Biomonitoring with Aquatic Benthic Macroinvertebrates

In Southern Costa Rica

In Support of Community Based Watershed Monitoring

by

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Foreword

The completed projected played a significant role in fulfilling objectives within my Plan of Study. Objective 1.1 is to gain in depth knowledge regarding water resource management techniques so that I may assess their practicality and usefulness. This project allowed me to gain an in depth knowledge of biomonitoring aspects of water resource management techniques. Furthermore, the project allowed me to assess their practicality and usefulness through the application of the assessments.

Objective 1.3 is to gain experience and develop skill within the area of watershed management practices. This research allowed me to gain important experience and develop skills within the area of watershed management. This experience was realized through the planning and design of components of a CBWMP, as well as the in-field testing of water quality and stream conditions.

Objective 2.1 is to develop a deep understanding of the social, economic and environmental history of Costa Rica so that I may understand how the present situation in the context of watershed management has been shaped. Living in Costa Rica for nine months and participating in a number of community events was very useful for providing me with an understanding of why some citizens have begun to feel that it is necessary for them to monitor their water resources.

Objective 2.2 is to further develop knowledge in the area of international development so that I am able to understand how this phenomenon has affected Costa Rica. Through my research as well as living experience within Costa Rica I was able to observe the way in which Costa Rica is part of a global world and thus how the phenomenon of international development has affected the country.

Objective 3.1 is to further develop knowledge and skills that are used within environmental planning so that I may be capable of developing environmental programs and projects. This research helped me to fulfill this objective through the development of CBMP components in which it is necessary to consider the interrelationships between people and ecological processes.

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List of Acronyms

BMWP	Biological Monitoring Working Party
BMWP-CR	Biological Monitoring Working Party-Costa Rica
CA	Correspondence Analysis
CBMP	Community Based Monitoring Program
DO	Dissolved Oxygen
FBI	Family Biotic Index
FBI-CR	Family Biotic Index-Costa Rica
FES	Faculty of Environmental Studies
JTU	Jackson Turbidity Units
N	Nitrates
OTS	Organization for Tropical Studies
P	Phosphates
ppm	Parts per Million
RPB	Río Peñas Blancas
RV	Río Volcán
SVA	Stream Visual Assessment
SVAP	Stream Visual Assessment Protocol
UCR	University of Costa Rica

Introduction

Watershed Management

It is becoming increasingly evident that we, humans, as global citizens need to embrace a methodology of ecological management that allows for the co-existence of both people and nature. At present time this is not the reality and instead:

> "A growing scarcity of fresh water relative to human demands is now evident in many parts of the world. Two of water's most fundamental functions – its role as a prerequisite for life, on the one hand, and its use as a commodity or economic resource on the other – are increasingly in conflict. In many areas, extracting more fresh water for agriculture, industry, or cities now places at risk the health of aquatic ecosystems and the life those ecosystems support "(Covich, 1993, Postel and Carpenter, 1997, as cited in Postel, 2000 p. 941).

Water is an integral part of all life on planet Earth. In the past, water has been viewed as an endless resource; however, it is apparent that human actions are affecting the quality and quantity of water resources that exist on Earth. Of substantial interest is the way in which water resources are being managed in the tropics. The majority of the world's biodiversity occurs within the tropics, and these plants and animals rely on interaction with water resources to survive.

Integrated Water Resources Management (IWRM) is an approach that has the capacity to efficiently handle multifaceted, complex environmental problems. For the purpose of this research, Integrated Water Resource Management is:

> "a process, which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (GWP TAC4, 2000, as quoted in Giupponi, C. et al. 2006, p. 6)".

IWRM is facilitated by using the watershed as a system boundary. A watershed is an ideal management unit as it is a natural boundary for many environmental flows. Furthermore, IWRM allows for and encourages community involvement in the management of their watershed. According to McConchie and McKinnon (2002), throughout the last couple of decades, there has been a widespread acceptance that public involvement is a critical element of effective environmental decision making. Moreover, they contend that those development projects that engage local people in the process of knowledge production are more likely to be sustainable over the long term. It is believed that the framework of IWRM is well suited for this research as it allows for the consideration of all the most important aspects and components of the system, and thus facilitates a better understanding of what is necessary for an achievable and sustainable solution.

