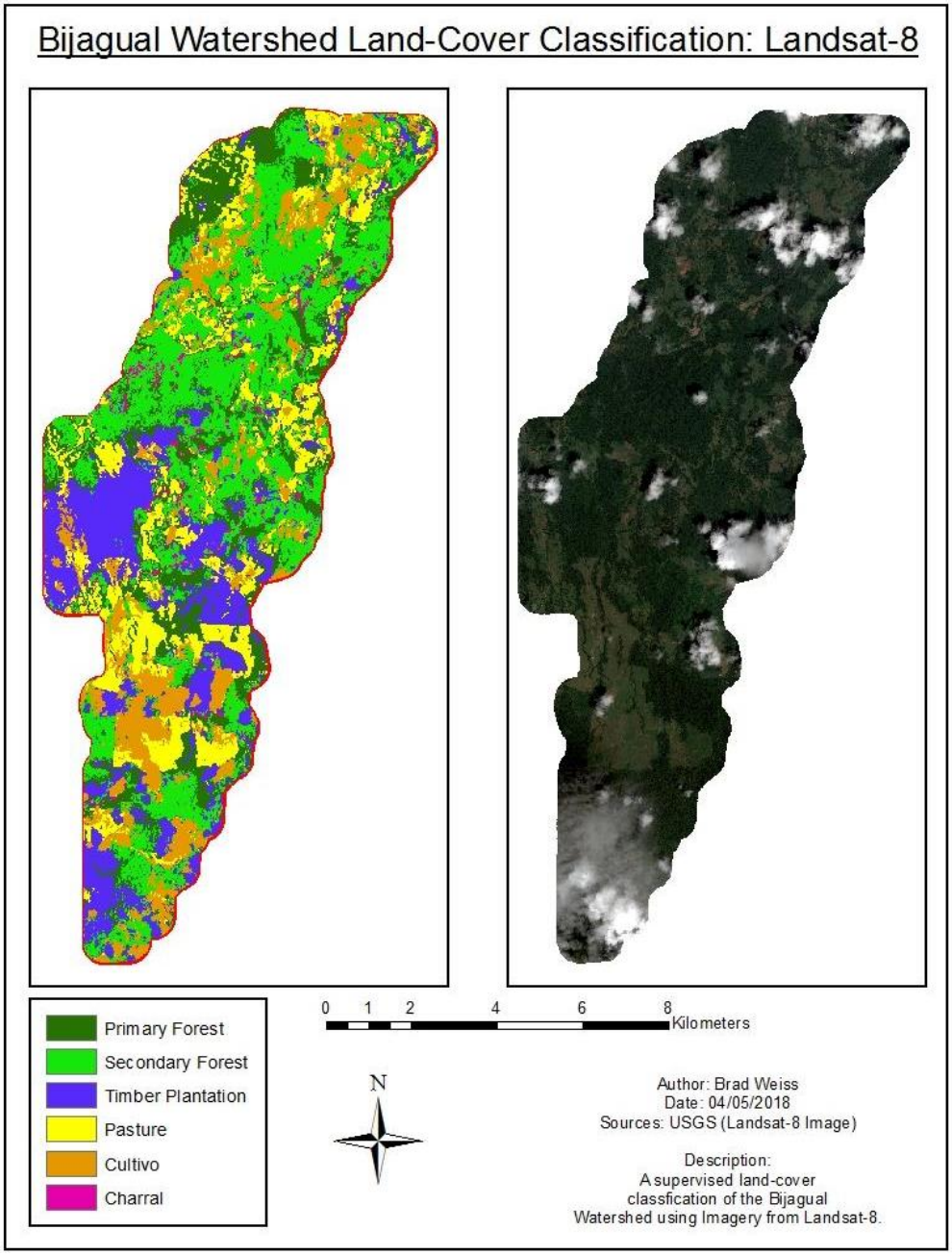

Figure 3.7: Landsat-8 classification map.

Table 3.1 shows the percent coverage for each cover-type within the watershed based on the Landsat-8 image, as well as a separate breakdown based on splitting the watershed into three approximately equal areas (North, Central, and South).

Cover Type	Primary	Secondary	Plantation	Pasture	Row Crops	Scrub
Percent Coverage (North)	22.11%	41.72%	4.29%	14.21%	16.08%	1.59%
Percent Coverage (Central)	18.93%	32.26%	24.88%	13.87%	7.08%	2.99%
Percent Coverage (South)	16.26%	19.42%	23.97%	16.48%	23.49%	0.38%
Percent Coverage (Total)	19.16%	31.44%	17.75%	14.79%	15.15%	1.72%

Table 3.1: Percent coverage of each cover-type within the Bijagual River watershed according to Landsat-8 classification.

The next classification map (Figure 3.8) was creating using only the Pleiades-1 image.

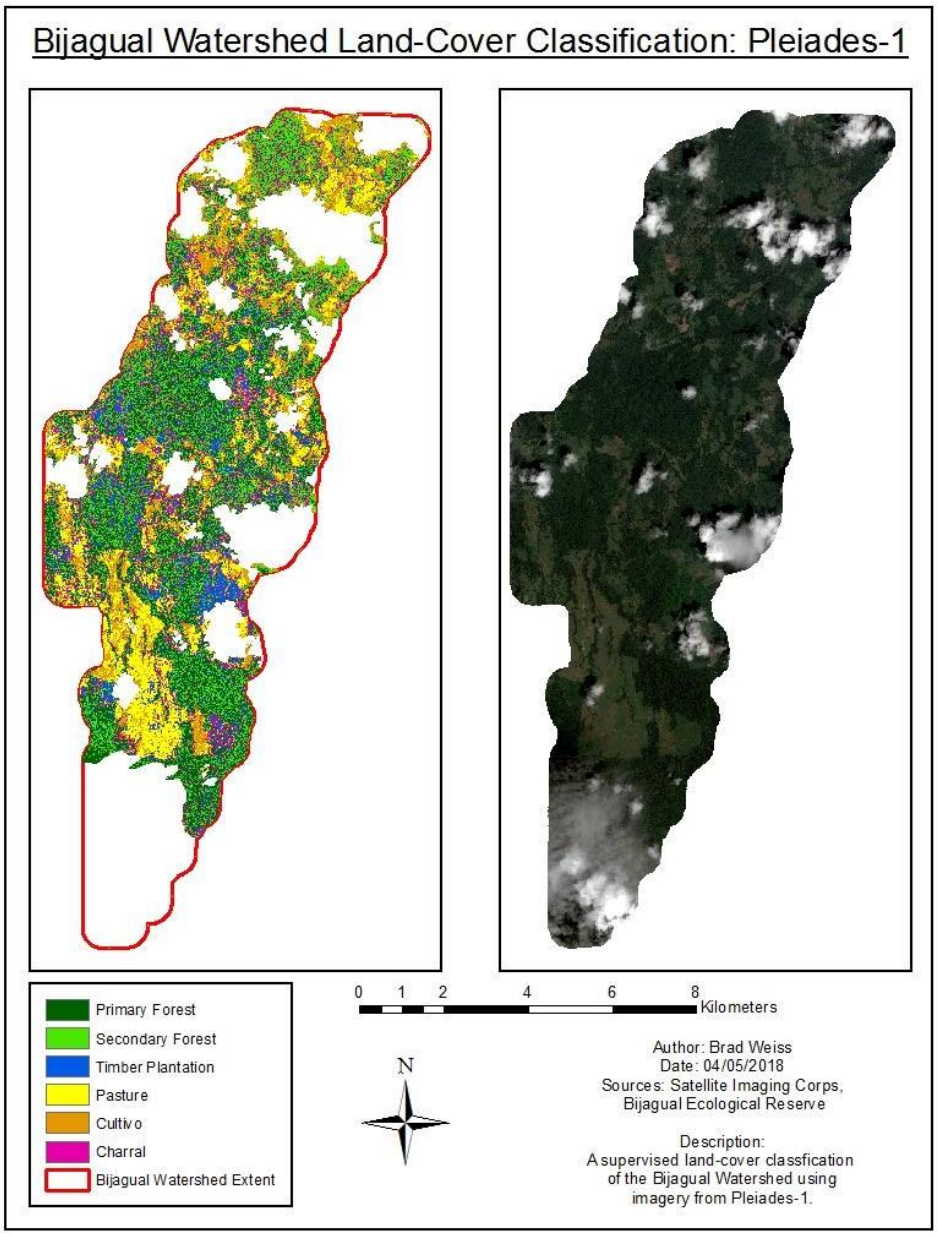

Figure 3.8: Pleiades-1 classification map.

Table 3.2 shows the percent coverage for each cover-type within the watershed based on the Pleiades-1 image, as well as a separate breakdown based on splitting the watershed into three approximately equal areas (North, Central, and South).

Cover Type	Primary	Secondary	Plantation	Pasture	Row Crops	Scrub
Percent Coverage (North)	16.35%	29.40%	5.69%	12.34%	20.65%	15.57%
Percent Coverage (Central)	27.79%	23.28%	12.68%	10.58%	10.27%	15.40%
Percent Coverage (South)	29.39%	15.84%	11.89%	21.75%	10.84%	10.29%
Percent Coverage (Total)	24.48%	23.39%	10.21%	13.97%	13.78%	14.16%

Table 3.2: Percent coverage of each cover-type within the Bijagual River watershed according to Landsat-8 classification.

The third classification map (Figure 3.9) was created from a layer stack including the Landsat-8 and Pleiades-1 imagery.

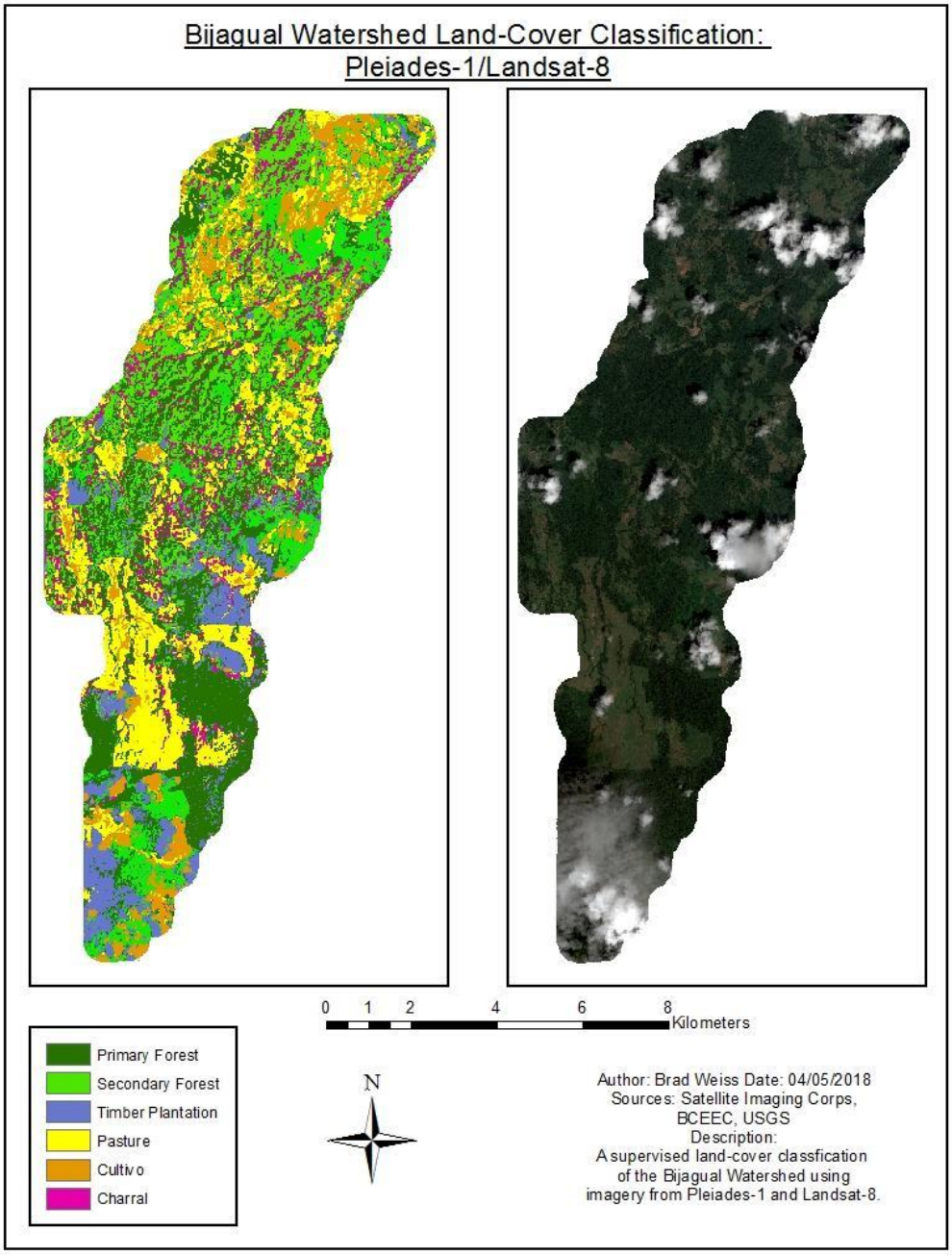

Figure 3.9: Pleiades-1/Landsat-8 Classification Map.

Table 3.3 shows the percent coverage for each cover-type within the watershed based on the Pleiades-1/Landsat-8 images, as well as a separate breakdown based on splitting the watershed into three approximately equal areas (North, Central, and South).

Cover Type	Primary	Secondary	Plantation	Pasture	Row Crops	Scrub
Percent Coverage (North)	13.92%	37.46%	2.11%	13.82%	20.31%	12.38%
Percent Coverage (Central)	32.35%	28.19%	7.57%	15.70%	3.51%	12.68%
Percent Coverage (South)	46.88%	3.59%	10.31%	31.56%	1.86%	5.82%
Percent Coverage (Total)	30.04%	24.98%	6.49%	19.09%	8.55%	10.85%

Table 3.3: Percent coverage of each cover-type within the Bijagual River watershed according to Landsat-8/Pleiades-1 classification.

Overall, the three classifications indicated that approximately half of the watershed is forested, with the remaining 50% of cover being distributed fairly evenly among the other classes. The most deforested areas appear to be in the south, towards the headwaters of the Bijagual River. This proximity to the source means that surface water features in the Bijagual watershed are exposed to non-forested areas almost immediately. For this reason, it seems that the most logical place to improve riparian corridors in the watershed would be in the south, where well placed reforestation projects could delay the exposure of rivers and streams to increased nutrient loading.

Discussion

Though the percent coverage of each land-cover type in the watershed differed between the various classifications, certain trends were present. Generally, the amount of primary and secondary forest decreased from north to south. This is reinforced when comparing the classification with the imagery, as some of the largest swaths of pasture and row crops exist in the southern part of the watershed. Also, the data indicates that a larger proportion of row crops exist in the northern part of the watershed, while a larger proportion of pasture exists in the south (with fairly even amounts in the center). This is not only confirmed by the imagery, but also by the training data and ground observations (more points for pasture were collected in the south, more points for row crops were collected in the north). This is also true for the timber plantation class, which is more present in the central and southern portions of the watershed than in the north. The scrub cover-type is overly represented in our results, as scrub patches were very small when present, and likely never comprised more than 5% of any portion of the watershed (north, central, or south).

Accuracy Assessment

The classification model yielded results with varying amounts of accuracy. As expected, the classification based solely on the Landsat-8 imagery was too coarse to be very effective, as it failed to capture finer features within the watershed.

Landsat	Primary	Secondary	Plantation	Pasture	Crops	Scrub	Total
Error Matrix	1	2	3	4	5	6	
1	147	40	8	3	10	193	401
2	0	152	73	12	116	0	353
3	21	2	115	0	36	0	174
4	3	2	1	184	1	0	191
5	31	5	5	0	35	0	76
6	0	0	0	0	5	0	5
Total	202	201	202	199	203	193	1200
Accuracy	72.77%	75.62%	56.93%	92.46%	17.24%	0.00%	
Omission Error	27.23%	24.38%	43.07%	7.54%	100.00%	100.00%	
Commission Error	63.34%	56.94%	33.91%	3.66%	53.95%	100.00%	
Total Accuracy	49.22%						

Table 3.4: Landsat-8 error matrix.

However, the error matrix (see Table 3.4) illustrates that the actual classification accuracy of the Landsat-8 image was the highest (49.22%). The most notable increase in accuracy was seen in the Landsat-8 image's ability to distinguish between primary and secondary forest types. The coarser resolution of the Landsat-8 imagery is likely responsible for this distinction, as there are less pixels per training polygon, which simplifies the amount of inputs from the dataset into the decision trees.

Pleiades	Primary	Secondary	Plantation	Pasture	Crops	Scrub	Total
Error Matrix	1	2	3	4	5	6	
1	55	75	24	0	3	62	219
2	61	56	54	1	19	56	247
3	43	19	108	3	70	70	313
4	0	0	0	169	23	0	192
5	12	4	2	18	16	0	52
6	30	44	15	9	70	11	179
Total	201	198	203	200	201	199	1202
Accuracy	27.36%	28.28%	53.20%	84.50%	7.96%	5.53%	
Omission Error	72.64%	71.72%	46.80%	15.50%	100.00%	94.47%	
Commission Error	74.89%	77.33%	65.50%	11.98%	69.23%	93.85%	
Total Accuracy	32.84%						

Table3.5: Pleiades-1 error matrix.

The classification based solely on the Pleiades-1 image was actually the least accurate (see Table 3.5), at 32.84%. The classification model had trouble distinguishing between primary and secondary forest, likely due to the finer pixel size of the Pleiades-1 imagery (2m for Pleiades-1 vs. 30m for Landsat-8). In other words, there are more pixels within each training polygon that need to be designated as either secondary or primary, and the similar spectral signatures of the two classes confounded this confusion. However, visually, the map does capture small-scale features within the terrain, suggesting that, with an improved training set, the classification would likely yield much more accurate results. The spectral variation within the map image supports this theory, as features are being distinctly classified, just often into the wrong class. It should be noted that, due to data loss from cloud cover, entire areas within the Pleiades-1 scene cannot be classified without the addition of another image.

Pleiades/Landsat	Primary	Secondary	Plantation	Pasture	Crops	Scrub	Total
Error Matrix	1	2	3	4	5	6	
1	66	93	16	0	12	63	250
2	99	76	68	0	0	64	307
3	12	4	104	0	19	15	154
4	1	5	7	127	169	0	309
5	0	0	1	71	0	0	72
6	27	18	3	0	0	54	102
Total	205	196	199	198	200	196	1194
Accuracy	32.20%	38.78%	52.26%	64.14%	0.00%	27.55%	
Omission Error	67.80%	61.22%	47.74%	35.86%	100.00%	72.45%	
Commission Error	73.60%	75.24%	32.47%	58.90%	100.00%	47.06%	
Total Accuracy	35.14%						

Table 3.6: Pleiades-1/Landsat-8 error matrix.

The classification based on the combined bands of Landsat-8 and Pleiades-1 predictably fell between the other two classifications with regard to accuracy (see Table 3.6), at 35.14%. The advantage of the Landsat-8 image's coarser pixels was diminished, as the 30m pixels were resampled to match the 2m resolution of the Pleiades-1 image prior to being run through the classification model (a necessary step during image preprocessing). Again, the same issue seen in the Pleiades-1 classification with distinguishing between primary and secondary forest were present, though to a lesser degree. The coverage of the classification was also improved, as the Landsat-8 imagery was able to fill in areas of the Pleiades-1 image that were empty due to cloud cover. This classification was very accurate in distinguishing pasture, with an accuracy of 92.46%.

Training Data Improvement

The results of the classification do not point to an issue in the random forest-based model, but rather a deficiency in the training dataset. This was not an entirely unforeseen issue. As was mentioned previously, the GPS points collected for use as training data had to be collected remotely (from a lateral position on a road), as the research team did not have access to the vast majority of private lands within the watershed. The on-the-ground view of an area is very different from the view provided by satellite imagery, and it is likely that a few polygons were incorrectly classed. Additionally, the lack of local expertise available during the classification process made it difficult to improve upon the accuracy of the training data using satellite imagery, as local research personnel affiliated with the project were not trained in image interpretation or in the use of geospatial software. Among the classifications, there was extremely low accuracy in classifying the crop and scrubland cover-types. Crops were often classified as pasture, due to their similar spectral properties. Implementing cadastral data defining property margins and related features in conjunction with a more accurate training dataset would likely improve this limitation, as the geometric shapes of row crop plots are likely more distinct from pastured areas then the actual spectral differences between the two. As for scrub, a lack of good sampling areas is likely responsible for the model's difficulty in accurately classifying this cover-type. In addition to being very small in area compared to plots of the other cover-types, patches of scrub were few and far between, limiting the ability for the model to train itself to identify this class spectrally.