One methodology that can be nested within the framework of IWRM is adaptive management. Concepts of adaptive management first appeared in the Gulf Island Recreation Simulation Study in 1968, where participants tried to bridge gaps between the various disciplines involved in the study (Gunderson et al., 1995 p. 490). However, formal development of adaptive management as a natural resource management approach can be traced back to the 1970s research conducted by an interdisciplinary team at the International Institute for Systems Analysis (IIASA) in Laxenburg Austria, headed by a Canadian ecologist C.S. Holling (NRC, 2004 p. 19).

The adaptive management approach uses systems thinking in the assessment and management of environmental issues and involves a "continual learning process that cannot conveniently be separated into functions like 'research' and 'ongoing regulatory activities,' and probably never converges to a state of blissful equilibrium involving full knowledge and optimum productivity" (Walters, 1986 p. 8). The expression "learning by doing" has become the catch-phrase for adaptive management (Schriber et al., 2004).

The adaptive management approach has interdisciplinary roots drawing upon theories from ecosystem sciences, economics, social sciences, engineering as well as other disciplines (NRC, 2004 p. 19). Furthermore, it is a methodology of ecosystem theory and therefore draws upon concepts such as:

- Complexity theory
- Resilience
- Organized connections between parts of a system
- Adaptiveness
- Uncertainty

Adaptive management does not wait to implement actions until "enough" is known about a managed ecosystem, but rather is designed to support action where there are limitations of scientific knowledge (NRC, 2004).

Monitoring programs play a key role in assessing the status and identifying possible trends in the environmental conditions of river basins. Furthermore they are able to assess the extent to which implemented measures actually have the expected effects in terms of improving the environmental status (Højberg et al., 2007). This project in particular focuses on the monitoring component of IWRM through the implementation and assessment of biomonitoring.

Biomonitoring

Biomonitoring is an environmental monitoring technique that utilizes living organisms to assess environmental health. The primary task in biomonitoring is the search for the ideal indicator, whose presence/abundance and/or behavior reflect a stressor's effect on biota (Resh and Rosenburg, 1993).

Traditionally, five taxonomic groups have been used in the assessment of water quality in streams. These include macroinvertebrates, algae, fish, bacteria and zooplankton. In recent times, aquatic macroinvertebrates have been the most popular organisms used in biomonitoring (Mackie, 2001). Historically, scientists from North America and Europe relied on only measurements of physical and chemical composition to determine water quality. It is now widely acknowledged that the results from this physiochemical approach reflect only those conditions that exist when the sample is taken. Conversely, biomonitoring is able to provide an indication of both current water quality conditions as well as longer-term changes (Resh et al., 1996, Jacobsen et al., 2008).

Project Scope, Objectives and Questions

The overarching objectives of the research project were the development and testing of components of a community based watershed monitoring program, as well as the collection of some baseline aquatic data for the two subwatersheds. The monitoring program included the collection of aquatic benthic macroinvertebrates, a simple chemical analysis as well as a stream visual assessment.

The purpose of this paper is to explore and characterize streams of two subwatersheds within the Río Terraba watershed, located in Southern Costa Rica. In doing so, this analysis will also evaluate the application of a number of biological indices to the area of study. The indices applied in the analysis are the Biological Monitoring Working Party – Costa Rica (BMWP-CR), the Hilsenhoff Family Biotic Index (FBI), a modified FBI for Costa Rica (FBI-CR)[1], measures of richness and diversity, and composition measures (discussed further in the Biomonitoring Section).

The main questions to be explored include:

1. What is the biological composition of the streams?
    a. Are conditions the same when comparing each watershed, high and low elevations, and large and small wetted widths?
2. Are there biological differences?
    a. If so what are they?
    b. Which indices best demonstrate this?
    c. Is the same biological pattern evident regardless of which index is used?