Recommendations for Future Work

Moving forward, there is much opportunity to improve upon the classifications generated during this project. Though the project design, collection techniques, and classification models used during both field collection and classification were sound, some of the inherent difficulties related to the collection of high-quality training data limited the accuracy of the generated map products. Luckily, improving the training dataset would not be a difficult task. Teaching field support members to create basic polygons in ArcMap would allow those with the most knowledge of the area to create training datasets that could then be run iteratively through the model, until the desired classification accuracy is reached. If this cannot be accomplished, simply identifying (drawing in) areas representing the different cover-types on a paper map would allow a person trained in using geospatial software to digitize these areas into training polygons, which could then be run through the model. Also, gaining access to more private property within the watershed would allow for more accurate collection of GPS data. The data generated by social science aspect of this project could be used to request permissions from landowners in the watershed, as it is likely that those willing to allow reforestation projects to occur on their property would not protest to the collection of a few GPS points on their property. Additionally, any future image acquisitions by the BCEEC of other involved parties could be quickly stacked with existing images and ran through the model to see if certain sensor data is more adept at classifying local cover-types.

Conclusion

Remote-sensing techniques can allow for the examination of large areas in a relatively quick and low-cost manner. In the Bijagual watershed, a supervised classification describing land-cover types within the area was created as a product for the BCEEC. The map products can be used to inform location decisions related to future reforestation projects within the watershed. Specifically, the relative increase in deforested area seen in the southern portion of the watershed would likely make this a prime area for reforestation, in addition to its proximity to the Bijagual River's tributary network. Though the techniques and models used in this portion of the project are sound, the training data could be improved to yield higher accuracies during future iterations of classification mapping. Specifically, improving the robustness of training datasets that have proved difficult to classify (i.e. scrub) would help improve the overall accuracy of the classification. Moving forward, as new data or imagery becomes available to the BCEEC and its partners, further iterations of the classification maps can be generated using the same techniques outline in this paper.

Section 4: Stream Monitoring Program

Community-based environmental monitoring is "a process whereby non-government organizations, community groups or individuals participate in long-term monitoring of selected species, habitats, or ecosystem processes with the ultimate goal of improving management of ecosystems and natural resources" (Yarnell & Gayton, 2003, p. 1). Monitoring programs that rely on volunteers have been shown to effectively collect data that reveal changes in ecosystem conditions and improve decision-making in natural resource management, thereby allowing communities to evaluate and address the impacts of anthropogenic activities (Danielson et al., 2013; Lawe et al., 2005; Yarnell & Gayton, 2003). Based on this foundational understanding of the utility of community-based monitoring efforts, the stream monitoring program developed in this portion of the project had two main objectives. First, the program was designed to quantify changes in stream ecosystem health as future grant-funded riparian reforestation and forest protection programs are implemented throughout the watershed. This provides a metric that can be used to evaluate the overall success of riparian forest conservation efforts, and clearly identified positive impacts may help secure additional funding in the future to further the BCEEC's goals of promoting habitat conservation and improving connectivity between disparate habitat patches. The stream monitoring program may also be used to identify additional changes in the watershed, unrelated to riparian conservation, that have either a positive or negative effect on water quality (WQ) as well as specific areas where conservation efforts should be prioritized. Second, the stream monitoring program provides an opportunity to involve local citizens in long-term monitoring and management of the Bijagual River watershed, which closely aligns with the BCEEC's goal of providing environmental education through hands-on learning opportunities.

A well-implemented stream monitoring program has the potential to generate reliable information that can be used to inform efforts to restore and conserve riparian forests throughout the Bijagual River watershed. Environmental monitoring programs that provide volunteer monitors with proper instruction, support, and oversight are capable of collecting high-quality data (Danielsen et al., 2003), which is increasingly being used to inform the management and conservation of natural resources (Fleener et al., 2004). Furthermore, community-based monitoring programs are recognized as an effective tool for engaging citizens in the planning and management of local ecosystems (Pollock & Whitelaw, 2005). As a result, communities with volunteer monitoring programs tend to have residents who are more actively engaged in local issues and have more influence on policy-makers (Lynam et al., 2007; Pollock & Whitelaw, 2005; Whitelaw et al., 2003). In short, a well-established stream monitoring program in the Bijagual River watershed has the potential to meaningfully engage the local community in the monitoring and management of the region's aquatic resources.

Literature suggests that engaging residents of the Bijagual River watershed in a stream monitoring program will provide an opportunity for environmental education and may promote pro-environmental behavior. Community-based environmental monitoring programs promote the sharing of knowledge and information between scientists and non-scientists. This democratization of science not only increases scientific literacy among the local community, but it also makes the scientific community more aware of local and traditional knowledge (Carolan, 2006). Participation in monitoring programs has been associated with increases in overall scientific understanding among local communities, leading to educational empowerment, increased self-confidence, and a stimulated desire to continue learning (Becker et al., 2005; Taylor et al., 2013; Danielsen et al., 2007). At the same time, participation by the

scientific community can lead to a newfound appreciation for traditional knowledge and local ecological understanding (Ortega-Álvarez & Sánchez-González, 2015). Furthermore, monitoring programs provide an opportunity to augment community members' knowledge of ecosystem processes and increase understanding of their role in the local environment (Evans et al., 2005). For this reason, it is perhaps unsurprising that volunteer monitors frequently report increased engagement in conservation actions following engagement in monitoring programs (Danielsen et al., 2007). In fact, monitoring programs have been shown to promote communities that are more sustainable overall (Whitelaw et al. 2003).

With this information in mind, a stream monitoring program was designed integrating a range of data to characterize the overall quality of stream ecosystems and to track changes in these ecosystems over time. Furthermore, the monitoring program was designed specifically to be conducted by volunteer citizen scientists. In other words, this program balances the collection of scientifically robust data with relatively easy and inexpensive data collection techniques and provides an opportunity for environmental education in topics such as the relationship between land cover, WQ, and biodiversity, invertebrate anatomy and taxonomy, and the use of scientific equipment and proper data collection techniques. An initial version of stream monitoring protocols was developed based on a literature review and then revised in a two-step process of consultation with the client and local partners and field-testing at eleven monitoring locations established throughout the Bijagual River watershed. Field-testing the sampling protocols also constituted a baseline assessment of the watershed's stream ecosystems, which included the collection of water quality data, aquatic macroinvertebrate surveys, and qualitative habitat observations. Additional materials were produced to enhance the stream monitoring program including an equipment checklist and data sheet to promote safe, effective, and accurate data collection as well as an aquatic macroinvertebrate taxonomic key for use as an educational tool.

Deliverables

As discussed with the client, the deliverable products generated from this portion of the project include:

1. A set of protocols that clearly define the equipment, materials, and methods for collecting monitoring data (Appendix D).
2. An equipment checklist so that monitors can be sure they have all the necessary items for safe and effective data collection (Appendix E).
3. A data sheet for use by monitors to record data in the field. The sheet will reduce errors and will ensure consistency in data collection from one sampling event to the next (Appendix F).
4. A species identification key, which can be used to determine the Orders of aquatic macroinvertebrates in the field. The key will serve as an engaging instructional tool that introduces concepts relating to invertebrate anatomy and taxonomy, while highlighting the influence of water quality on biodiversity (Appendix G).
5. A database of stream monitoring data. This database was populated with data collected during the baseline assessment of stream quality and organized in such a way that it can be easily updated following subsequent monitoring events and as additional monitoring locations are established (examples of how the database is organized can be found in Appendix H)

Methods

The stream monitoring program was developed through a review of stream ecology literature, best practices and lessons-learned from similar stream monitoring programs, and in consultation with the BCEEC and local partners. Monitoring protocols were refined following a period of field-testing at

baseline monitoring locations throughout the Bijagual River watershed. The final version of the stream monitoring protocol is organized into three sections: “Water Quality Sampling”, “Biotic Survey”, and “Physical Habitat Observations”. Methods for developing the final monitoring protocols, data sheet, equipment checklist, and aquatic macroinvertebrate taxonomic key follow. These items can be found in Appendices D-G.

Developing Initial Stream Monitoring Protocols

Preliminary stages of developing a stream monitoring protocol focused on reviewing an analogous “Adopt a Stream” program, developed 20 years ago and implemented over the course of a single year in the nearby town of Puerto Viejo de Sarapiquí (Laidlaw, 1996). This case study indicated the types of water quality parameters that can be used as indicators of stream quality in a tropical rainforest ecosystem. In addition, protocols used by the Huron River Watershed Council (HRWC) to assess stream habitat quality in Ann Arbor, MI were adapted for implementation in the Bijagual watershed program (HRWC, 2018). Early conversations with the BCEEC revealed that the organization owned a YSI Professional Plus meter[1] with accessory probes that measured temperature, dissolved oxygen, conductivity, pH, and nitrate concentration. In addition, methods for measuring turbidity and phosphate concentrations were incorporated into the protocols to create a more holistic evaluation of water quality. Thus, the initial protocols found in the “Water Quality Sampling” and “Physical Habitat Observations” portions of the initial stream monitoring protocols were developed by incorporating effective components of analogous stream monitoring programs, improving upon areas deemed to be unsuccessful, and integrating technology and resources that were available through the client.

In addition to the “Water Quality Sampling” and “Physical Habitat Observations” sections discussed above, the Bijagual project also incorporates surveys of aquatic macroinvertebrates. Unlike chemical analysis, which only reveals in-stream conditions at the time of data collection, macroinvertebrate-based metrics reflect the longer-term, prevailing trends in water quality. Furthermore, the diverse taxa and their respective sensitivities to environmental degradation produce a spectrum of responses, which allows for a more nuanced assessment of stream ecosystem health (Resh, Norris, & Barbour, 1995). There are numerous examples of national and local governments (e.g. Australia’s Department of Water, the United States Environmental Protection Agency, and the Michigan Department of Environmental Quality (MDEQ)) incorporating aquatic macroinvertebrate surveys into their WQ monitoring programs (van Looij, 2009; Somerville & Pruitt, 2004; MDEQ, 1997). Similarly, Great Britain’s Department of the Environment developed its own Biological Monitoring Working Party (BMWP) index to assess water quality based on aquatic macroinvertebrates (Hawkes, 1998). The BMWP index assigns each taxonomic family of macroinvertebrates a value based on its pollution tolerance, and a total BMWP index score for a stream is calculated by summing the individual tolerance values of all families present within a stream. Abundance and generic diversity are not factored into the final index value. However, the Average Score per Taxon (ASPT) can be calculated by dividing the total BMWP index score by the number of taxonomic families present in the stream. The ASPT score reduces the influence of taxonomic abundance and more accurately reflects the presence or absence of sensitive taxa (Armitage, Moss, Wright, & Furse, 1983).

Because this method of assessment is relatively easy and inexpensive, it has been adapted for other countries throughout the world. However, taxonomic composition is also a function of ecological conditions, which vary significantly by region meaning that aquatic macroinvertebrate tolerances must

[1] Yellow Springs Instruments, Inc., Yellow Springs, OH, USA

be adapted specifically for an ecological region (Ruiz-Picos, Sedeño-Díaz, & López-López, 2017). By Executive Decree No. 33903-S-MINAE, Costa Rica's Ministerio de Ambiente y Energía (Ministry of Environment and Energy) adopted the BMWP index adapted for Costa Rica (BMWP-CR) as the official, government-approved method for assessing the country's water quality (Ministerio de Ambiente y Energía, 2007). The decree assigns a value (1-9) for each taxonomic family and establishes six categories of water quality based on total score. Higher values indicate higher sensitivity to environmental degradation, thus higher total scores indicate a stream of higher ecological quality. The family values and the water quality classifications are summarized in two tables found in Appendix I. The Bijagual stream monitoring protocols use the BMWP-CR to analyze macroinvertebrates collected through biotic surveys because it is employed by the Costa Rican government, and because the BMWP-CR index has been used in numerous water quality studies throughout Costa Rica (Rizo-Patrón, Kumar, Colton, Springer, & Trama, 2013).

Selecting Monitoring Locations

The initial stream monitoring protocols were field-tested at baseline monitoring locations established within the Bijagual River watershed. A process for selecting monitoring locations was developed and used to establish eleven baseline monitoring locations, which were sampled in July and August 2017 (Figure 4.1). This same site selection process detailed in the following paragraph can be used to establish additional monitoring locations in the future as landowners willing to allow stream access on their private property are identified.

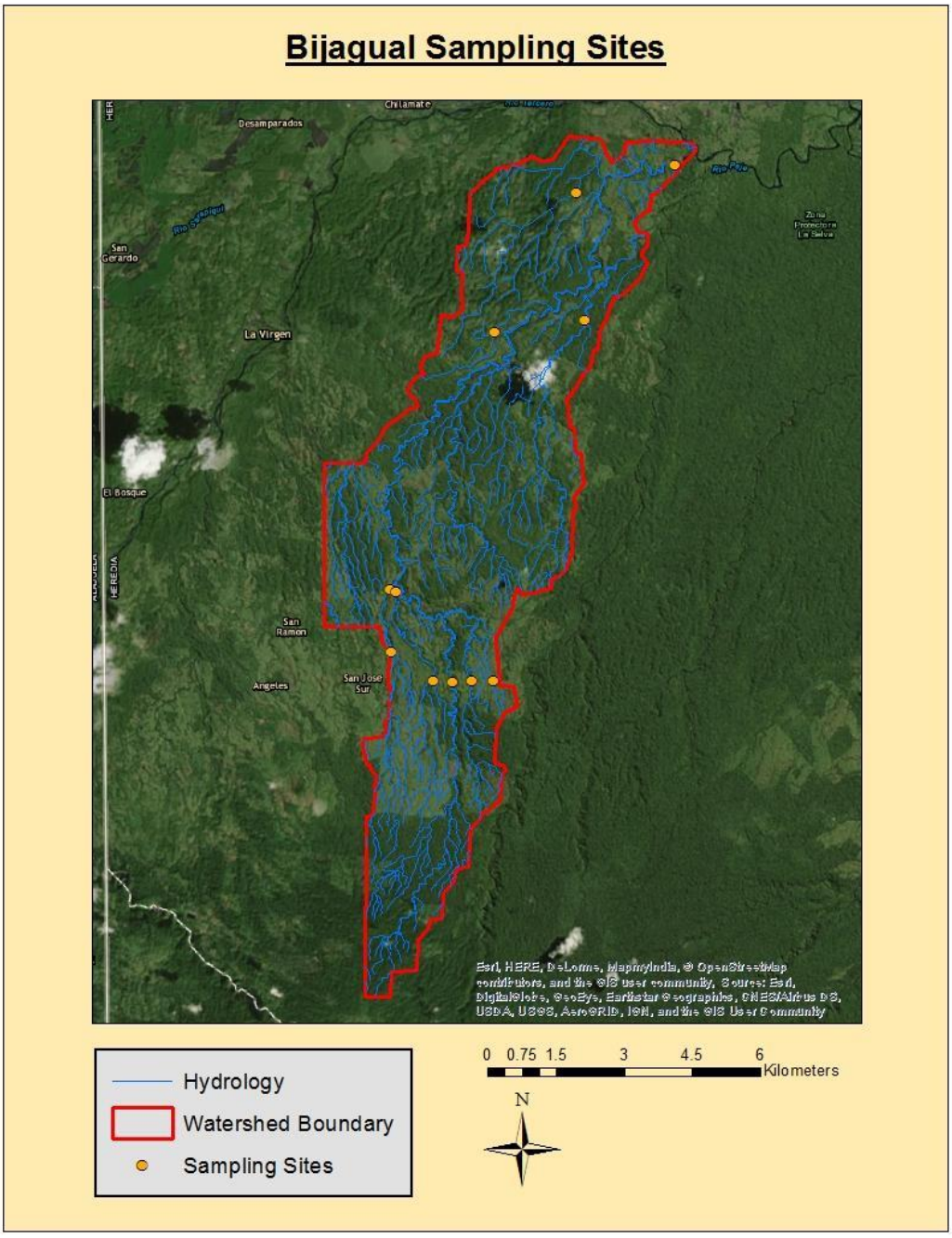

Figure 4.1: Baseline stream monitoring locations.

Two key considerations were taken into account when selecting locations for stream monitoring. First, to facilitate the engagement of a wide range of volunteers in the monitoring program, the monitoring locations must be easily accessible by car or by a relatively short walk from a well-maintained road. Proximity to maneuverable roads is essential to ease the burden of transporting equipment to and from the site. In other words, long overland hikes were avoided to ensure that volunteers can safely and easily reach the site and to promote a more inclusive and enjoyable monitoring program. The second consideration was stream size. The streams must be large enough to ensure that there is continuous

baseflow throughout the dry season and that they contain most, if not all, of the macrohabitats that could potentially support macroinvertebrate populations. Ideally, the stream should have at least one riffle-pool complex as well as vegetated banks with submerged roots and aquatic vegetation, leaf packs, and foam. On the other hand, the streams cannot be so large that monitors are unable to easily and safely wade across.

With these two considerations in mind, potential stream monitoring locations were identified in a desktop survey using Google Earth prior to arriving in the Bijagual River watershed. Although the watershed's road network is clearly visible on Google Earth, identifying streams from aerial imagery proved challenging because they were often concealed by dense tree canopy cover. As a result, the desktop survey incorporated a geospatial stream data layer produced by the United States Geological Survey (USGS), which mapped the locations of the Bijagual River and its tributaries (USGS, 2005). The Bijagual River watershed could them be remotely surveyed to visually identify potential stream monitoring locations.

This survey method identified a somewhat extensive public road network traversing the watershed. However, large swaths of the watershed remained inaccessible by car, particularly areas contained within expansive farms as well as the area protected by Braulio Carrillo National Park. Furthermore, while the Costa Rican government has jurisdiction over waterways (i.e. streams are public property even if they flow through private property), much of the land within the Bijagual River watershed is privately owned. This means that accessing public streams in an expedient manner is often only possible by traversing private property, which requires permission from the landowner. For this reason, it was decided that until permission is solicited from landowners, stream monitoring will be limited to areas where public roads crossed streams so that monitors can easily enter a stream without trespassing onto private property. An additional advantage of sampling these areas is that the locations will be accessible in perpetuity because there is no risk of a landowner rescinding permission to access. The desktop survey method identified twelve potential monitoring locations at the intersection of public roads and mapped streams (Figure 4.2). The geographic coordinates of these locations were recorded so that the suitability and location of the streams could later be verified on the ground.

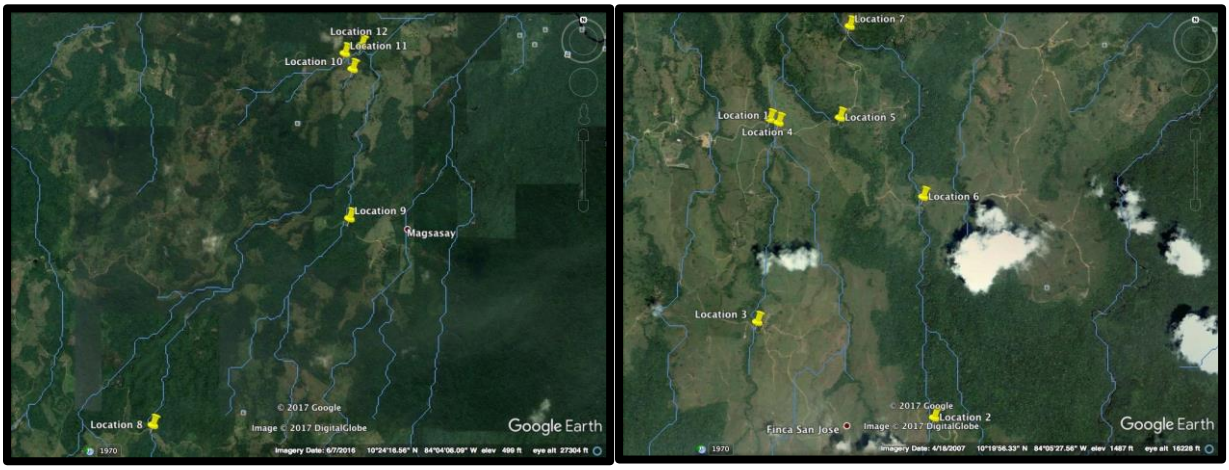

Figure 4.2: Stream crossing locations identified in initial desktop survey.

Upon arrival to the Bijagual River watershed, field mapping of the region's road network commenced, which included mapping stream crossings. The on-the-ground survey revealed that several of the stream

crossings identified during the initial desktop evaluation did not exist due to inaccuracies in the stream geospatial layer. Conversely, additional stream crossings were identified on-the-ground that did not appear in the initial desktop survey. Each of the 36 stream crossings ultimately mapped in the watershed was evaluated against the two criteria outlined above (i.e. easily accessible from the road and of sufficient size to maintain perennial baseflow and to contain a range of macrohabitats while still being wadeable) (Figure 4.3).

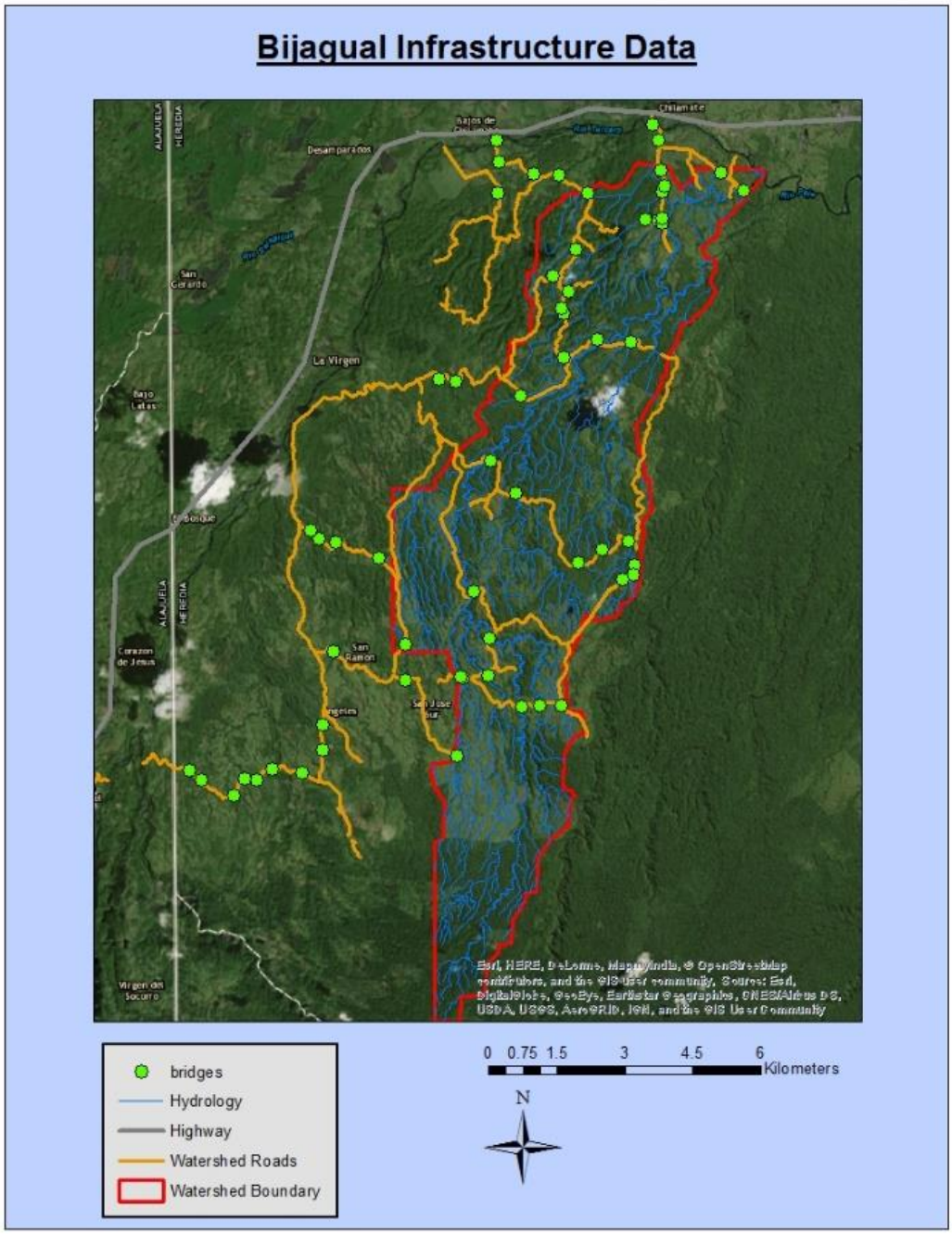

Figure 4.3: Stream crossings mapped in the Bijagual River watershed.

Of these 36 stream crossings, nine were deemed suitable as baseline monitoring locations. In addition, baseline monitoring data was also collected at two sites located within the BER, which were easily accessible by short hikes. Thus, a total of eleven sites located throughout the watershed were selected, all of which were sampled in July and August 2017 (see Figure 4.1).

Field-Testing and Revising the Initial Monitoring Protocols

With the eleven baseline monitoring locations identified (see Figure 4.1), the initial stream monitoring protocols were revised following a two-step process of consultation with the BCEEC and local partners and field-testing. This process served the dual purpose of identifying shortcomings in the initial monitoring protocols and collecting baseline data on stream ecosystem quality in the Bijagual River watershed. Revising the initial stream monitoring protocols was crucial to the development of a stream monitoring program that is not only scientifically robust, but also more reflective of the goals of the client and partner organizations and manageable for the client in the long-term.

Discussions with the client, Paul Foster of the BCEEC, as well as with local partners who will be assisting in the implementation of the stream monitoring program, namely Socorro Avila Araya of the Organization for Tropical Studies, were carried out to determine the staff and resources available to implement various portions of the stream monitoring program and to incorporate additional expertise. As an aquatic macroinvertebrate taxonomist, Sra. Avila has considerable expertise in conducting aquatic surveys and identifying macroinvertebrate taxa. In addition to this technical expertise, Sra. Avila also has access to La Selva's laboratories and equipment, which are useful in the identification of macroinvertebrate taxa. Sra. Avila agreed to provide technical and logistical support for the stream monitoring program, which allowed for an expansion of the "Biotic Survey" portion of the initial protocols. Initially, the monitoring protocols called for identifying aquatic macroinvertebrates to the Family taxonomic level only, as this is the specificity required for analysis using the BMWP-CR. Sra. Avila had both the capacity and the desire to identify aquatic macroinvertebrates to a higher level of specificity for her personal research. Therefore, the revised monitoring protocols suggest identifying aquatic macroinvertebrates, "at least to Family or to a more specific taxonomic level if possible". While identifying to more specific taxonomic levels provides a more detailed evaluation of stream quality, only Family-level data may be analyzed using the BMWP-CR.

Furthermore, the initial protocols for collecting aquatic macroinvertebrates were taken directly from Stein, Springer, and Kohlmann (2008), whereby any and all available macrohabitats within the stream were sampled for a standardized 10 minutes. However, in light of Sra. Avila's experience with macroinvertebrate sampling and her own research goals, the Stein et al. (2008) protocols were adapted to standardize for macrohabitats rather than for time. Thus, the final version of the protocols calls for sampling six different macrohabitats in every stream in whatever amount of time it takes to do so (with the exception of riffles, which are sampled for one minute). Incorporating Sra. Avila's considerable experience with macroinvertebrate sampling ensures that the methods for the biotic surveys are robust and will provide a more accurate characterization of the health of stream ecosystems. Both of these revisions are reflective of the goals of the stream monitoring program's local partners, and the more detailed data will provide a clearer characterization of the stream ecology in the Bijagual River watershed.

Field-testing the initial protocols at the eleven baseline monitoring locations revealed that the initial sampling process was too time-consuming. Implementing the protocols in their original form would

have required up to six hours of effort in the field per monitoring location. Such a time commitment is likely unrealistic given that this is a volunteer-based program. To shorten the length of time that monitors spend in the field, the "Physical Habitat Observations" portion of the protocols was significantly scaled back. Specifically, to quantify bank erosion and stream incision, the initial protocols called for measuring the stream depth at 10 equidistant locations along a transect. Monitors were also asked to estimate stream flow through a series of calculations based on these measurements. Rather than quantitatively measuring these two stream characteristics, evidence of bank erosion is visually identified (i.e. steep, vertical, or undercut banks, exposed tree roots, sparsely vegetated banks, etc.), and monitors characterize the stream's substrate (i.e. the approximate ratio of cobble to pebbles to sand and the percent of cobble embeddedness). In addition, volunteers comment qualitatively on the amount of flow currently in the stream and if there is evidence that stream has recently overflowed its banks. These methods will still identify issues of bank erosion and sedimentation without requiring as much time.

The process of field-testing the protocols also highlighted the substantial amount of time required to identify aquatic macroinvertebrates. The high level of biodiversity observed in several streams coupled with Sra. Avila's desire to identify macroinvertebrates to the most specific taxonomic level possible (rather than to Family only) meant that the identification process required between two and four days for each individual stream. In light of this, the "Biotic Survey" portion of the protocols was also revised to reduce the frequency of biotic surveys from four times a year to twice a year. Again, the stream monitoring program incorporates the Family-based BMWP-CR index to assess stream quality. As such, identifying macroinvertebrates to lower taxonomic levels (i.e. Genus and Species), is not required, although it does provide additional information relating to stream ecosystem health.

The final version of the stream monitoring protocols can be found in Appendix D.

Developing Additional Stream Monitoring Program Materials

In addition to the stream monitoring protocols, an equipment checklist, data sheet, and aquatic macroinvertebrate taxonomic key were created for use by monitors in the field. The equipment checklist and data sheet were developed to be used in conjunction with the stream monitoring protocols, while the taxonomic key is a supplementary item that is not essential to the stream monitoring program. Collectively, these materials are designed to promote safe, effective, and accurate data collection in the field and to enhance the educational value of the experience.

The equipment checklist clearly identifies all of the items required to safely and effectively implement the stream monitoring protocols. It also recommends additional items that volunteer monitors may wish to have on-hand. As such, the equipment checklist is most effective if consulted prior to visiting the monitoring site, when the volunteers, client, and local partners are preparing for a monitoring event. The equipment checklist can be found in Appendix E.

In order to reduce data collection errors and to ensure that the same types of data are collected at all monitoring locations, a data sheet was developed for recording data in the field. The sheet has a combination of fill in the blank, short response, and check boxes as well as space for monitors to sketch pictures and record longer written observations. In addition, brief versions of the data collection protocols are included and more advanced stream monitoring concepts are explained with visuals and/or definitions. The data sheet can be found in Appendix F.

Identification of aquatic macroinvertebrates to the most specific taxonomic level possible per the stream monitoring protocols requires laboratory equipment and significant taxonomic expertise. As such, it is an activity that must be completed in a laboratory and is largely inaccessible for volunteer monitors in the field. However, handling and closely observing macroinvertebrates is a fun, engaging, and educationally enriching activity for volunteers. Therefore, a simple aquatic macroinvertebrate taxonomic key was developed for use in the field to more directly engage volunteers, introduce concepts in macroinvertebrate anatomy and taxonomy, and highlight biodiversity (or lack thereof) in the stream. The key, which was adapted from two existing taxonomic keys, allows for the identification of specimens to Order based on anatomical features that can easily be identified with only a hand lens. The taxonomic key can be found in Appendix G.

Baseline Stream Monitoring Results

Each of the eleven suitable stream monitoring locations identified within the Bijagual River watershed were sampled in July and August 2017 (see Figure 4.1). The baseline monitoring data was organized in a database, which can be easily updated by the BCEEC following subsequent monitoring events and as additional monitoring locations are established (examples of how the database is organized can be found in Appendix H). Because the stream monitoring protocols were revised as the baseline data was collected, sampling methods varied somewhat between streams. Specifically, the "Physical Habitat Observations" section of the protocols was developed much later in the baseline data collection process. As a result, this data is only available for Stream 10 and Stream 11. However, the "Water Quality Sampling" and "Biotic Survey" sections of the monitoring protocols were revised prior to collecting baseline data. Thus, WQ and aquatic macroinvertebrate data are available for all eleven streams. The baseline monitoring data are summarized below, organized into the same three sections established in the final version of the stream monitoring protocols.

Water Quality Sampling

Results of the water quality sampling are presented in Table 4.1. Temperature ranged from 21.7°C (Stream 4) to 25.9°C (Stream 1). The lowest dissolved oxygen concentration was 4.84 mg/L (Stream 1), while the highest dissolved oxygen concentration was 7.79 mg/L (Stream 10). Conductivity varied widely, with the lowest conductivity measured in Stream 6 (15.3 µS/cm) and the highest measured in Stream 4 (76.8 µS/cm). Similarly, pH was lowest in Stream 6 (5.34) and highest in Stream 4 (7.62). Nitrate concentrations ranged from 0.02 mg/L (Stream 11) to 0.31 mg/L (Stream 2). For unknown reasons, a stable measurement of nitrate concentration could not be collected in Stream 5. Phosphate concentration was 0.04 mg/l in all streams with the exception of Streams 6, 7, and 8, in which the phosphate concentration was 0.02 mg/l.

Stream	Temperature (°C)	Dissolved Oxygen (mg/L)	Conductivity (µS/cm)	pH	Nitrate (mg/L)	Phosphate (mg/L)
1	25.9	4.84	37.4	6.48	0.14	0.04
2	24.6	6.86	50.1	7.07	0.31	0.04
3	24.3	7.55	27.6	7.22	0.11	0.04
4	21.7	7.65	76.8	7.62	0.1	0.04
5	22.7	7.16	31.6	7.1	*	0.04
6	23.9	5.06	15.3	5.34	0.10	0.02
7	23.4	7.66	22.5	6.73	0.04	0.02
8	22	7.9	31.5	7.46	0.06	0.02
9	24.6	7.06	21.5	6.06	0.07	0.04
10	22.6	7.79	60.2	7.51	0.06	0.04
11	23.9	7.78	27.9	7.22	0.02	0.04

*Table 4.1: Stream water quality data. *Nitrate concentration could not be determined in Stream 5.*

Finally, at each of the eleven streams, the Secchi disk remained visible when the Secchi tube was completely filled with stream water, meaning that turbidity was too low to be measured using this technique.

Biotic Survey

Using the BMWP-CR index, results from the biotic surveys indicate that all but two of the streams (Stream 1 and Stream 6) are categorized as "Blue", or the highest level of stream quality. Index scores among all the "Blue" streams ranged from Stream 9 (118) to Stream 5 (186). Stream 1 classified "Green" quality stream compared to Stream 6, which is of lower quality ("Yellow"). After averaging each BMWP-CR index score across the number of taxa observed in a particular stream, Stream 5 had the highest ASPT (5.81), while Stream 6 had the lowest (4.23). Results from the biotic surveys are presented in Table 4.2.

Stream	BMWP-CR Index Score	ASPT	Quality Level
1	70	4.38	Green
2	163	5.62	Blue
3	150	5.36	Blue
4	136	5.67	Blue
5	186	5.81	Blue
6	55	4.23	Yellow
7	146	5.62	Blue
8	127	5.29	Blue
9	118	5.62	Blue
10	145	5.58	Blue
11	166	5.53	Blue

Table 4.2: Biotic survey data.

Discussion

The stream monitoring program is one of four distinct, yet interrelated components of a broader project that seeks to improve habitat connectivity between disparate forest patches by re-establishing and protecting forests along riparian corridors found on privately-owned land. The overall objective of the stream monitoring program is both to promote community engagement in the monitoring and management of the Bijagual River watershed and to establish a mechanism for evaluating the impacts of future riparian zone restoration and conservation programs. To that end, performing a baseline assessment of stream ecosystem quality was critical to the development of a long-term stream monitoring program that is both scientifically robust and engaging for the local community. The baseline stream assessment provided an opportunity to field-test and revise the stream monitoring protocols and to establish a baseline for identifying changes in stream ecosystems as future monitoring data is collected. What follows is a discussion of the stream monitoring protocol as contextualized through the baseline assessment results.

The baseline monitoring data seems to suggest that the methods for measuring phosphate concentrations may not result in accurate or precise data. For one, comparing the water sample color to the color index card is somewhat subjective. In addition, the color of the water sample can appear different depending on if the monitor is standing in a shaded area or in direct sunlight. It is also not a particularly sensitive method of measuring phosphate concentration (there only four possible readings are 0 mg/L, 0.1 mg/L, 0.2 mg/L, and 0.4 mg/L), reducing the precision of the results. Finally, studies in nearby La Selva have shown that phosphate concentrations can naturally attain concentrations of 0.4 mg/L due to geothermal inputs from surrounding volcanoes (Pringle, 1991). This concentration pushes the boundary of what can be accurately measured using the methods outlined in the Bijagual stream monitoring protocols.

Using the BMWP-CR index to evaluate stream quality suggested that the streams within the Bijagual River watershed were mostly of the highest possible quality. It should be noted that even though specimens collected as part of these surveys were frequently identified to more specific taxonomic levels, only Family data was used to assess stream quality per the tolerances established in the BMWP-CR. In other words, Genera richness did not influence the BMWP-CR index scores calculated in this assessment. However, sampling effort likely did contribute to the high BMWP-CR index scores. The Costa Rican government's "Executive Decree No. 33903-S-MINAE" outlines methodologies for conducting macroinvertebrate surveys, which specify equipment, techniques, and intensities that vary depending on the physical characteristics of the stream (i.e. stream width and depth) (Ministerio de Ambiente y Energía, Propuesta de Ley del Recurso Hídrico, 2007). Rather than following the government's sampling methodologies, the "Biotic Survey" section of the stream monitoring protocols outlines different macroinvertebrate sampling methods adapted from Stein et al. 2008 in collaboration with Sra. Avila of La Selva while still using the established BMWP-CR tolerance values. This was done in an effort to more closely align the stream monitoring program with Sra. Avila's own research priorities. It is therefore possible that the BMWP-CR scores are inflated because the macroinvertebrate sampling protocols used in this stream monitoring program are more intense than the government's proposed methods.

In fact, previous studies conducted in Costa Rica have shown that BMWP-CR index scores can vary depending on the sampling equipment, method, and intensity (Stein et al. 2008, Gutiérrez-Fonseca &

Lorion, 2014, Maue & Springer, 2016). Various survey methods produce varying Family richness depending on the macrohabitats sampled and time spent sampling. Gutiérrez-Fonseca and Lorion (2014) demonstrate that BMWP-CR index scores can vary with sampling effort to such an extent that different water quality classifications can be assigned to a single stream. Because there are advantages and limitations of each sampling methodology, Stein et al. (2008) suggest that the assessment of water quality is likely more accurate when combining multiple methods, as the protocols used in the Bijagual stream monitoring program does. With these limitations in mind, using the BMWP-CR index remains a valuable mechanism for analyzing macroinvertebrate data collected during biotic surveys, and it will likely prove useful in quantifying changes in macroinvertebrate community assemblages through time. This is especially true, provided that the same survey methods established in this stream monitoring program are followed in subsequent years. As long as the survey methods remain constant, outliers in index scores can be attributed to sampling error or problems within the stream.

In summary, ecological conditions can vary along a gradient between and within streams in response to numerous variables, including as a result of variations in land cover and riparian forest conservation programs. In an effort to understand how these two variables in particular affect stream quality in the Bijagual River watershed, the standardized sampling protocols established in this stream monitoring program allow for direct comparison between streams. Perhaps more importantly, the Bijagual stream monitoring program provides a useful mechanism for evaluating changes in an individual stream over time as riparian buffers are restored, provided that data is collected over the long-term and compared to baseline conditions.

Limitations

In light of the methods used in the development of the stream monitoring protocols and additional materials, the results of the baseline assessment, and the current status of the overall stream monitoring program, three limitations must be considered.

The initial baseline assessment conducted in July and August 2017 was limited in that stream selection was based primarily on two considerations: accessibility and stream size as it related to perennial baseflow, the presence of macrohabitats, and wadeability. This limited our baseline monitoring efforts to areas where public roads crossed streams that contained at least one riffle-pool complex as well as vegetated banks with submerged roots and aquatic vegetation, leaf packs, and foam. Thus, the establishment of monitoring locations did not explicitly take land cover into account. Similarly, at the time of the baseline assessment, there was little information available regarding the level of interest among landowners in reforestation projects along streams on their property. Given that one of the goals of the monitoring program is to track changes in stream quality as the reforestation programs are implemented, a more informative program would have captured a variety of land cover classifications as well as areas upstream and downstream of properties with owners interested in riparian forest conservation projects.

Because the protocols were revised and adapted as the baseline assessment was being conducted, not all of the parameters were collected at every stream monitoring location. Specifically, water chemistry data and macroinvertebrate samples were collected at all eleven streams, but the qualitative habitat assessments (i.e. visual evidence of erosion, characterization of stream substrate, and identification of land cover on each side of the stream) were implemented much later in the process (i.e. only Stream 10 and Stream 11). Although all of the parameters for evaluating stream quality outlined in the final stream

monitoring protocols were not collected at every monitoring location, the final version of the stream monitoring protocols was successfully field tested at the final two streams and will be implemented in all future monitoring events. Finally, the data sheet, equipment checklist, and aquatic macroinvertebrate taxonomic key were developed after baseline monitoring was completed. As such, these additional monitoring program materials were not field-tested. However, this is not expected to significantly undermine the stream monitoring program because these materials were adapted from the final version of the protocols and because the BCEEC has the ability to make revisions to these documents if necessary.