Predictions

1. Because of the diversity of the habitats sampled, the range of elevations and land-uses, I predicted that the biological composition of the streams within both watersheds will be diverse. In terms of elevation, there is a large difference in elevation within each watershed, because of this I expect that the communities might differ from low to high

[1] The modified FBI (FBI-CR) was tailored to take into account the geographic and biophysical differences between temperate and neotropical regions. The modifications were developed for the purposes of this project and carried out in consultation with Monika Springer, an aquatic entomologist at the University of Costa Rica. Refer to the Biomonitoring Section for further details.

elevation. Furthermore due to the large differences in gradient observed at many sites, I expected to find a high percentage of Ephemeroptera, Plecoptera, and Trichoptera. Furthermore, due to the substrate found in many streams I also predicted to find a high percentage of scrapers (such as Elmidae and Leptohyphidae).

2. Due to the differences in land-use between the two watersheds, I expected to see a difference in the biological composition between the watersheds. Because the BWMP-CR was designed for Costa Rica, I expected that this index would be the most accurate in identifying differences in biotic composition. BMWP-CR is based on species sensitivity as well as species richness; therefore other metrics such as richness, abundance or the FBI may also demonstrate similar biological patterns

Organization of this paper

The remainder of this paper while exploring biological monitoring in Costa Rica will address the objectives and questions presented in the Introduction. The second section (titled Study Area), geographically describes the study area. Section 3 (Biomonitoring) will explore biomonitoring, as well as highlight community based and volunteer monitoring programs within Costa Rica. Section 4 (the Costa Rican Context) addresses water management and agriculture in Costa Rica, and contextualizes the use of benthic macroinvertebrates for biomonitoring in the Tropics as well as Costa Rica. Section 5 (Methods) outlines the in-field as well as analytical methodologies implemented in the study. Section 6 (Results) presents the results of the study, and lastly Section 7 (Conclusions) summarizes with conclusions.