Finally, the stream monitoring program is limited because it was not developed in collaboration with Bijagual River watershed residents. Given the background of the BCEEC, OTS, and the members of this project team, the program evaluates stream ecosystems through a scientific lens that is inherently biased toward the Western positivist theory of understanding the natural world. In other words, it does not incorporate other sources of knowledge such as traditional ecological knowledge. Reed (2008), in his review of research on stakeholder participation in environmental management, notes that in environmental management programs, scientific knowledge and local understandings should be brought together. By uniting these two different types of knowledge, practitioners are better prepared "to produce more relevant and effective environmental policy and practice" (Reed, 2008, p. 2425). Therefore, a more robust stream monitoring program would have co-produced knowledge of ecological conditions by including other metrics of stream ecosystem quality that are potentially more relevant for local communities.

Recommendations for Future Work

The overall objective of this portion of the project was to establish a stream monitoring program designed to both promote community engagement in the monitoring and management of the Bijagual River watershed and to evaluate the impacts of grant-funded reforestation and forest conservation programs in riparian corridors. In order to address the limitations presented in the previous section and to more successfully fulfill the stream monitoring program's two objectives, the following recommendations for future work are presented in no particular order:

1. Expand stream monitoring locations onto private property
2. Develop approaches to sharing stream monitoring data with the community
3. Translate stream monitoring protocols and equipment checklist; consider options for field use
4. Institute aquatic macroinvertebrate "Identification Days"
5. Secure long-term funding and support
6. Develop a metric to quantify community engagement
7. Incorporate local and traditional knowledge

Each of the above recommendations is discussed in more detail in the sections that follow.

Expand Stream Monitoring Locations onto Private Property

With the stream monitoring protocols established, the BCEEC should expand monitoring locations onto private land to more effectively capture variability in land cover and quantify the impacts of riparian reforestation and forest protection programs on stream ecosystems. Such an expansion will depend on gathering additional information, in particular the identification of landowners willing to permit access to streams on their private property and landowners committed to establishing and protecting riparian

buffers. Ideally, permanent monitoring locations should be established upstream and downstream of areas where these riparian restoration and conservation programs are implemented. If such locations are easily accessible, the client might also consider establishing several control monitoring locations in the headwaters of the Bijagual River watershed, which reside within the relatively undisturbed and permanently protected confines of the Braulio Carrillo National Park.

However, it should be noted that implementation of the stream monitoring program requires considerable time, particularly with respect to macroinvertebrate identification. A conservative estimate of the time it takes to identify macroinvertebrates to the most specific taxonomic level possible is three days for every one day in the field (i.e. approximately four days are required to collect and process monitoring data for one site). Therefore, it is likely infeasible to adequately monitor more than twenty locations within the watershed given the staff resources currently available. In light of this consideration, some of the monitoring locations established in Summer 2017 may be abandoned in favor of other locations that will better capture the effects of land cover and the establishment and protection of riparian buffers. In addition, aquatic macroinvertebrate identification efforts may be scaled-back such that specimens are identified to Family only, rather than to Genus or Species. By reducing the amount of time spent identifying macroinvertebrates, the BCEEC may be able to manage more monitoring locations.

Share Stream Monitoring Data with the Community

To further the BCEEC's goal of promoting community engagement in conservation and environmental education, it is important that results gathered from the stream monitoring program be made available to volunteers and the broader Bijagual River watershed community. Presenting monitoring data provides an opportunity to receive feedback from other experts and can help secure additional program funding (Karr, 2006). Communicating the results of monitoring programs also promotes buy-in among the local community, which in turn encourages continued volunteer engagement and boosts recruitment of new monitors (Mckay & Johnson, 2017). In other words, disseminating the results of the stream monitoring program may help recruit new volunteer stream monitors and may encourage landowners to implement reforestation and forest protection measures on their property.

Information access is frequently cited as one of the major challenges for community-based monitoring programs (Milne et al., 2006). To counteract this, there are several platforms through which the stream monitoring data can be shared:

- Internet-based programs exist, such as CitSci.org, where data can be made available to the public. These databases are easily searchable so that residents of the Bijagual River watershed can find data from the monitoring location closest to them. In addition, the paper data sheet provided as part of this project can be adapted into a digital form for use in conjunction with an online database. In this way, data can be recorded on smartphones or tablets and saved directly into an online database.
- The BCEEC may choose to present findings at schools or at community events such as the Environmental Fair at La Selva. Given that it is potentially challenging to effectively communicate environmental data, this discussion-based platform for sharing information has the added benefit of providing opportunities for community members to ask questions.

However, to enhance engagement and education, the data must also be presented in a manner that is accessible, using simple and concise language (Ortega-Álvarez and Sánchez-González, 2015). Because the raw data gathered as part of the stream monitoring program may be meaningless for many members of the community, it needs to be summarized and contextualized to make the information easier to understand and therefore more meaningful. For example, the Huron River Watershed Council creates "Fact Sheets" for many of its monitoring sites. These user-friendly documents provide an overall rating of stream quality, summarize monitoring information collected at the site, and track changes in the site over time (examples can be found at https://www.hrwc.org/adopt/factsheets). Finally, if such information-sharing events or measures are put in place, the BCEEC should be mindful of how information is communicated given that different members of the community will have differential views of forest conservation and water quality. In general, it is important to keep the message hopeful (e.g. "restoration of degraded streams is possible so that they look more like the healthier streams").

Translate Stream Monitoring Protocols, Data Sheet, and Equipment Checklist; Consider Options for Field Use

Currently, the stream monitoring protocols, data sheet, and equipment checklist are in English only, and each of these items should be translated into Spanish. This would allow the BCEEC to distribute these materials to volunteers prior to monitoring events, so that they can familiarize themselves with the monitoring process in advance of data collection. It may also prove beneficial to have a Spanish version of the protocols on-hand for reference while in the field.

The protocols, equipment checklist, and aquatic macroinvertebrate taxonomic key should be laminated. Alternatively, if all-weather printer paper is available (e.g. Rite in the Rain©) it can be used in a standard copier or laser printer (i.e. NOT inkjet printers) to create more durable versions of these materials for use in the field. Not only is this material waterproof and resistant to tearing, it has the added benefit of allowing monitors to directly write on the sheets, which may be a particularly useful option for the data sheet.

Institute Aquatic Macroinvertebrate "Identification Days"

In addition to using the aquatic macroinvertebrate taxonomic key (Appendix G) to identify insects to Order in the field, volunteers may also take part in aquatic macroinvertebrate "Identification Days" in the lab. During these events, volunteers can use microscopes to identify macroinvertebrates to more specific taxonomic levels than is possible in the field. Even with limited knowledge of entomology and macroinvertebrate taxonomy, volunteers can assist in visually sorting macroinvertebrates by Order, at which point the BCEEC, OTS staff, or someone more familiar with taxonomy can assist in identifying the specimens to Family (for analysis by the BMWP-CR) or a more specific taxonomic level if possible. In this way, volunteers have the opportunity to (1) gain experience using laboratory equipment, such as microscopes, (2) to observe specimens in more detail than is possible with hand lenses in the field, (3) to learn about the identifying characteristics of various taxonomic groups. In addition, "Identification Days" may help significantly reduce the time it takes for the BCEEC and its partner organization to identify macroinvertebrates.

Secure Long-Term Funding and Support

Orlando Vargas, of the Organization for Tropical Studies, was interviewed on July 18, 2018 at La Selva Biological Station as part of an assessment of a previous stream monitoring program in the region (Vargas, Personal Communication, July 18, 2018). Mr. Vargas was involved in the implementation of an

"Adopt-A-Stream" program in Puerto Viejo de Sarapiquí, Heredia Province, Costa Rica in 1995. He, along with the educational staff at La Selva, provided technical and logistical support for the program. The conversation with Mr. Vargas revealed the importance of securing long-term funding and support for the stream monitoring program. The importance of financial and non-monetary resources is also reflected in the literature. In evaluations of citizen science-based monitoring programs, reliable long-term funding is consistently identified as a main constraint (Danielsen et al., 2003; Gallo & Waitt, 2011; Ortega-Álvarez & Sánchez-González, 2015). Although the Bijagual stream monitoring program was specifically designed to minimize cost, a reliable source of continued financing will be required. Future expenses can be expected including the transportation cost of visiting monitoring locations, supplies and equipment (e.g. alcohol to preserve and transport macroinvertebrates, calibration solutions for the YSI meter, maintaining equipment and if needed replacing damaged or lost equipment, etc.), and labor costs for technical and logistical support for the program.

Reliable resources and support for monitoring programs can be assured through partnerships and collaborations with a range of institutions (Latimore & Steen, 2014). The BCEEC is deeply embedded in the Bijagual River watershed and is committed to the stream monitoring program in the long-term. Furthermore, the BCEEC has a strong working relationship with OTS staff at La Selva Biological Station, which provides technical and logistical support for this stream monitoring program. That being said, the BCEEC may wish to consider acquiring its own laboratory equipment and expertise to continue the identification of macroinvertebrates to Family in the event that La Selva no longer supports the stream monitoring program. In addition, fostering partnerships with local institutions (e.g. schools, churches, community groups, etc.) may be required to expand and secure the base of volunteer support.

Develop a Metric to Quantify Community Engagement

Given that one of the two objectives of the stream monitoring program was to promote community engagement in the monitoring and management of the Bijagual River watershed, the BCEEC should consider developing a metric to objectively quantify community engagement. Currently there is no mechanism in place to evaluate if the stream monitoring program is achieving its community engagement objective. Potential options for assessing community engagement include:

- Developing and maintaining a volunteer stream monitor database. This database would record basic information such as the number of volunteers, how frequently they participate in the stream monitoring program, how long they have participated in the program, etc.
- Conducting social science surveys of volunteers to assess changes in perceptions or attitudes concerning forest conservation and water quality, understanding of environmental conditions within the watershed, etc.

Developing a method of evaluating the degree to which the stream monitoring program is promoting community engagement will allow the BCEEC to develop strategies to involve a wider range of Bijagual River watershed residents.

Incorporate Local and Traditional Knowledge

Given that the stream monitoring program was developed with little input from the local community, the BCEEC should explore potential metrics for evaluating stream quality that rely on local and traditional ecological knowledge. This form of institutional knowledge is acquired over long periods of time by local people in direct contact with the environment (USFWS, 2011). It is perhaps the case that

residents of the Bijagual River watershed have substantial local knowledge relating to the ecological dynamics within the watershed. In addition, long-term residents may have a strong institutional memory of stream quality, including knowledge of historic population sizes and distributions and other in-stream conditions, which can be used to inform restoration goals. Through surveys of participants in community-based monitoring programs, Mckay and Johnson (2017) found that reflecting the interests and values of the community by incorporating local knowledge can be critical to the success of such programs. Furthermore, incorporating these additional forms of knowledge has been shown to enhance monitors' self-confidence and to foster an appreciation for local knowledge (Danielsen et al., 2007). Collecting and incorporating local knowledge will require surveying Bijagual River watershed residents to identify local metrics for assessing stream health and to determine parameters that are more relevant for the community. Incorporating local and traditional knowledge may make the program more credible and meaningful in the eyes of local residents, which in turn may ensure continued participation in the stream monitoring program. In short, local and traditional knowledge can complement the methods contained in this stream monitoring program, thereby providing a more comprehensive evaluation of stream quality.

Section 5: Interpretive Trail Signage Design

The fourth and final component of this project encompassed designing educational and directional signage for a network of interpretive trails located within the Bijagual Ecological Reserve (BER). The system of signs was designed around two objectives. The first was to increase public awareness of the ecological diversity of the Bijagual River watershed and the intrinsic value of restoring and conserving it. The second objective was to make the existing trail network safer and easier to use. In addition to directional signs that indicate shortcuts, distances to the trailhead, and boundaries of the BER, the signage system also includes educational signs with information regarding the local flora and fauna, land use history, and ongoing conservation efforts within the watershed. As such, the signage system advances the BCEEC's mission to provide local residents as well as outside visitors with engaging opportunities for environmental education.

Interpretive signs are frequently integrated within self-guided trails. While these signs can be used to draw attention to specific stationary features found along the trailside (e.g. plants, geologic features, cultural artifacts, etc.), they might also highlight dynamic components (e.g. wildlife) as well as convey information about the history and processes that have shaped the ecosystem. (United States Department of Agriculture, 2013) As such, an interpretive trail network is an informal yet engaging educational opportunity that provides visitors access to the Reserve's unique plants and animals and conveys important information about the cultural and natural history that has shaped the surrounding ecosystem. (Brusatte, 2018) It is likely that the members of the local community, foreign students, and eco-tourists who visit the BER will vary in terms of their knowledge, age, nationality, and interests. However, an effectively designed interpretive signage system can share the land's story with each of these diverse groups by allowing easier navigation while enhancing understanding of the Reserve's ecology and promoting conservation of nature and wildlife. In other words, an effective self-guided trail, "draws in the visitor, captures a curiosity, develops an interest, and leaves the visitor with an undeniable sense of place and a little bit more knowledge than he or she had before" (Westrup, 2002).

An extensive and well-maintained trail network has been established within the BER. Currently, the trails are marked with simple, green plastic signs topped with small white cards indicating the trail name and distance to the trailhead (Figure 5.1). In addition, painted wooden boards demark the boundaries of the Reserve to prevent visitors from trespassing onto private land. However, the lack of educational and informative signs for visitors has remained a problem. Because the existing signs do not provide comprehensive information about the Reserve, visitors frequently have questions about where they are, where they are allowed to be, and what are the features along the way. Of even greater concern, without appropriate signage, visitors may find themselves in areas of the Reserve that are not open to the public for safety reasons. Therefore, this component of the project focused on designing a signage system within the BER to improve the visitor experience, increase awareness of the importance of environmental conservation, and to ensure safety.

Figure 5.1: Existing signs within the Bijagual Ecological Reserve.

To achieve this objective, interpretive signs were developed to provide ecological information about the BER as well as trail maps, distances between features of interest, and emergency information. The signage system was designed in consultation with the client and based on case studies from similar nature reserves in the Sarapiquí region. Principles of effective sign design were used to ensure a user-friendly network of signs.

Deliverables

As discussed with the client, the deliverable products generated from this portion of the project include:

- A list of suggested photographs to incorporate in the interpretive signs. The list is organized by sign type and content and indicates the specific features (e.g. animals, plants, etc.) the client needs to photograph from around the Reserve (Appendix J)
- Designs for a total of 23 signs (21 trailside interpretive signs and 2 informational trailhead signs). Graphic elements and layout are included for all 23 signs. (Appendix K)
- Text content for 20 signs (out of the total 23 signs) in English. (Appendix K)

Methods

The signage system was designed through an iterative process and in close consultation with the BCEEC. Several drafts were provided to the client, whose input was then incorporated into subsequent drafts until a final design was produced. Signs were based on design principles with the objective of creating a trail network that is educationally engaging as well as safe and easy to navigate. Presented in the following sections is a more detailed account of the methods by which the final design and content of the interpretive signage system were developed.

Initial Consultation with the BCEEC

In order to begin the process of designing an interpretive trail, the designer conducted a brief stakeholder interview with the client, BCEEC director Paul Foster. This stakeholder interview assessed the client's requirements and the status of the existing signage system and educational infrastructure within the Reserve. The designer asked the following key questions:

- What is the current signage system?
- What are the goals of the new signage system?
- How detailed should the design be for the new signage system?

Next, in order to better understand the key features of the existing trails and develop a plan for where to install signs, the designer walked three main trails with the client to record the features along the way (Figure 5.2) and choose best places to set up the signs. This step provided the designer with the opportunity to experience the trail and get first hand data about the species present on the reserve, as well as assess how tourists feel during the whole journey.

Figure 5.2: Entrance to SLP trail (left) and monkey pot (right).

As the designer walked the Reserve with the client, it became apparent that there were almost no signs in the Reserve except the simple, plastic trail markers along some of the main trails. The client expressed a desire to improve upon the current signage system by developing educational interpretive signage along three trails: Sendero La Puerta (SLP), Sendero Dendrobates (SDE), and Sendero Pozas (SPO). In addition to improving the overall educational experience of visiting the Preserve, the project also aimed to improve the safety of visitors and to prevent them from hiking off of the Reserve. Thus, in addition to the interpretive signs, a series of directional signs was also incorporated into the signage system.

The client requested that the designer focus on the physical sign designs, including graphic design and content for signs along the three main trails. The signs were requested to be in both English and Spanish. However, because the designer knows little about Spanish. The Spanish text content would be translated by client or volunteers he recruits in the future. The client and the designer agreed that the designer would not focus on trail layout or other educational approaches such as mobile app or brochures.

Iterative Design Process to Create Signs

In a typical design process, the designer begins with material such as pictures and the script content. A typical design round should include the following steps:

- Visit site and decide theme of each board
- Draft sketch
- Discuss sketch with client
- Repeat this process until the final design is approved by the client.

However, due to time limitations, the designer for this project was unable to obtain the photographic material at the beginning of this process, so the design strategy was changed as follows:

First, for the graphic design, the designer drew sketches related to each topic and placed them on the bottom of the board to indicate what the theme was. For example, for the Howler Monkey sign, the designer used an image of a forest and a monkey to emphasize the theme (Figure 5.3). Second, images related to the topic from internet were used as examples on the signs to indicate the client what would need to collect for each sign. A photographic requirement list was provided to client (Appendix J). Third, three different layouts were designed to correspond to signs with different numbers of images and descriptions. Fourth, the text content was created based on interview and fieldwork; the English version will be created by designer and the Spanish version will be translated by client in future. Thus, the Spanish text now is the English version as placeholder.

Figure 5.3: Example of a sketch from a howler monkey sign.

With this new process, the designer was able to push the design process forward and get feedback from the client in terms of sketches and contents of the boards without photos.

Case Study at La Selva

On four separate occasions while conducting fieldwork in Costa Rica, the designer went to the nearby La Selva Biological Station with the client. La Selva has an extensive trail network with approximately 61 km of trails, 16 km of which are paved. All trails have signs every 50 meters, indicating the acronym of the trail and the distance to the trailhead. The distance increases as visitors move away from the area where the main buildings are located (Kahler, 2016). Visiting La Selva provided an opportunity to study the site's interpretive signage system. This opportunity proved useful in identifying appropriate signage materials for a tropical climate and to gain inspiration for overall design.

There are 5 main categories of interpretive signs within La Selva including species tags, directional signs, warning signs, trailside signs and trailhead signs (Figure 5.4). The color green was used as main color and other color choices followed analogous color harmony. Photographs taken within the reserve of key features and activities were used as the background of the signs (Figure 5.5).

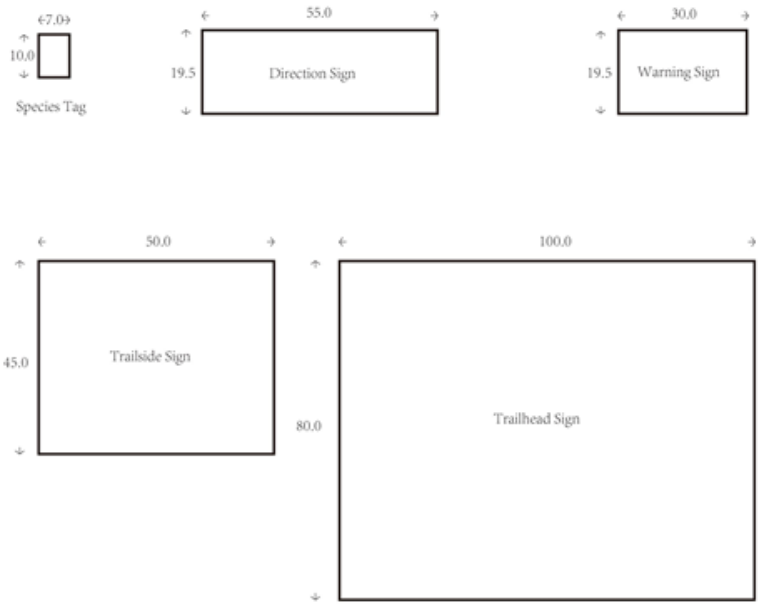

Figure 5.4: Five main sizes of interpretive signs at La Selva Biological Station.

Figure 5.5: Signs in La Selva Biological Station.

Signage Design Principles

Two graphic design guidelines were identified for the whole signage system at the Bijagual Ecological Reserve. The first guideline is the 3-30-3 rule (Gross et al., 2006). This rule indicates that a person should be able to skim the bold titles on the sign and understand the key message in 3 seconds, read the mid-sized text and get some details in 30 seconds, and read the entire text (as well as look at the graphics) in 3 minutes. In order to attract a reader to the sign, the overall appearance of the sign (a combination of graphics, colors, layout, and titles) must be carefully considered. The word count should be between 75-150 words of main content on each signs to ensure tourists read it through and obtain useful information (Paul, 2008). The second guideline is focal point & visual flow. For Costa Rica, the read pattern is a "z pattern" - left to right, and top to bottom. Therefore, the focal point of the sign is the left corner, and the right bottom corner area is the last impression. Therefore, the most important content should be located in the central and upper parts of the signs (Bradley, 2015).

Software used

During the design process, sketches were drawn to communicate ideas to the client and discuss design drafts. Adobe Illustrator was used to create vector sketch of each signs. Adobe Photoshop was used to personalize the graphics and layout of the boards. These source files will be provided to clients for possible future edits.

Existing Extent of the Reserve's Signage System

The Bijagual River and the Tirimbina River are two largest rivers within the Reserve, along which there are seven waterfalls (Figure 5.6). Along the main road (marked with the green line in Figure 5.6), there are three privately owned areas (grey area) that are not accessible to visitors.

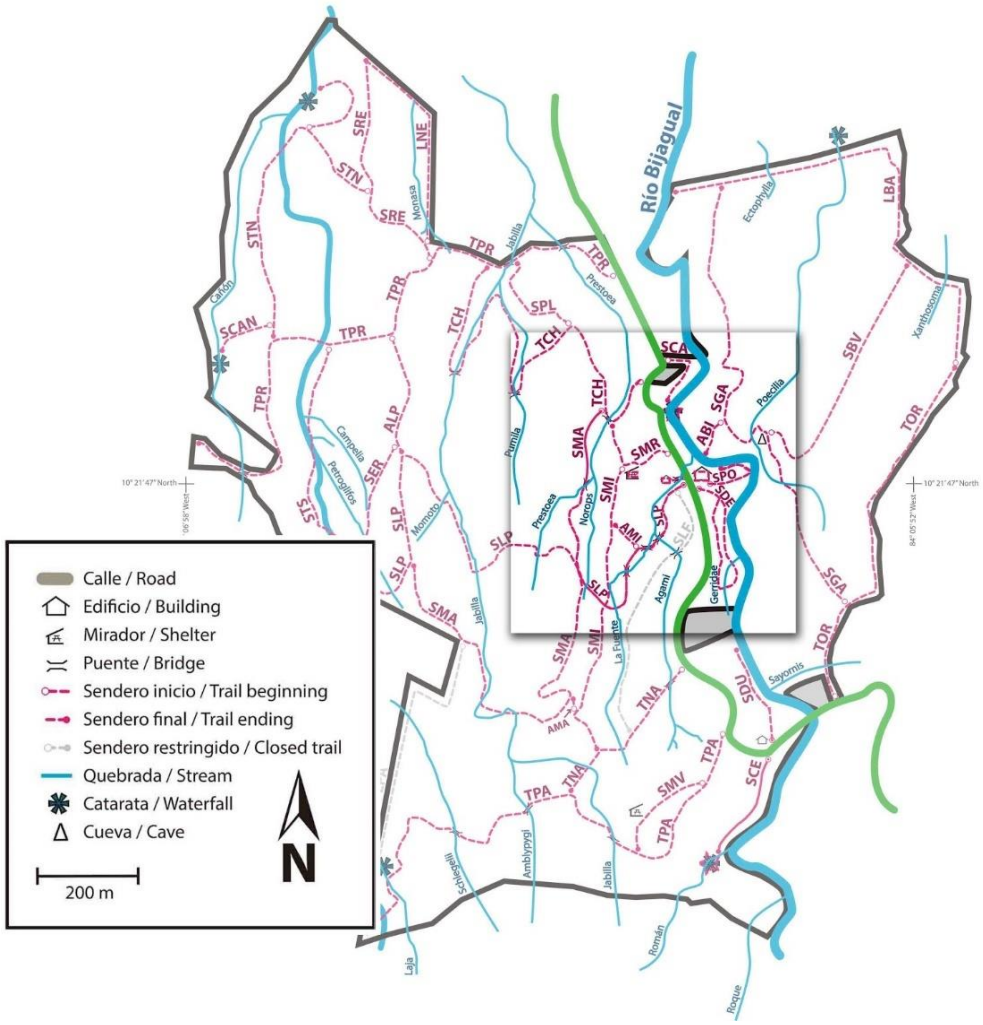

Figure 5.6: Bijagual Ecological Reserve trail map.

Although there are about 20 trails within the Bijagual Ecological Reserve, after discussing with client, considering convenience, safety and accessibility for tourists, this portion of project focused on just three main walking trails which have been developed and maintained for several years by BER (Figure 5.7). There are different ecosystems along the trails including forest, stream, wetland, and an arboretum.

Figure 5.7: Location of tourist center (red) and the three trails: SLP (purple), SPO (yellow), and SDE (green). The blue lines are streams.

These three walking trails are located around the BER. The main walking trail is the SLP. The SLP is approximately 1200 meters long and requires approximately 1 hour to complete. As the most important trail for eco-tourists, it covers different types of ecosystems such as forest, stream, wetland and an arboretum, which revealing the changing land use history. The second walking trail, the SDE, is located near Bijagual River and is approximately 500 meters long, requiring about 25 minutes to complete. It starts at the BER's tourist center, down to Bijagual River and makes a round trip back to the BER's tourist center. Colonies of leafcutter ants and red poison frogs are commonly observed along this trail. The third walking trail, the SPO, is approximately 200 meters long and requires approximately 15 minutes to complete. The main feature of this trail is the water level, which changes seasonally.

After analyzing the existing signs, and completing onsite field work including interviewing the client, the designer and client agreed on the goal of designing three categories of signs:

- Trailhead Signs: this included three trailhead signs with trail maps and overall introduction of the nature reserve
- Trailside Signs: this included introduction of plants and wildlife, ecosystem, land use history, and scientific research
- Directional signs: this included "No Entry" and "Shortcut" signs

Signage Design

Trailside Sign Design

Trailside signs are a main part of the design which focus on building an educational and interactive signage system to help navigate tourists, protect nature and wildlife, and show the history of the reserve. Signs provide people information about key features along the way such as plants, wildlife, ecosystem, distance between each tourist attractions, and emergency information. The goal of trailside interpretive signs is to "save lives, reduce vandalism, decrease wildfires, protect wildlife and cultural artifacts, and enable visitors to become more appreciative of an area's natural and cultural resources" (United States Department of Agriculture, 2013).

Location and key features (SLP Trail)

The signs along SLP trail indicate key features, highlight both the natural and the cultural history of the land, and provide directions and shortcuts. In total, there are 17 of these trailside signs along the SLP trail. Originally, the design plan was to install signs where people first come across a particular feature. However, it was soon realized that such a sign installation plan would locate nearly 90 percent of the signs in the first half of the trail, leaving very little for people to explore in the second half of trail. Thus, it was decided that a more engaging experience would be to have signs dispersed evenly along the whole trail. In Figure 5.8, the SLP trail is represented in purple, and the number along the trail represents the location of either and interpretive trailside sign, a directional sign, or a trailhead sign.

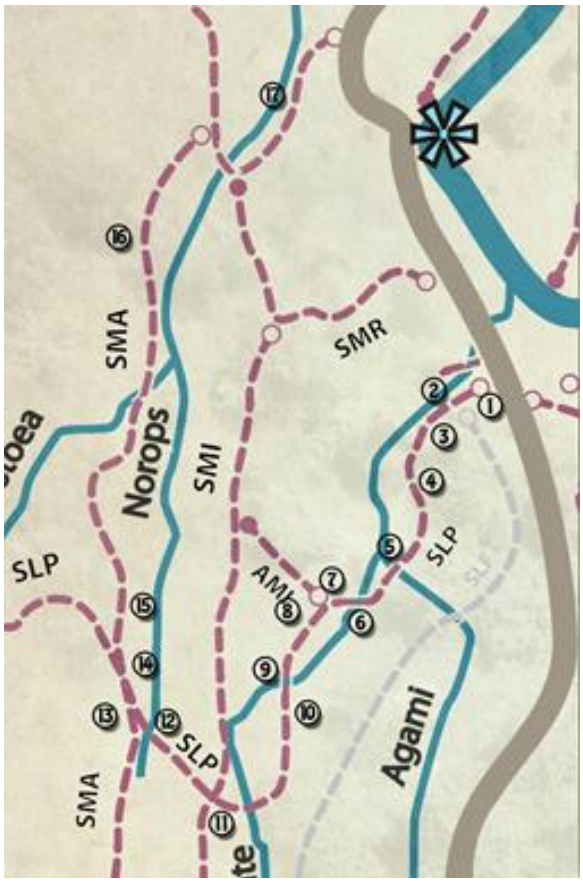

Figure 5.8: Proposed locations of signs along the SLP

Design principles

Since trailside signs are located close to the features they interpret, visitors receive information at the times and places they reach the features. It is important to give a clear explanation to the environment around and keep tourists interests. The designer established the following list of design objectives for the trailside boards:

- Each sign should focus on one central theme and have few words describe the concept or a story.
- Don't use a picture as background
- Signs should vary in layouts (with different numbers of pictures)
- Use sketches to indicate the theme of the signs to ensure that visitors understand the content

Based on those principles, an example of a trailside sign is below (Figure 5.9). It should be noted that the Spanish text is a placeholder, and the client will translate it in future.

Figure 5.9: Interpretive trailside sign design example.

Trailhead Sign Design

Trailhead signs are an important component of this signage system. They provide information about the tourist's current location, key features, distance between each tourist attractions and general information about the whole nature reserve. Using interview feedback about the goal of new signs and based on field work outcomes, the designer suggested that trailhead information boards be located in the following three places:

- The beginning of SPO trail
- The beginning of SLP trail SLP
- The intersection of the SLP and the SMA, in the middle of the SLP trail

Design principles

In order to ensure that the trailhead boards share the same design style, the designer established the following list of design objectives for the trailhead boards:

- Identify the location of the intersection of different trails and unique scenery such as waterfalls in the watershed
- Provide basic information on the whole reserve
- Design styles should match with their context (in or on the edge of forest)
- Tie in with existing signs' color schema, if possible
- Use complementary colors for emphasis
- Use BCEEC logo
- Serve as design inspiration for other signs

However, due to a lack of information and data about the whole nature reserve, the content of the trailhead signs has not yet been created (it will be edited by the client at a later time). An example of the trailhead sign design (with example text) is show below (Figure 5.10, Spanish is placeholder, client will translate it in future).

Figure 5.10: Trailhead sign design example.

Directional Signs Design

Shortcut Signs

There are two shortcut signs on the SLP trail. The first shortcut is located at the intersection of SLP and AMI. By taking a shortcut along the AMI, tourists are able to return to the tourist center in 15 minutes. If they do not take the shortcut, and instead continue along the SLP trail, it will take approximately one hour to complete the route.

The second shortcut is at the intersection of the SLP and SMI trails. For tourists who continue on the SLP trail, it will take 40 minutes to complete the route. If they take the SMI shortcut, they will reduce their return time to 15 minutes (Figure 5.11).

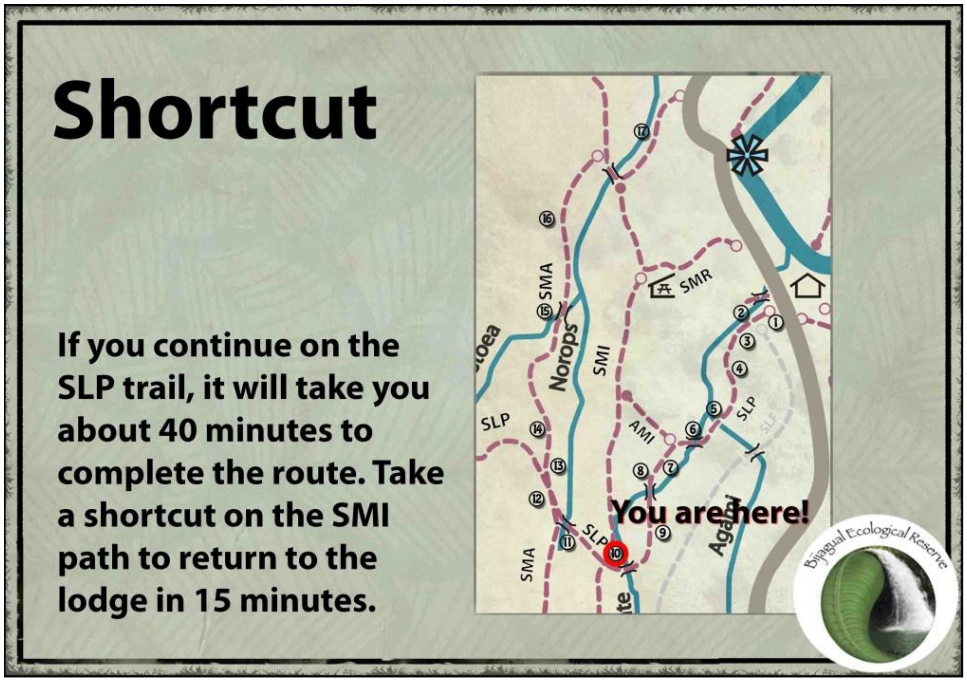

Figure 5.11: Shortcut sign design example.

No Entry Signs

No Entry signs are important for preventing tourists from entering private property. No Entry Signs will be located at the boundary of the SDE trail and outside private property as a warning to alert tourists not to enter private areas (Figure 5.12, Spanish is placeholder, client will translate it in future).

Figure 5.12: No entry sign design example.

Limitations

There are several limitations to the signage system design in terms of methods as a result of time limitations. First, photos were not received from the client in time to design the signage system with specific images in mind. Ideally, different signs would follow the same design principle but would differ in details or layout. If the client takes high quality photographs, these pictures could be used as a background for the trailside signs.

The second limitation is that the text contents are in English only. Spanish contents are all placeholders in the examples. Our client will help with the Spanish translation part to make the signs into overall integrated designs.

Recommendations for Future Work

Based on the development of the signage system, there are several recommendations for moving forward.

First, designing signage without pictures is challenging for both graphic design and content creation. Therefore, once pictures are obtained, it is recommended that the client edits the design based on the pictures.

Secondly, due to time constraints, the designer was unable to conduct interviews with tourists before commencing the design process. We recommend that the client conduct interviews and surveys about what tourists and other stakeholders want in the educational signs and signage system and then edit the design.

Third, the signage system developed and described herein only covers the three main trails. We recommend that signs be developed that cover more trails in the future in order to provide a better tour experience.

Finally, we recommend that the Bijagual Ecological Reserve collect tourist's feedback after the signs are put into use. This feedback will allow for improvements to future signage designs.

Section 6: Conclusion

This project aimed to provide the Bijagual Center for Environmental Education and Conservation with the resources and information necessary to achieve its goal of increasing habitat connectivity and improving water quality by re-establishing and protecting riparian corridors. In support of this goal, this project achieved the following four objectives:

- Utilize social science research methods to identify people in the region who would be interested in reforesting, and understand current areas of environmental concern among people in the region;
- Create current accurate land-cover maps to assist with the site-selection phase of future reforestation efforts, as well as establish optimal stream monitoring locations;
- Provide a mechanism for citizen engagement and assessment of the effectiveness of reforestation on improving water quality by developing a citizen-science stream monitoring program; and
- Develop a plan for an interpretive trail to enhance knowledge of the importance of the reserve's ecosystems.

The interviews and surveys completed in this project have identified people within the watershed who are interested in reforestation and citizen science projects. The BCEEC will be able to use this information to target their reforestation interventions and effectively move forward with reforestation in the region. Further, this research revealed a broad desire for educational programming in the region related to conservation and reforestation. The BCEEC should expand its educational programs in order to meet this need.

The creation of several land-cover classifications will give the BCEEC additional information when deciding where to site future reforestation projects. The land cover maps indicate about half of the area within the watershed has no canopy (has been deforested to some degree). By breaking the watershed up into three sections, patterns of land-cover from north to south identify particularly large areas of deforested land in the southern portion of the watershed where reforestation actions may be particularly needed. The techniques used for this portion of the project are sound, however, the classifications could be sharpened in the future by improving the training data and adding other image sources.

A stream monitoring program was designed to evaluate changes in water quality and to engage the local community in the monitoring and management of the Bijagual River watershed's aquatic resources. This program balances the collection of scientifically robust data with relatively easy and inexpensive data collection techniques and provides an opportunity for environmental education in topics such as the relationship between land cover, WQ, and biodiversity, invertebrate anatomy and taxonomy, and the use of scientific equipment and proper data collection techniques. Baseline data, including water quality data, aquatic macroinvertebrate surveys, and qualitative habitat observations, were collected at eleven locations throughout the watershed. Additional materials were produced to enhance the stream monitoring program including an equipment checklist and data sheet to promote safe, effective, and accurate data collection as well as an aquatic macroinvertebrate taxonomic key for use as an educational tool.

The interpretive signage system addressed two problems. First, existing signs don't provide enough educational information about ecosystem, environmental issues, or wildlife knowledge. Second, they don't provide location or safety information for emergencies. To solve these problems, the interpretive signage system design included trailhead signs, trailside signs and directional signs, which cover a wide range of themes such as general information about the nature reserve, emergency and information about wildlife, habitat and the ecosystem that the tourist is likely to encounter. Therefore, this component of the project improved the tourists experience by increasing awareness of the importance of environmental conservation and ensuring safety. As an important part of the environment education system, it also addresses the community perception that there is a need for educational opportunities for local people to learn about the local ecosystems and the environmental issues surrounding them. Thus, the signage system design advances the mission to provide local residents as well as tourists with engaging opportunities for environmental education.

Looking toward the future, there are four key recommendations that will further the BCEEC's organizational mission. First, the BCEEC should engage in structural and informational interventions to increase participation in reforestation efforts as well as provide educational opportunities to the community. Second, the BCEEC should refine the training data used in geospatial analysis of the Bijagual River watershed to improve the accuracy of land cover maps and then use this training data to produce additional land cover classifications at regular intervals in the future. Third, with a framework for a stream monitoring program established, the BCEEC should now incorporate land cover data in the establishment of additional monitoring locations, with special attention given to areas where landowners agree to implement riparian corridor conservation efforts. Finally, the BCEEC should construct the interactive trail within the Reserve to provide an engaging educational opportunity for the local community. In short, these efforts will ensure that the BCEEC achieves its goal of increasing habitat connectivity and improving water quality by re-establishing and protecting riparian corridors.

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Appendices

Appendix A: Environmental Attitudes Interview Guide (Spanish/English)

Actitudes Medioambientales / Environmental Attitudes

Entiendo que mis respuestas serían compartidas con la Reserva Ecológica Bijagual y sus colaboradores para que puedan desarrollar programas.

I understand that my responses will be shared with the Bijagual Ecological Reserve and its collaborators so they can develop their programs.

Sí (1) / Yes (1)

Q1 Nombre / Name

Q2 No. de Teléfono / WhatsApp / Telephone number / WhatsApp Number

Q3 Género / Gender

Masculino (1) / Male (1)

Feminino (2) / Female (2)

Prefiero no contestar (3) I prefer not to answer (3)

Q4 Edad / Age_____

Q6 Nivel de Educación / Level of Education

Escuela primaria (1) / Primary school

Escuela secundaria (2) / Secondary school

La universidad (3) / University

Q7 ¿Cuántas personas viven en su casa? / How many people live in your house?

Q7.1 ¿Cómo se relacionan con usted? How are they related to you? _____

Q8 Por favor responder con su nivel de acuerdo con la frase siguiente: **Me importa la conservación**.

Please respond with your level of agreement with the following sentence: **Conservation is important to me.**

Muy en desacuerdo (1) / Strongly disagree (1)

En desacuerdo (2) / Disagree (2)

Indiferente (3) / Indifferent (3)

En acuerdo (4) / Agree (4)

Muy en acuerdo (5) / Strongly agree (5)

Q9 Por favor responder con su nivel de acuerdo con la frase siguiente: Yo creo que la protección del terreno cerca de donde vivo tiene un impacto positivo en mi vida.

Please respond with your level of agreement with the following sentence**: I believe that the protection of the land near where I live has a positive impact on my life.**

Muy en desacuerdo (1) / Strongly disagree (1)

En desacuerdo (2) / Disagree (2)

Indiferente (3) / Indifferent (3)

En acuerdo (4) / Agree (4)

Muy en acuerdo (5) / Strongly agree (5)

Q10 Por favor responder con su nivel de acuerdo con la frase siguiente: **Cuando mi vecino contamina su terreno y agua, eso tiene impacto negativo en mi vida.**

Please respond with your level of agreement with the following sentence: **When my neighbor contaminates his land and water, that has a negative impact on my life.**

Muy en desacuerdo (1) / Strongly disagree (1)

En desacuerdo (2) / Disagree (2)

Indiferente (3) / Indifferent (3)

En acuerdo (4) / Agree (4)

Muy en acuerdo (5) / Strongly agree (5)

Q11 Ciencia ciudadana es cuando personas que no son científicos recolectan y analizan datos. ¿Si unas reservas en el área empiezan programas así, en qué tipos de proyectos le gustaría participar?

Citizen science is when people who are not scientists collect and analyze data. If some reserves in the area start programs like this, in what types of projects would you like to participate?

actividades con invertebrados acuáticos (1) / activities with aquatic invertebrates (1)

actividades con plantas (2) / activities with plants (2)

actividades con mamíferos como monos y pacas (3) / activities with mammals like monkeys and pacas (3)

actividades con insectos (incluyendo hormigas) (4) / activities with insects (including ants)

actividades con aves (5) / activities with birds (5)

otras actividades (6) / other activities (6)

ninguna (7) / none (7)

Q12 Usted vive en una… / You live on a...

lote (1) / lot (1)

quinta (2)

finca (3)

otra (4) / other (4) _____

Q13 ¿Que tamaño es su propiedad? / How big is your property?

Q14 ¿Cuándo se mudó a esa propiedad? / When did you move to this property?

Q15 ¿Ud. es el dueño/ la dueña de la propiedad donde vive? / Are you the owner of the property where you live?

Sí (1) Yes (1)

No (2) No (1)

Mostrar esta pregunta si " Sí" está elegida / Display this question if "yes" is selected

Q15.1 ¿Conoce ud. la historia de su propiedad? (por ejemplo, si vive usted en una finca, quien vivo ahí antes de usted, que ellos cultivaron, sus metodos de agricultura) / Do you know the history of your property? (For example, if you live on a finca, who lived here before you, what they grew, their methods of agriculture)

Sí (1) Yes (1)

No (2) No (1)

Q15.2 ¿Importa usted la historia de su propiedad? / Is the history of your land important to you?

Sí (1) Yes (1)

No (2) No (1)

Q16 ¿Ud. tiene terreno por el Río Bijagual? Do you have land along the Bijagual River?

Sí (1) Yes (1)

No (2) No (1)

Mostrar esta pregunta si " Sí" está elegida / Display this question if "yes" is selected

Q16.1 ¿Hay partes de su terreno por el Río que han sido cortado o limpiado? / Are there parts of your land along the river that have been cut or cleaned?

Sí (1) Yes (1)

No (2) No (1)

Mostrar esta pregunta si "Sí" está elegida / Display this question if "yes" is selected

Q16.1 A ¿Por qué Ud. cortó la vegetación cerca del río? / Why did you cut the vegetation near the river?

acceso al río para su ganado (1) / access to the river for your cattle (1)

presencia de serpientes en la vegetación (2) / presence of snakes in the vegetation (2)

acceso al río para personas (3) / access to the river for people (3)

plantar cosechas de agricultura (4) / to plant agricultural crops (4)

otra razón (5) / another reason (5)

Q16.1.B ¿Le gustaría participar en un proyecto de reforestación por el Río Bijagual? Would you like to participate in a reforestation project along the Bijagual river?

Sí (1) / Yes (1)

No (2) / No (2)

Q16.1.C ¿Qué requiere para participar en un proyecto de reforestación? / What would you require to participate in a reforestation project? _____

Mostrar esta pregunta si "no" está elegida / Display this question if "no" is selected

Q16.1.D ¿Por qué usted ha mantenido la vegetación por el Río Bijagual? / Why have you maintained the vegetation along the Bijagual River?

Si vive en una finca o una quinta: / If respondent lives on a finca (rural property, larger than ~ 2 hectares, used for agricultural purposes) or quinta (larger than a lot, but principally non-agricultural):

Q17 ¿Usted tiene charral (bosque en regeneración) en su finca? Do you have charral (regenerating forest) on your land?

Sí (1) / Yes (1)

No (2) / No (2)

Mostrar esta pregunta si "Sí" está elegida / Display this question if "yes" is selected

Q17.1 ¿Por qué usted deja parte de su finca como charral? / Why have you left part of your land as charral? _____

Mostrar esta pregunta si "No" está elegida / Display this question if "no" is selected

Q17.2 ¿Por qué no tiene charral en su finca?

Si vive en una finca o una quinta: / If respondent lives on a finca or quinta:

Q18 ¿Recibe Ud. algunos incentivos para su finca (por ejemplo de FONAFIFO o otra organización)? Do you receive any incentives for your finca (for example from FONAFIFO or another organization)?

Sí, por reforestación (1) / Yes, for reforestation (1)

Sí, por protección de bosque (2) / Yes, for forest conservation (2)

Sí, por regeneración natural (3) / Yes, for natural regeneration (3)

Sí, por otra razón: (4) / Yes, for another reason (4) _____

Si no esta recibiendo incentivos / If not receiving incentivos

Q19.A ¿Si no recibe incentivos, por qué es? Hay barreras que impiden su participación? / If you are not receiving incentives, why is that? Are there barriers that impede your participation? _____

Q20 ¿En su opinión, qué beneficios hayan de tener charral (bosque en regeneración) en una finca? / In your opinion, what benefits are there to having charral on a finca?

Appendix B: Advertisement for La Selva's Feria Ambiental (Environmental Fair)


11ma
Feria Ambiental La Selva 2017
Organización para Estudios Tropicales
Fecha:
12 de noviembre
Lugar:
Estación Biológica La Selva, Sarapiquí.
Horario:
8:30a.m. a 4:30p.m.
En el marco de la celebración del 50 aniversario en 2018
Actividades:
- Entrada gratis
- Caminatas guiadas (traer zapatos cerrados)
- Venta y exposición de productos de la zona
- Exposiciones científicas
- Presentaciones artísticas
Servicio de transporte gratuito:
Salida de los parques de La Virgen y Río Frío
- 8:00 a.m.
- 1:00 p.m.
Salida de La Selva
- 12:00 m.
- 4:30 p.m.
Sitio web: www.tropicalstudies.org
EstacionBiologicaLaSelva
Para mayor información llámenos al 2766-6565 ext. 101 / 110

Appendix C: Environmental Attitudes Survey (English/Spanish)

Values Survey Project – La Selva Environmental Fair, November 12, 2017

The survey will be used by the Organization for Tropical Studies, the University of Michigan, and the Bijagual Ecological Reserve in a project to assess the environmental awareness of the region. Your name would not be connected to the answers. The survey is voluntary l and you can stop at any time. If you continue you are giving your permission to participate in the survey.

Name (if you want to provide it)

Age _____

Community

Are you (or your family) the owner(s) of the property where you live? (mark with an X)

Yes. ____

No.____

I don't want to answer_____

To me, conservation means…

Do you think that most people in your community are interested in taking care of the environment? (mark with an X)

Yes ____

No____

I don't know ___

Patches of forest inside farms reduce the value of the farm. (mark with an X)

Completely agree ____

Agree _____

Neutral ____

Disagree ___

Completely disagree ____

I don't know or I don't understand ___

I like to keep wild animals as pets. (mark with an X)

Completely agree ____

Agree _____

Neutral ____

Disagree ___

Completely disagree ____

I don't know or I don't understand ___

Water receipts must include a tax to help with the costs necessary to protect watersheds, rivers, streams, and springs. (mark with an X)

Completely agree ____

Agree _____

Neutral ____

Disagree ___

Completely disagree ____

I don't know or I don't understand ___

If you see a tepezcuintle on your property, would you hunt it?

Absolutely ____

Maybe _____

Yes or no _____

Probably not _____

Never again _____

I do not know or I do not understand _____

Which materials do you recycle? (mark all that apply with an x)

Paper ___

Aluminum ____

Can ___

Plastic _____

Scrap _____

Any _____

I do not know or I do not understand _____

What do you do with the garbage that you do not recycle?

What are the most important problems for the environment in your community?

What are the biggest obstacles to a solution to the environmental problems of the previous question?

Other comments?

Thank you for your participation!

Informed consent (Slip presented after survey was completed)

Thank you for your participation! The survey will be used by the Organization for Tropical Studies, the University of Michigan, and the Bijagual Ecological Reserve in a project to assess the environmental awareness of the region. Your name would not be connected to the answers. The survey is by will and you can stop at any time. If you continue, that is, you are giving your permission to participate in the survey. If you have questions, please contact WhatsApp to Paul Foster (8330-8472) or Audrey Pallmeyer (+1 612-978-5780).

Encuesta Proyecto Valores – Feria Ambiental La Selva, 12 de noviembre 2017

La encuesta será utilizada por la Organización para Estudios Tropicales, la Universidad de Michigan, y la Reserva Ecológica Bijagual en un proyecto para evaluar la conciencia ambiental de la región. Su nombre no sería conectado con las respuestas. La encuesta es por voluntad y Usted se puede parar en cualquier momento. Si sigue, es decir que está dando su permiso para participar en la encuesta.

Nombre (si quiere)

Edad _____

Comunidad

¿Usted (o su familia) es el dueño o la dueña de la propiedad donde vive? (marcar con un X)

Si. ____

No.____

No quiero contestar _____

Para mí la conservación significa:

¿Cree Usted que a la mayoría de las personas en su comunidad les interese cuidar el medio ambiente? (marcar con un X)

Si ____

No____

No sé ___

Los parches de bosque dentro de las fincas reducen el valor de la finca. (marcar con un X)

Completamente de acuerdo ____

De acuerdo _____

Neutral ____

En desacuerdo ___

Completamente en desacuerdo ____

No sé o no entiendo ___

Le gusta mantener animales silvestres como mascotas. (marcar con un X)

Completamente de acuerdo ____

De acuerdo _____

Neutral ____

En desacuerdo ___

Completamente en desacuerdo ____

No sé o no entiendo ___

Los recibos del agua deben incluir un impuesto para ayudar con los costos necesarios para proteger las cuencas, los ríos, las quebradas, y las nacientes. (marcar con un X)

Completamente de acuerdo ____

De acuerdo _____

Neutral ____

En desacuerdo ___

Completamente en desacuerdo ____

No sé o no entiendo ___

¿Si Usted ve un tepezcuintle en su propiedad, lo cazaría?

Absolutamente si ____

Tal vez _____

Si o no _____

Probablemente no _____

Nunca jamás _____

No sé o no entiendo _____

Cúales materiales reciclan? (marcar con un X a todos que aplican)

Papel ___

Aluminio ____

Lata ___

Plástico _____

Chatarra _____

Ningún _____

No sé o no entiendo _____

¿Que hace con la basura que no recicla?

¿Cuáles son los problemas más importantes para el medio ambiente en su comunidad?

¿Cuáles son los obstáculos mayores para una solución a los problemas ambientales de la pregunta anterior?

¿Otros comentarios?

¡Muchas gracias por su participación!

Informed consent (Slip presented after survey was completed)

¡Muchas gracias por su participación! La encuesta será utilizada por la Organización para Estudios Tropicales, la Universidad de Michigan, y la Reserva Ecológica Bijagual en un proyecto para evaluar la conciencia ambiental de la región. Su nombre no sería conectado con las respuestas. La encuesta es por voluntad y Usted se puede parar en cualquier momento. Si sigue, es decir que está dando su permiso para participar en la encuesta. Si tenga preguntas, favor de contactar por WhatsApp a Paul Foster (8330-8472) o Audrey Pallmeyer (+1 612-978-5780).

Appendix D: Stream Monitoring Protocols

Sampling Protocols

Monitoring is conducted year round with each location sampled monthly. Every effort is made to collect data prior to afternoon rain events, and sampling should not be conducted during or immediately following heavy precipitation when the water is highly turbid. The location, date, arrival and departure times, names of the monitors, and current and recent weather conditions including ambient air temperature, cloud cover, and precipitation are recorded on data sheets during each sampling event.

Water Quality Sampling

Water quality (WQ) sampling should be conducted first (i.e. before monitors collect aquatic macroinvertebrates).When conducting water quality sampling, monitors should collect measurements from the middle of the stream, taking care to avoid areas where the streambed has been recently disturbed. If measurements are collected while standing in the streambed, monitors should face UPSTREAM while being careful not to stir up any sediment. Measurements may also be collected from a bridge or from rocks or islands in the middle of the stream prior to monitors entering the water. All measurements should be immediately recorded on the data sheets provided.

The WQ parameters temperature, dissolved oxygen, conductivity, pH, and nitrate are measured using a YSI Professional Plus meter[1] and accessory probes. Prior to data collection events, each prob e should calibrated following the protocols provided by YSI, Inc. to ensure accuracy of measurements. When using the meter, the probe must be completely submerged in the water column without dragging the streambed or coming into contact with rocks, logs, or other submerged objects. Once the meter is turned on, the letters “AS”, located next to each parameter, will flash until a stable reading is measured. Gently swirling or bobbing the probe in the water can help the readings to stabilize. If a stable reading cannot be taken after several minutes, vigorously shake the probe in the water to force out any air bubbles or sediment that may be leading to inaccuracies and then try again. When all of the “AS” indicators stop flashing, press “Enter” to record the data. The readings can then be found by pressing the “File” button, selecting “View Data”, selecting “Show Data”, and then scrolling to the bottom to see the most current data set. Immediately record the data onto the data sheet.

Turbidity is measured using a Secchi tube. Monitors fill the tube with stream water until the black and white disk at the bottom of the tube (called a Secchi disk) is no longer visible when looking directly through the water column from above. While holding the tube vertically, the bottom of the tube is pushed against a rock or other hard, flat surface to slowly release water through the valve at the bottom of the tube until the black and white areas of the disk are distinguishable. The turbidity of the sample is indicated as NTU values on the side of the tube at the bottom of the meniscus. If the disk is visible when the tube is completely full of water, the turbidity as should be recorded as >60 NTU on the data sheet.

Phosphate concentration is measured using a LaMotte TesTab Phosphate Kit. The test tube should be rinsed with stream water three times prior to collecting a sample. Then fill the test tube should be filled with 5mL of water, add a phosphorous TesTab, secure the cap, and shake the tube until the tablet dissolves. A chemical reaction will begin to cause the sample to change color. After 5 minutes, monitors compare the sample to a color chart, which indicates the amount of phosphate in the sample, and record the data on the data sheet.

Biotic Survey

Macroinvertebrate surveys are conducted only twice annually: once during the dry season (January – February) and once during the wet season (July – August). Although each stream is different, monitors sample all available macrohabitats within the stream following protocols adapted from Stein et al. (2008). To standardize the sampling effort, the following microhabitats will be sampled when they are present and safe access is possible:

- Two riffles
- One pool
- Submerged leaf packs
- Submerged vegetation
- Submerged roots
- Foam

Riffles are sampled twice for one minute each. One monitor disturbs the substrate by lifting rocks and kicking or sweeping the streambed. A second monitor holding a D-shaped net immediately downstream collects organisms, along with organic and inorganic material disturbed by the first monitor. Organisms that remain attached to lifted substrate may be removed by hand and placed into the net.

Macroinvertebrates are also collected from a single pool within the stream. A pool is sampled only if its bottom contains organic material, such as leaf litter and woody debris. To collect the macroinvertebrates, monitors initially drag a D-shaped net through the organic material along the pool's bottom. As the substrate is disturbed, monitors also sweep the net through the water column to collect any organisms and organic material that have become suspended in the water.

Submerged leaf packs are collected by hand and transferred directly to a D-shaped net. Monitors should hold the D-shaped net immediately downstream of the leaf pack during collection to catch any leaves or organisms that are carried away by the current. One D-net full of submerged leaves constitutes one sample.

All submerged vegetation and roots within the site are sampled. Monitors gather the vegetation and roots into the D-shaped net and shake vigorously to dislodge any macroinvertebrates, or monitors drag the net under the vegetation and roots and then sweep through the water column. In addition, any organisms that remain attached to vegetation or roots may be removed by hand and placed into the net.

Foam collects in eddies or stagnant pools downstream of riffles and waterfalls. Monitors attempt to collect all foam within the sample area by skimming it off the water surface using a fine mesh net. The foam is stored and transported in a sampling bag with water.

All collected material is emptied into a sorting tray. Using tweezers, monitors then transfer aquatic organisms from the sorting tray to sample bottles filled with alcohol. With the organisms preserved in alcohol, the samples can be transported back to the lab for identification at least to Family or to a more specific specific taxonomic level if possible. A Biological Monitoring Working Party - Costa Rica (BMWP-CR) index value is then calculated for each stream based on the taxonomic Families identified in the biotic survey. It should be noted that while identifying aquatic macroinvertebrates to Genus and/or

Species provides a more detailed characterization of macroinvertebrate community assemblages, only Family data can be analyzed using the BMWP-CR.

Physical Habitat Observations

Monitors determine the width of the riffle that was sampled for macroinvertebrates by stretching a measuring tape from the water's edge on one bank to the water's edge on the opposite bank such that the tape is perpendicular to both banks and taut across the surface of the water. Using a meter stick, monitors then measure the depth at the deepest point within the sampled riffle. In addition, monitors measure the width and depth of the sampled pool, if it is safe to do so. Finally, monitors record approximately how far upstream or downstream the riffle and pool are from the bridge or stream access point and indicate their locations on a sketch of the stream monitoring location.

Other physical habitat observations are recorded on the data sheet including stream flow and color, evidence of human activity within the stream, bank erosion and substrate characteristics, and land use along the stream banks. Monitors estimate the stream flow as either lower than normal, normal, or higher than normal, describe the color of the water, and indicate if there are any unusual colors or odors that might indicate water pollution. Evidence of human influence within the stream includes channelization (i.e. the stream has clearly been artificially straightened), hard engineering (including dams, riprap, culverts, concrete bottom and/or banks), and pipes, outfalls, or discharge into the stream. Monitors also describe the percent canopy cover over the stream as well as the predominant land use (e.g. primary/secondary forest, row crop agriculture, pasture, clear cut, residential/commercial/industrial, etc.) on either side of the bank and approximately how far beyond the bank the land use extends. Finally, evidence of bank erosion (e.g. exposed tree roots, banks denuded of vegetation, and steep, vertical, or undercut banks) are noted. Related to this, monitors characterize the streambed by indicating the types and relative proportions of substrate present (e.g. boulder, cobble, pebble, sand, and silt/clay) as well as the extent to which cobble is covered by silt or sand within the riffle (also known as “embeddedness”). In addition to written notes, monitors take photographs standing in the middle of the stream and facing upstream and downstream. The photographs should capture the typical character of the stream as well as any abnormalities or observations described above. Photograph numbers should be recorded on the data sheet.

Appendix E: Stream Monitoring Equipment Checklist

Stream Ecosystem Assessment

Equipment List

Volunteers will need the following list of materials in order to conduct stream assessments

- ☐ Clipboard, data sheets, and pencils
- ☐ Digital camera or cell phone
- ☐ Secchi tube
- ☐ YSI Meter with probes to collect
  - ☐ pH
  - ☐ Conductivity
  - ☐ Temperature
  - ☐ Dissolved Oxygen
  - ☐ Nitrate
- ☐ LaMotte TesTab Phosphate Kit
- ☐ Measuring tape
- ☐ Measuring stick
- ☐ Timer/Stopwatch
- ☐ Long handled, D-shaped net
- ☐ Long handled, fine mesh net
- ☐ Sorting trays
- ☐ Tweezers
- ☐ Hand lenses
- ☐ Species identification key
- ☐ Two or more storage vials/bags with alcohol

Recommended items:

- ☐ Bug spray
- ☐ Sunscreen
- ☐ Hat
- ☐ Rubber boots
- ☐ Work gloves
- ☐ Food/water

Appendix F: Stream Monitoring Data Sheet

Stream Ecosystem Assessment

Data Sheet

Stream Name: _____ Latitude/Longitude: _____

Investigators: _____ Number of Photos: ___

Date: _____ Start Time: _____ End Time: _____

Part 1: Weather

Air Temperature _____ °C

Indicate the amount of cloud cover:

- ☐ Sunny (no clouds)
- ☐ Partly cloudy (more sky than clouds)
- ☐ Mostly cloudy (more clouds than sky)
- ☐ Overcast (no sky)

Is it currently raining? Yes/No

If it is raining, indicate the amount:

- ☐ Light Rain
- ☐ Medium Rain
- ☐ Heavy Rain

Briefly describe the weather in the last 24 hours. Indicate any weather events that could have an impact on what you observe in the stream today. For example, has it rained? If so, estimate how much? Has it been dry? If so, for how many days?

_____

_____

_____

_____

_____

Part 2: Water Quality Sampling

When conducting water quality sampling, monitors should collect measurements from the middle of the stream, taking care to avoid areas where the streambed has been recently disturbed. If measurements are collected while standing in the streambed, monitors should face UPSTREAM while being careful not to stir up any sediment. Measurements may also be collected from a bridge or from rocks or islands in the middle of the stream prior to monitors entering the water.

YSI Meter

Did the measurements on the YSI stabilize (numbers no longer flashing)? Yes/No

Parameter	Measurement
Water Temperature	_____ C
Dissolved Oxygen	_____ mg/L
Conductivity	_____ µS/cm
pH	_____
Nitrate	_____ mg/L

LaMotte TesTab Phosphate Kit

Was the phosphate sample bottle rinsed 3X with stream water? Yes/No

Did the tablet completely dissolve, and was the color analyzed after 5 minutes? Yes/No

Phosphate _____ mg/L

Secchi Tube

Turbidity _____ NTU

Part 3: Sketch of Stream Monitoring Site

In the space below, sketch the stream monitoring site. In your sketch, indicate approximately where water quality measurements were collected (**Part 2**), any important habitat observations (**Part 4**), as well as the locations of habitats sampled in the biotic survey (**Part 5**).

Part 4: Habitat Observations

Indicate the level of stream flow (how much water is in the stream channel):

- ☐ Lower than normal
- ☐ Normal
- ☐ Higher than normal

Is there evidence that the stream recently overflowed its banks? Evidence includes vegetation along banks that has been flattened by flowing water, sediment/debris deposited above the current water line, water stained leaves above the current water line, etc. Yes/No

Indicate the color of the water:

- ☐ Clear
- ☐ Milky
- ☐ Muddy
- ☐ Other? (Explain) _____
  _____

Are there any unusual odors (e.g. manure, fish, sewage, etc.) or colors? If yes, describe them. Can you identify the source?

_____
_____

Indicate any evidence of human activity and/or influence within the stream:

- ☐ Hard engineering (e.g. riprap, dams, concrete)
- ☐ Channelization
- ☐ Pipes or outfalls
- ☐ Pollution (e.g. trash, discharges)
- ☐ Other? (Explain) _____
  _____

Briefly list any animals that you saw or heard in the water or near the stream (fish, frogs, snakes, etc.)

_____
_____
_____

Facing UPSTREAM, estimate the percent canopy cover over the stream and briefly describe the predominant land cover on either side:

Percent Canopy Cover _____%

Left Bank _____
_____
_____

Right Bank _____
_____
_____

Facing UPSTREAM, indicate any evidence of bank erosion (take photos!):

	Left Bank	Right Bank
Exposed tree roots	☐	☐
Soils devoid of vegetation	☐	☐
Steep, vertical, or undercut banks	☐	☐

Indicate all the types of substrate that are present in the stream. Refer to the diagram to the right.

- ☐ Boulders (>256 mm)
- ☐ Cobble (64 – 256 mm)
- ☐ Pebbles (2 – 64 mm)
- ☐ Sand (0.0625 – 2 mm)
- ☐ Silt/Clay (<0.0625 mm)

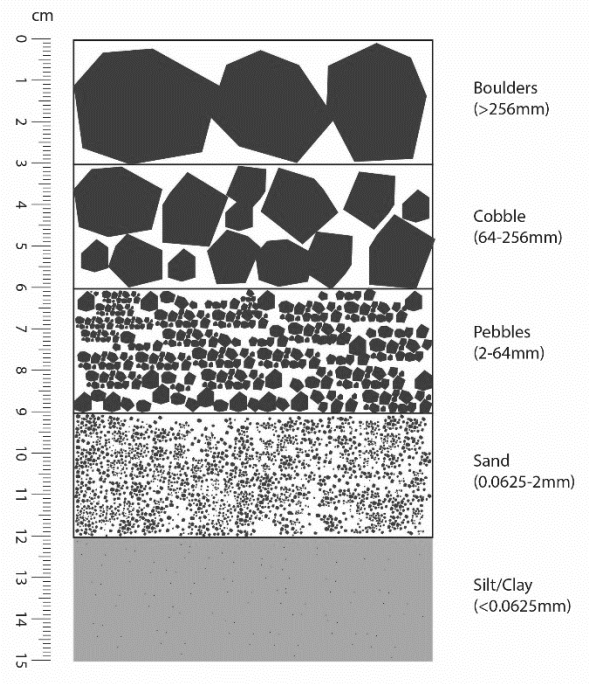
In a riffle, estimate the proportion of cobble to pebble to sand. Refer to the diagram to the right.

Cobble _____%
Pebble _____%
Sand/Silt _____%

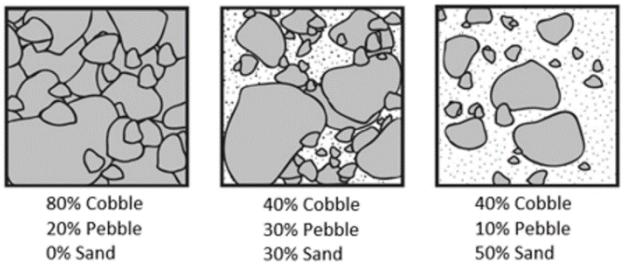
In a riffle, indicate how embedded the cobble is. Refer to the diagram to the right

- ☐ <25%
- ☐ 25% - 50%
- ☐ 50% - 75%
- ☐ >75%

Types of Substrate

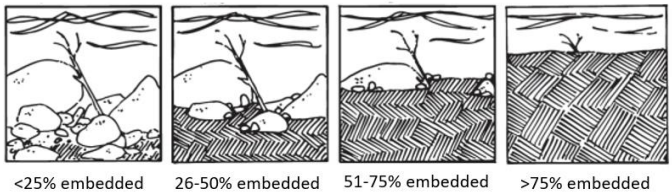


Sediment Proportion



Drawing reproduced from *The Streamkeeper's Field Guide: Watershed Inventory and Stream Monitoring Methods*[1]

Embeddedness



Drawing reproduced from *Hoosier Riverwatch: Volunteer Stream Monitoring Training Manual 2017*[2]

[1] Murdoch, Tom, Martha Cheo, and Kate O'Laughlin. (2006). *The Streamkeeper's Field Guide: Watershed Inventory and Stream Monitoring Methods*. Everett, WA: Adopt-a-Stream Foundation. Print.

[2] Indiana Department of Environmental Management. (2017). *Hoosier Riverwatch: Volunteer Stream Monitoring Training Manual 2017*. Available from, http://www.in.gov/idem/riverwatch/files/volunteer_monitoring_manual.pdf

Part 5: Macroinvertebrates

Indicate which habitats were sampled for aquatic macroinvertebrates. Also indicate the approximate locations of these habitats in your sketch of the stream (**Part 2**):

Habitat	Effort	Yes	No	Other? (Explain)
Riffle	2 rapids; 60 seconds each	☐	☐	_____
Pool	1 pool	☐	☐	_____
Leaf Packs	1 net-full	☐	☐	_____
Submerged Veg.	All available	☐	☐	_____
Roots	All available	☐	☐	_____
Foam	All available	☐	☐	_____

Other habitats? Explain: _____

_____

Indicate the width and depth of surveyed riffles and pool. Be sure to mark the locations of these habitats in your sketch of the stream (**Part 2**):

Riffle 1		**Riffle 1**		**Pool 1**	
Width	_____ m	Width	_____ m	Width	_____ m
Depth	_____ m	Depth	_____ m	Depth	_____ m

Definitions of Terms

Downstream –direction the water is flowing TO

Embeddedness –percentage that boulders/cobbles/pebbles are covered by sand/silt/clay

Foam – white bubbles often amassed in floating clumps; often found in stagnant eddies or pools downstream of riffles

Leaf Pack – damp or wet leaves that are stuck together in a clump; often found caught on submerged limbs or wedged in between rocks

Pool – a section of the stream that has deep, slow-moving water; typically the surface of the water is smooth

Riffle – a section of the stream that has shallow, fast-moving water; typically rocks break the surface of the water

Roots – roots from trees, vines, or other plants that are submerged in the water

Streambed –bottom of the stream

Submerged Vegetation – plants that live in the water; often found along stream banks or on islands in the middle of the stream

Substrate –types/sizes of materials that make up the streambed

Upstream –direction the water is flowing FROM

Appendix G: Aquatic Macroinvertebrate Taxonomic Key

Clave Taxonómica de Macroinvertebrados Acuáticos

Con patas articuladas

Sin patas articuladas

5 (o más) pares de patas

4 pares de patas

3 pares de patas

Con concha

Sin concha

Diminuto y a menudo de color rojo brillante

Vea página 2

MOLLUSCA

Mejillón de agua dulce

Caracol

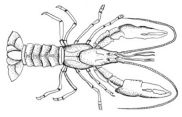
Con una cabeza y/o prolegs o colas carosas

DIPTERA

Vea página 4

Como una pequeña langosta

DECAPODA



Cangrejo de río

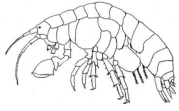
ARACHNIDA

Coloradilla acuática

Sin una cabeza ni tentáculos o colas carosas

Nada en el agua

AMPHIPODA



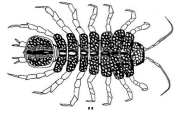
Camarón

Cuerpo segmentado

Cuerpo plano y no segmentado

Camina en el fondo de la quebrada

ISOPODA



ANNELIDAE

Gusano acuático

HIRUDINEA

Sanguijuela

PLATYHELMINTHES

Planaria/Gusanoplano

Tres Pares de Patas

Con una casita portátil (hecha de arena, piedras, pequeñas o material orgánico)

Sin una casita portátil

Sin alas o almohadillas de ala

Con alas o almohadillas de ala

Con ganchos en el extremo del cuerpo

Sin ganchos en el extremo del cuerpo

Vea página 3

Sin filamentos laterales

Con filamentos laterales

Con filamentos laterales y con uno filamento en el extremo de cuerpo

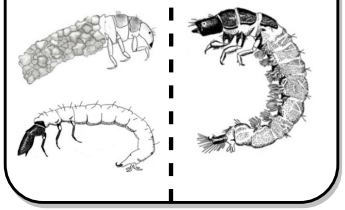
Con prolegs carnosas

Sin prolegs carnosas

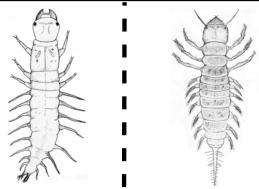
Sin agallas planas

Con agallas planas

TRICHOPTERA



MEGALOPTERA

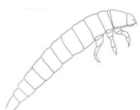


LEPIDOPTERA

Larva de mariposa acuática

COLEPTERA

Moneda de agua



Larva de escarabajo

Con Alas o Almohadillas de Ala

- Con colas
  - 2 colas sin agallas planas
    - **PLECOPTERA**
      
      Mosca de piedra
  - 2 o 3 colas con agallas planas
    - **EPHEMEROPTERA**
      
      Mosca de mayo
  - 3 colas planas sin agallas planas
    - **ODONATA**
      
      Zygoptera
      
      Anisoptera
- Sin colas
  - Con almohadillas de ala
    - Boca grande con bisagras
      - **ODONATA**
  - Con alas
    - Cubierta dura de ala alas paralelas
      - **COLEOPTERA**
        
        Escarabajos adultos
    - Alas de cuero alas superpuestas
      - **HEMIPTERA**
        
        Chinche acuática

DIPTERA

Cabeza pequeña y a menudo no visible

Cabeza distinta y visible

6-7 pares de prolegs y 2 colas carnosas largas

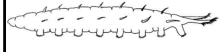
Colas carnosas en extremo

Pequeña cabeza retráctil y anillos carnosas alrededor de siete segmentos

Un extremo es más grande que el otro

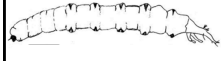
Ambos extremos de tamaño similar

Empididae

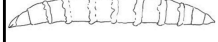


Gusano bailarín

TIPULIDAE



TABANIIDAE



Larva de tábano

SIMULIIDAE

Larva de arenilla

CHIRONOMIDAE

Adaptado de "Identification Guide to Freshwater Macroinvertebrates",
preparado por Stroud Water Research Center,
970 Spencer Road, Avondale, Pennsylvania, USA 19311

Appendix H: Example Stream Monitoring Database

Stream Name	Stream ID	Lat	Long	Start Time	End Time	Monitors	Number of Photos	Air Temperature	Cloud Cover	Is it raining?	Weather in the last 24 hours
Finca Sura	1	10.43669987	-84.04540253								
7/21/2017				0943	1256	S. Avila, W. Stinnette	6		Mostly cloudy	No	Light drizzle ending over an hour ago
Road behind Selva Verde	2	10.43120003	-84.06520081								
7/22/2017				0903	1212	S. Avila, W. Stinnette	2		Mostly sunny	No	Heavy rain overnight
Rio Majon	3	10.4059	-84.06369781								
7/24/2017				0823	1130	S. Avila, S. Lynch, W. Stinnette	5		Overcast	No	
Quebrada Roman	4	10.34049988	-84.10320282								
7/26/2017				0920	1317	S. Avila, S. Lynch, W. Stinnette	7		Overcast	Light Rain	Has rained consistently for the last 48 hours
Stream with no bridge	5	10.33460045	-84.09480286								
7/27/2017				0900	1251	S. Avila, W. Stinnette	6		Sunny		
Naciente Rio Majon	6	10.33450031	-84.08280182								
7/28/2017				1004	1104	S. Avila, W. Stinnette	7		Mostly cloudy		Heavy rain overnight
Quebrada Plana	7	10.33460045	-84.08719635								
7/28/2017				1112	1418	S. Avila, W. Stinnette	5		Mostly cloudy		Heavy rain overnight
Rio Bijagual	8	10.33430004	-84.09089661								
7/29/2017				0933	1227	S. Avila, W. Stinnette	5		Overcast	Medium rain	Has been raining for approximately 2 hours
Southeast Road	9	10.40390015	-84.08180237								
7/31/2017				1022	1256	S. Avila, W. Stinnette	4		Mostly cloudy		Rain overnight
Quebrada Roman en Bijagual	10	10.35289955	-84.10340118								
8/1/2017				1045	1409	S. Avila, W. Stinnette	4		Sunny		No rain within last 24 hours
Quebrada Roque en Bijagual	11	10.35239983	-84.10220337								
8/1/2017				1418	1557	S. Avila, W. Stinnette	5		Sunny		No rain within last 24 hours

Stream Name	Stream ID	Stream Flow	Overflow Banks	Water Color	Unusual Odors	Human Activity	Observed Animals	Percent Canopy Cover	Land Cover		Evidence of Bank Erosion		Types of Substrate	Cobble:Pebble:Sand	Embeddedness	Riffle 1		Riffle 2		Pool		Other observations?
									Left Bank	Right Bank	Left Bank	Right Bank				Width (m)	Depth (m)	Width (m)	Depth (m)	Width (m)	Depth (m)	
Finca Sura	1																					
7/21/2017																4.75	0.07			4.83	0.45	
Road behind Selva Verde	2																					
7/22/2017				Slightly cloudy					Forested >10 m, upstream there is pasture within 10m	Forested >10 m						5.13	0.25			3.90	0.75	
Rio Majon	3																					
7/24/2017				Cloudy		Road goes through the stream; man-made structures (rock/riprap to stabilize bank, rock/concrete/metal structures in the stream)			Forested >10m	Forested >10m						5.10	0.22			7.80	0.41	
Quebrada Roman	4																					
7/26/2017				Clear		Able to drive through stream on a gravel road (observed cattle crossing through stream)			Forested >10m	Forested >10m						9.10	0.23			11 (Approx)	0.34	
Stream with no bridge	5																					
7/27/2017				Clear	Occassionally smelled manure	Road goes through stream	Frogs, tadpoles, damselflies, large spider, fish		Forested >10m	Forested >10m						8.40	0.19			11.60	0.68	
Naciente Rio Majon	6																					
7/28/2017				Clear			Small fish	0%	Deforested; tree plantation	Deforested						1.00	0.44			No Sample	No Sample	Lots of plants and algae in the water
Quebrada Plana	7																					
7/28/2017				Clear			Tadpoles, small fish, damselflies		Tree plantation	Pasture with narrow riparian buffer			Very little sediment			5.30	0.21			7.40	0.84	
Rio Bijagual	8																					
7/29/2017				Clear			Small fish, damselflies, spiders		pasture with narrow riparian buffer	House with pasture; no buffer						4.60	0.36			5.21	0.46	Cow was standing directly in the stream
Southeast Road	9																					
7/31/2017				Cloudy			Small fish		Pasture; planted trees; no riparian buffer	Pasture; planted trees; no riparian buffer			Very fine sediment; mucky			3.04	0.20			No Sample	No Sample	Two forks converge 8 m upstream of bridge
Quebrada Roman en Bijagual	10																					
8/1/2017				Slightly cloudy			Frogs, tadpoles, small fish		Forested >10m	Forested >10m			Little sedimentation			9.90	0.21			5.0 (approx)	0.23	
Quebrada Roque en Bijagual	11																					
8/1/2017				Clear					Forested >10m	Forested >10m			Little sedimentation			4.30	0.19			6.39	0.40	

Stream Name	Stream ID	Water Temp (°C)	D.O. (mg/L)	Conductivity (µS/cm)	pH	Nitrate (mg/L)	Phosphate (mg/L)	Turbidity (NTU)	Notes
Finca Sura	1								
7/21/2017		25.9	4.84	37.4	6.48	0.14	0.04	>60	
Road behind Selva Verde	2								
7/22/2017		24.6	6.86	50.1	7.07	0.31	0.04	>60	
Rio Majon	3								
7/24/2017		24.3	7.55	27.6	7.22	0.11	0.04	>60	
Quebrada Roman	4								
7/26/2017		21.7	7.65	76.8	7.62	0.1	0.04	>60	
Stream with no bridge	5								
7/27/2017		22.7	7.16	31.6	7.1	*	0.04	>60	*Unable to record nitrate concentration, possibly too low to measure
Naciente Rio Majon	6								
7/28/2017		23.9	5.06	15.3	5.34	0.10	0.02	>60	
Quebrada Plana	7								
7/28/2017		23.4	7.66	22.5	6.73	0.04	0.02	>60	
Rio Bijagual	8								
7/29/2017		22	7.9	31.5	7.46	0.06	0.02	>60	
Southeast Road	9								
7/31/2017		24.6	7.06	21.5	6.06	0.07	0.04	>60	
Quebrada Roman en Bijagual	10								
8/1/2017		22.6	7.79	60.2	7.51	0.06	0.04	>60	
Quebrada Roque en Bijagual	11								
8/1/2017		23.9	7.78	27.9	7.22	0.02	0.04	>60	

		2 Riffles	Pool	Leaf Packs	Sub. Veg.	Roots	Foam	Other?	Tolerance Score					9							
									Order	Odonata	Diptera	Diptera	Ephemeroptera	Plecoptera	Trichoptera	Trichoptera	Trichoptera	Trichoptera	Ephemeroptera	Odonata	Odonata
Stream Name	Stream ID	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No	Explain	Family	Polythoridae	Blephariceridae	Athericidae	Heptageniidae	Perlidae	Lepidostomatidae	Odontoceridae	Hydrobiosidae	Ecnomidae	Leptophlebiidae	Cordulegastridae	Corduliidae
Finca Sura	1																				
7/21/2017		Yes	Yes	Yes	Yes	Yes	Yes														
Road behind Selva Verde	2																				
7/22/2017		Yes	Yes	Yes	Yes	Yes	Yes						9	9					8		
Rio Majon	3																				
7/24/2017		Yes	Yes	Yes	Yes	Yes	Yes							9					8		
Quebrada Roman	4																				
7/26/2017		Yes	Yes	Yes	Yes	Yes	Yes	Substrate in waterfall; Leaf pack in waterfall					9	9					8		
Stream with no bridge	5																				
7/27/2017		Yes	Yes	Yes	Yes	Yes	Yes						9	9		9	9		8		
Naciente Rio Majon	6																				
7/28/2017		Yes	No	No	Yes	No	Yes														
Quebrada Plana	7																				
7/28/2017		Yes	Yes	Yes	Yes	Yes	Yes			9			9	9					8		
Rio Bijagual	8																				
7/29/2017		Yes	Yes	Yes	Yes	Yes	Yes							9					8		
Southeast Road	9																				
7/31/2017		Yes	No	Yes	Yes	Yes	Yes						9	9					8		
Quebrada Roman en Bijagual	10																				
8/1/2017		Yes	Yes	Yes	Yes	Yes	Yes							9					8		
Quebrada Roque en Bijagual	11																				
8/1/2017		Yes	Yes	Yes	Yes	Yes	Yes			9			9	9		9			8		

		8													7									6		
Odonata	Odonata	Trichoptera	Trichoptera	Trichoptera	Trichoptera	Blattodea	Coleoptera	Coleoptera	Coleoptera	Odonata	Odonata	Odonata	Odonata	Tricoptera	Tricoptera	Amphipoda	Amphipoda	Odonata	Megaloptera	Trichoptera	Trichoptera	Trichoptera				
Aeshnidae	Perlestidae	Limnephilidae	Calamoceratidae	Leptoceridae	Glossosomatidae	Blaberidae	Ptilodactylidae	Psephenidae	Lutrochidae	Gomphidae	Lestidae	Megapodagrionidae	Protoneuridae	Platysticitidae	Philopotamidae	Talitridae	Gammaridae	Libellulidae	Corydalidae	Hydroptilidae	Polycentropodidae	Xiphocentronidae				
					8									7					6							
	8				8		7	7	7	7		7	7	7	7			6								
	8				8		7	7		7		7			7			6	6							
	8				8		7		7						7			6	6			6				
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					8		7					7			7			6	6							
					8		7	7	7	7		7			7			6	6			6				
					8		7	7		7		7			7			6	6	6						

Ephemeroptera Euthyplociidae	Ephemeroptera Isonychiidae	Lepidoptera Pyralidae	Trichoptera Hydropsychidae	Trichoptera Helicopsychidae	Coleoptera Dryopidae	Coleoptera Hydraenidae	Coleoptera Elmidae	Coleoptera Limnichidae	Ephemeroptera Leptohyphidae	Ephemeroptera Oligoneuriidae	Ephemeroptera Polymitarcyidae	Ephemeroptera Baetidae	Tricladida Planariidae	Turbellaria (class)	Coleoptera Chrysomelidae	Coleoptera Curculionidae	Coleoptera Haliplidae	Coleoptera Lampyridae	Coleoptera Staphylinidae	Coleoptera Scirtidae	Coleoptera Dytiscidae	Coleoptera Gyrinidae	Coleoptera Noteridae
									5	5			5							4			
				5			5		5	5			5							4	4	4	
				5	5		5		5	5			5	5						4			
		6		5			5		5	5			5							4			
				5	5		5		5	5			5	5									
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				5	5		5		5	5			5	5									
				5			5		5	5			5	5							4		
		6		5			5		5	5			5	5									
				5			5		5	5			5	5									

Diptera Dixidae	Diptera Simulidae	Diptera Tipulidae	Diptera Dolichopodidae	Diptera Ceratopogonidae	Diptera Sciomyzidae	Diptera Empididae	Diptera Muscidae	Diptera Stratiomyidae	Diptera Tabanidae	Ephemeroptera Caenidae	Hemiptera Belostomatidae	Hemiptera Corixidae	Hemiptera Naucoridae	Hemiptera Pleidae	Hemiptera Nepidae	Hemiptera Notonectidae	Odonata Calopterygidae	Odonata Coenagrionidae	Trombidiformes Hydracarina (Acarina)	Coleoptera Hydrophilidae	Diptera Psychodidae	Gastropoda (class) Valvatidae	Gastropoda (class) Hydrobiidae
	4	4			4	4			4		4		4						4				
	4				4								4				4	4	4				
4	4				4		4						4				4	4	4				
4	4	4											4				4						3
4	4	4											4				4	4				3	3
	4	4			4													4	4	3	3		
4	4	4			4								4				4	4	4				
	4	4			4								4				4	4	4		3		
	4	4											4				4	4					
	4	4											4				4	4	4				3
4	4				4								4				4		4		3		3

Gastropoda (class) Lymnaeidae	Gastropoda (class) Physidae	Gastropoda (class) Planorbidae	Gastropoda (class) Bithyniidae	Gastropoda (class) Bythinellidae	Gastropoda (class) Unidentified	Veneroida Sphaeridae	Arhynchobdellida Hirudinea: Glossiphonidae	Arhynchobdellida Hirudinea: Hirudidae	Arhynchobdellida Hirudinea: Erpobdellidae	Isopoda Asellidae	Diptera Chironomidae	Diptera Culicidae	Diptera Ephydridae	Diptera Syrphidae	Annelida Oligochatea (all classes)	BMWP-CR
			3									2			1	
					3						2	2				70
																0
																0
																0
																0
											2				1	163
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																0
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											2		2			186
																0
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Appendix I: Biological Monitoring Working Party – Costa Rica (BMWP-CR)

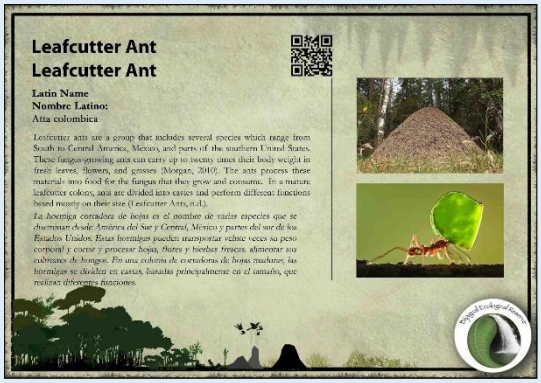
Order	Family	Value
Odonata	Polythoridae	9
Dipterans	Blephariceridae; Athericidae	
Ephemeroptera	Heptageniidae	
Plecoptera	Perlidae	
Trichoptera	Lepidostomatidae; Odontoceridae; Hydrobiosidae; Ecnomidae	
Ephemeroptera	Leptophlebiidae	8
Odonata	Cordulegastridae; Corduliidae; Aeshnidae; Perilestidae	
Trichoptera	Limnephilidae; Calamoceratidae; Leptoceridae; Glossosomatidae	
Blattodea	Blaberidae	
Coleoptera	Ptilodactylidae; Psephenidae; Lutrochidae	7
Odonata	Gomphidae; Lestidae; Megapodagrionidae; Protoneuridae; Platysticitidae	
Trichoptera	Philopotamidae	
Crustacea	Talitridae; Gammaridae	
Odonata	Libellulidae	6
Megaloptera	Corydalidae	
Trichoptera	Hydroptilidae; Polycentropodidae; Xiphocentronidae	
Ephemeroptera	Euthyplociidae; Isonychidae	
Lepidoptera	Pyralidae	5
Trichoptera	Hydropsychidae; Helicopsychidae	
Coleoptera	Dryopidae; Hydraenidae; Elmidae; Limnichidae	
Ephemeroptera	Leptohyphidae; Oligoneuriidae; Polymitarcyidae; Baetidae	
Crustacea	Crustacea	
Tricladide	Turbellaria	
Coleoptera	Chrysomelidae; Curculionidae; Haliplidae; Lampyridae; Staphylinidae; Dytiscidae; Gyrinidae; Scirtidae; Noteridae	4
Dipterans	Dixidae; Simulidae; Tipulidae; Dolichopodidae; Empididae; Muscidae; Sciomyzidae; Ceratopogonidae; Stratiomyidae; Tabanidae	
Hemiptera	Belostomatidae; Corixidae; Naucoridae; Pleidae; Nepidae; Notonectidae	
Odonata	Calopterygidae; Coenagrionidae	
Ephemeroptera	Caenidae	
Trombidiformes	Hidracarina	
Coleoptera	Hydrophilidae	3
Dipterans	Psychodidae	
Mollusk	Valvatidae; Hydrobiidae; Lymnaeidae; Physidae; Planorbidae; Bithyniidae; Bythinellidae; Sphaeridae	
Annelida	Hirudinea: Glossiphonidae; Hirudidae; Erpobdellidae	
Crustacea	Asellidae	
Dipterans	Chironomidae; Culicidae; Ephydridae	2
Dipterans	Syrphidae	1
Annelida	Oligochatea	

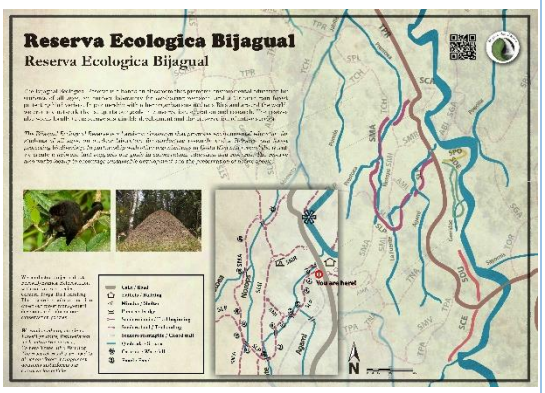
Quality Description	BMWP-CR Score	Classification
Excellent	>120	Blue
Water of good quality, not polluted or not altered in a sensitive way	101-120	Blue
Water of regular quality, eutrophic, moderate pollution	61-100	Green
Bad quality water, polluted.	36-60	Yellow
Bad quality water, very polluted.	16-35	Orange
Extremely bad quality waters polluted	<15	Red

Appendix J: Photographic Requirements

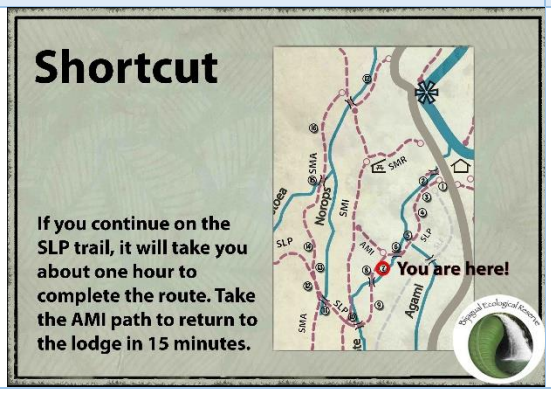
Series	Picture 1	Picture 2	Picture 3 (if possible)	Picture 4 (if possible)
SPO 1	river in low level	river in high level	river in high level	species here in general
SDE 1	close-up of ants	close-up of ants	close-up of ant colony	close-up of ant colony
SDE 2	close-up of howler monkey	close-up of howler monkey	mother and baby monkey	groups of monkeys
SDE 3	before reforestation	pics of volunteers and scientists	pics of volunteers and scientists	forest now
SDE 4	pics of plants growing there	pics of plants growing there	pics of animals growing there	pics of animals growing there
SLP 1	general picture of bijagual	general picture of bijagual	typical animal in bijagual	typical plant in bijagual
SLP 2	close-up of frog	close-up of frog	habitat pics	habitat pics
SLP 3	pics before arboretum established	start point of arboretum	pics for now	pics for now
SLP 4	scientists working pics	scientists working pics	tropical forest pics(aerial pics forest in bijagual)	tropical forest pics(aerial pics forest in bijagual)
SLP 5	pic of primary forest	pic of primary forest	pic of light gap	pic of secondary forest
SLP 6	pic of fishes	pic of fishes	pic of macroinvertebrate	pic of
SLP 8	pic of lodging	pic of lodging	pic of what looked like before lodging	pic of now
SLP 9	pic of fungi	pic of fungi	pic of fungi	pic of fungi
SLP 13	pic of poison frog	pic of leaf cutting ant	pic of howler monkey	pic of fungi
SLP 14	close-up of leaves	close-up of fruit	pic of whole tree	pic of whole tree
SLP 15	pic before reforestation	pic before reforestation	pic after reforestation	pic after reforestation
SLP 16	close-up of Great Green Macaw	Flying Great Green Macaw	close-up of Great Green Macaw	Baby Great Green Macaw
SPO 1	Pic of river in dry season	Pic of river in wet season	Pic of trees on the bank	Pic of wildlife near river

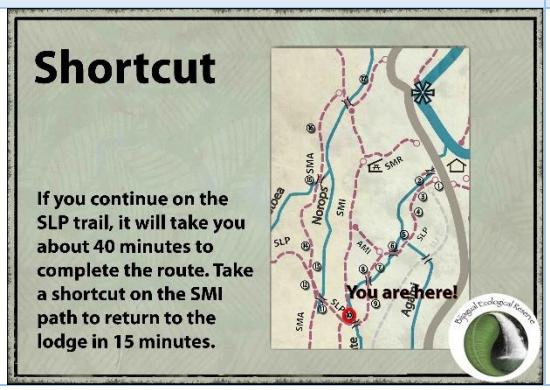
Appendix K: Designs for Trailside and Trailhead Signs

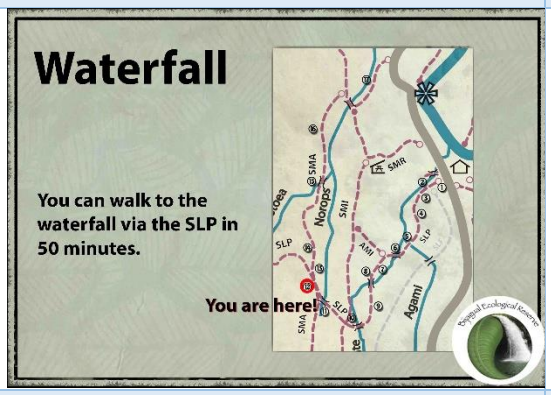
	Sign Design	Text Content	Citation
SDE 1		Leafcutter ants are a group that includes several species which range from South to Central America, Mexico, and parts of the southern United States. These fungus-growing ants can carry up to twenty times their body weight in fresh leaves, flowers, and grasses (Morgan, 2010). The ants process these materials into food for the fungus that they grow and consume. In a mature leafcutter colony, ants are divided into castes and perform different functions based mostly on their size (Leafcutter Ants, n.d.).	Morgan, R. (n.d.). Ant, Leaf Cutter 2010 - Welcome to the Cincinnati Zoo. Retrieved April 7, 2018, from http://cincinnatizoo.org/wp-content/uploads/2011/03/FactSheet-AntLeafCutter2010.pdf Leafcutter Ants - info and games. (n.d.). Retrieved April 07, 2018, from http://www.sheppardsoftware.com/content/animals/animals/breeds/ant_leafcutterant.htm
SDE 2		Howler monkey habitats span from southern Mexico to northern Argentina. They are considered to be among the loudest animals on earth. The sound produced by male individuals can travel three miles through dense rainforest. Despite their name and loud voices, individuals are quiet the majority of the time (Donovan, 2003). The sounds of howler monkeys can be heard from the Bijagual Ecological Reserve, especially in the early morning and evening hours. Threats to howler monkeys include human predation, habitat destruction and capture for use as pets or zoo animals.	Donovan, S. (2003). *Howler monkeys*. Chicago, IL: Raintree.
SDE 3		Between 2002 and 2009, 30 hectares (ha) of land that had previously been used as pasture were reforested with native species, including 10 different species of trees. Trees in reforested areas are measured regularly to assess survival rates and growth rates of native tree species (Bijagual Ecological Reserve, n.d.)	Bijagual Ecological Reserve. (n.d.). Retrieved April 07, 2018, from http://bijagual.org/

SDE 4		Created by client in future	
SDE 5		No Entry! Private Property	
SLP 1		The Bijagual Ecological Reserve is a hands-on classroom that promotes environmental education for students of all ages, an outdoor laboratory for conducting research, and a 709-acre rainforest protecting biodiversity. In partnership with other organizations in Costa Rica and around the world, we create a network that supports our goals in conservation, education and research. The reserve also works locally to encourage sustainable development and the preservation of native species.	Material quoted from: Bijagual Ecological Reserve. (n.d.). Retrieved April 07, 2018, from http://bijagual.org/
SLP 2		Costa Rica is home to more than 150 species of frogs and there are countless to be discovered. The red poison frog (*Oophaga Pumilio*) ranges from eastern central Nicaragua through Costa Rica and northwestern Panama. They are relatively small (around 17.55-22mm, 0.69–0.87 in) and can often be found in disturbed areas or leaf litter in the forest (Henderson, 2002).	Henderson, C. L. (2002). *Field guide to the wildlife of Costa Rica*. Austin: University of Texas Press.

SLP 3		Created by client in future	
SLP 4		Climate change has increased the earth's average temperature over the past century by 1.4 degrees Fahrenheit, which is leading to dramatic changes on our planet. (Lynch, 2014) The tropical forest ecosystem has also been influenced by these fluctuations. (Dunne, 2018) This thermometer collects data such as temperature and precipitation to look for evidence of the impacts of climate change on the rainforest.	Lynch, P. (2014, September 16). Secrets from the past point to rapid climate change in the future. Retrieved April 14, 2018, from https://climate.nasa.gov/news/649/secrets-from-the-past-point-to-rapid-climate-change-in-the-future/ Dunne, D. (2018, January 30). Rainforests: Scientists concerned climate change is altering the tropical life cycle. Retrieved April 14, 2018, from https://www.carbonbrief.org/rainforests-scientists-concerned-climate-change-is-altering-the-tropical-life-cycle
SLP 5		Rainforest in Costa Rica ranks first in the world in biodiversity per area unit (Costa Rica Tropical Rainforest. N.d.). There are several layers that comprise the rainforest canopy. Tree falling can produce an opening in the forest canopy, creating a localized increase in available light. These so-called "light gaps" allow light exposure to the soil and create resources for seeds and young plants to grow, which maintains diversity and richness and keeps the whole ecosystem working.	Costa Rica Tropical Rainforest. (n.d.). Retrieved April 07, 2018, from http://www.costarica21.com/Tropical-Rainforest.html

SLP 6		"Aquatic Macroinvertebrate" sounds like a complicated term, but if you break it down, it is easy to know what it means: "aquatic" means water "macro" means big "invertebrate" means without a backbone So really "aquatic macroinvertebrate" is a fancy term for a large bug that lives in rivers, streams, and ponds. Because aquatic macroinvertebrates are sensitive to changes in water quality, their presence or absence can be used to evaluate the health of a stream. Families of damselflies (Polythoridae), mayflies (Heptageniidae), and stoneflies (Perlidae) that are sensitive to water and habitat quality have been found in streams within the Bijagual Ecological Reserve. These organisms indicate that the Reserve's streams are healthy ecosystems!	
SLP 7		You are here! If you continue on the SLP trail, it will take you about one hour to complete the route. Take the AMI path to return to the lodge in 15 minutes.	

SLP 8		During pre-Columbian times, the indigenous people relied on agriculture and hunting, setting up permanent communities in the area. At this site there is evidence of past logging activities. Standing here, you will see big trees with vines and lots of palms. We can tell that some trees are harvested in the past because there are big trees and small palm trees in the same area. Since the 1970s, farmers have harvested some trees for timber. After cutting down a tree, the farmers attach a chain to it and drag it up the hill for construction.	
SLP 9		Fungi have three major roles in keeping our forests healthy: decomposing plant material and recycling nutrients back into the soil; removing diseased and weak trees, and supplying nutrients to healthy trees to help them thrive. Without fungi, our forests would not survive. About 69,000 species of fungi have been discovered worldwide, but it is thought that as many as 1.6 million actually exist! (Fungi.n.d.)	Fungi. (n.d.). Retrieved April 07, 2018, from https://treesforlife.org.uk/forest/forest-ecology/fungi-95/
SLP 10		If you continue on the SLP trail, it will take you about 40 minutes to complete the route. Take a shortcut on the SMI path to return to the lodge in 15 minutes.	

SLP 11		Since 2009, the Comisión Nacional del Programa Bandera Azul Ecológica has awarded a Blue Flag to the Bijagual Ecological Reserve for its efforts in protecting water quality and minimizing impact on the environment. We collaborate with Panthera Costa Rica on the Jaguar Corridor Initiative which is striving to protect core jaguar populations from Mexico to Argentina. We also collaborate on a riverine biological corridor project with local landowners and La Selva Biological Station to improve the connectivity between existing forest patches in the Sarapiquí region. (Bijagual Ecological Reserve, n.d.)	Material quoted from: Bijagual Ecological Reserve. (n.d.). Retrieved April 07, 2018, from http://bijagual.org/
SLP 12		You can walk to the waterfall via the SLP in 50 minutes.	
SLP 13		There are about 700 native and naturalized vascular plant species, 82 species of mammals and 289 bird species found in the Reserve. Scientists are still working on species list of amphibians, reptiles, protostomes, fish and fungi. These numbers could change overnight because of a new discovery! (Bijagual Ecological Reserve, n.d.)	Bijagual Ecological Reserve. (n.d.). Retrieved April 07, 2018, from http://bijagual.org/

SLP 14		The monkey pot tree is named after the pot-shaped fruits it produces. Monkeys are known to reach into these pot-shaped fruits to take out the seeds. The monkey pot tree can grow up to 20 meters tall with branches that spread vertically and horizontally (Monkey Pot Tree, n.d.).	Monkey Pot Tree. (n.d.). Retrieved April 07, 2018, from https://www.nparks.gov.sg/gardens-parks-and-nature/heritage-trees/ht-2013-214
SLP 15		In 2009 Dr. Cris Hochwender and students from the University of Evansville planted 200 trees in this area. They measure the plot every two years. The purpose of the project is to determine growth rates and survival of native tree species with potential for reforestation and timber production in the region. Measurements have shown that tree growth is robust and can support high levels of plant understory biodiversity. Ask for the record of height of different species of trees in the reforestation period when you return to the center if you are interested! (Bijagual Ecological Reserve, n.d.)	Material quoted from: Bijagual Ecological Reserve. (n.d.). Retrieved April 07, 2018, from http://bijagual.org/
SLP 16		Do you hear a bird calling overhead? That could be the Great Green Macaw, lalso known as Buffon's macaw or the great military macaw. This parrot species is native to Central and South American, and can be found in Nicaragua, Honduras, Costa Rica, Panama, Colombia and Ecuador (Forshaw,1978). On average, a great green Macaw is 1 meter long and can weigh nearly 1.5kg (Dunning Jr, 2008).	F., J., C., [Illustrator, W. T., A., D., . . . Forshaw Joseph M Cooper William T. (1978, January 01). Parrots of the World. Retrieved April 07, 2018, from https://www.abebooks.co.uk/book-search/title/parrots-of-the-world/author/forshaw-and-cooper/ Dunning Jr., J. B. (2008). CRC Handbook of Avian Body Masses, Second Edition. Retrieved April 07, 2018, from https://www.crcpress.com/CRC-Handbook-of-Avian-Body-Masses-Second-

			Edition/Dunning-Jr/p/book/9781420064445
SLP 17		Thank you for visiting! Donation List:	
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