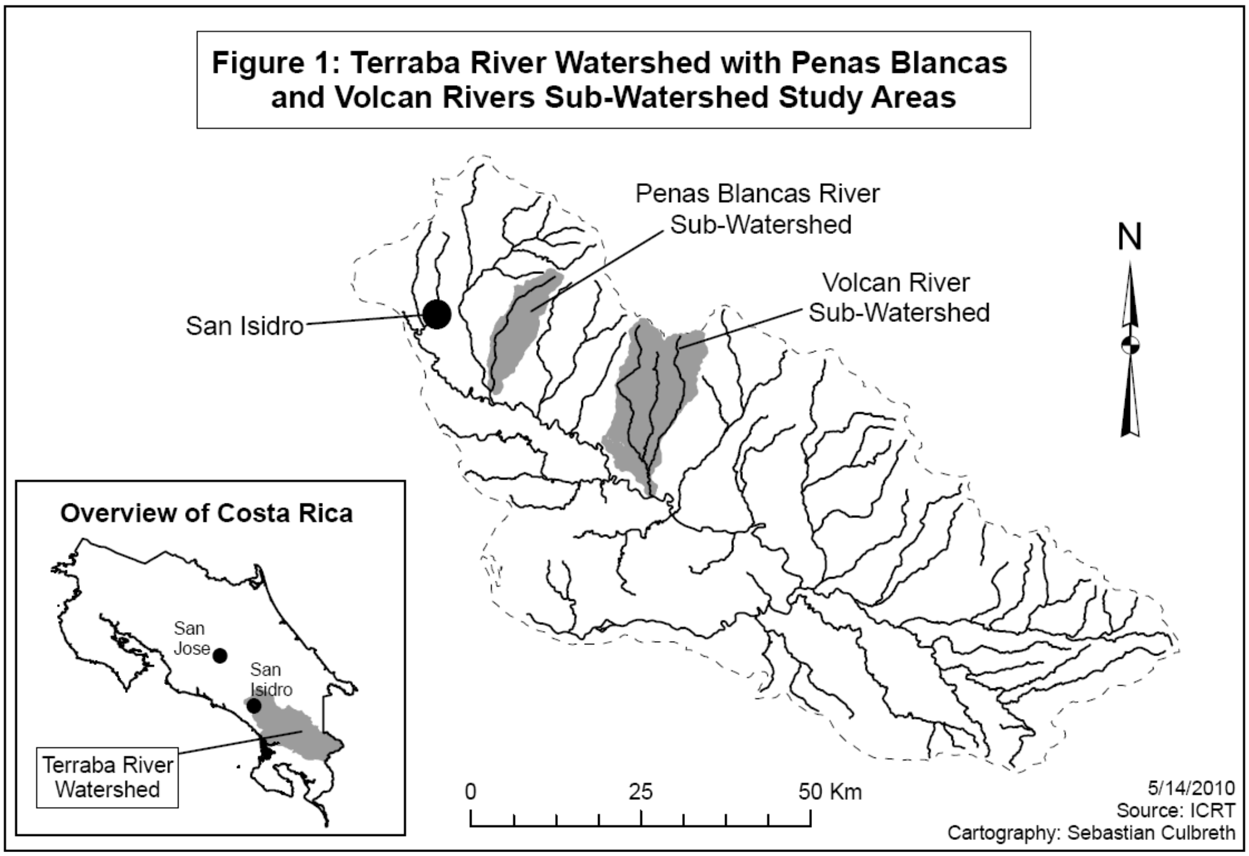
Study Area

This section describes the geographical location within which the research took place. The Río Terraba watershed is the largest within Costa Rica and has a drainage area of approximately 5100 km^2. More specifically, the focus of the project was within the two subwatersheds of Río Peñas Blancas and Río Volcán. Figure 1 depicts the location of the Río Terraba watershed and the two subwatersheds within the geographical context of Costa Rica.

The subwatershed of Río Volcán has a drainage area of approximately 230 km^2 (McConnell Smith, 2008). The headwaters of Río Volcán begin within the La Amistad Pacífico Conservation Area. The Volcán river basin was once dominated by cattle ranching and small scale farming, but is now characterized largely by industrial pineapple farming. However, higher in the watershed there still remains cattle farming and the remnants of old coffee farms. Montaña del Tigre, owned by PINDECO (a subsidiary of Del Monte) is an additional protected area that exists in the southern area of the Volcán basin.

The headwaters of the subwatershed of Río Peñas Blancas begins within the protected mountain forests of Chirripó National Park and encompasses an area of 88.9 km^2 (Young, 2001). Like the Volcán river basin, the Peñas Blancas river basin also has agriculture. The agriculture that exists within the Peñas Blancas basin is approximately one half small scale coffee and sugar cane farming, while the other half is comprised of cattle farming and pineapple fields (personal communication Martin Bunch, July 2010). While the area does contain a significant amount of small scale coffee farms, also present are large scale plantations of coffee, sugar cane as well as the recent encroachment of pineapple. Conversely, amongst the agriculture, dispersed throughout the watershed, exists a substantial amount of forest cover within protected areas such as Chirripó National Park, Las Nubes Biological Reserve and Los Cusingos Bird Sanctuary.

Figure 1: Terraba River Watershed with Peñas Blancas and Volcán Rivers Subwatershed Study Areas



Biomonitoring

Introduction

This section presents the topic of biomonitoring. Biomonitoring is a technique that utilizes living organisms in the assessment of environmental health. The success of biomonitoring is dependent on the ability to find and utilize an indicator species whose presence/abundance and/or behavior reflect stresses in the environment (Resh and Rosenburg, 1993). This biomonitoring study used aquatic benthic macroinvertebrates as an indicator of stream health within the Peñas Blancas and Volcán watersheds of Costa Rica from January 2009 to March 2009.

Advantages and Disadvantages of Biomonitoring

The use of aquatic benthic macroinvertebrates within a biomonitoring program has both advantages and disadvantages; a summary of these are presented Table 1 below. The term aquatic benthic macroinvertebrates refers to organisms that inhabit the bottom substrates (sediments, debris, logs, macrophytes, filamentous algae, etc) of freshwater habitats, for at least part of their life cycles. *Macro*invertebrates are those retained by mesh sizes greater than or equal to 200 to 500 µm. Nectonic and surface-dwelling organisms, such as larger shrimp and the families of Veliidae and Gerridae are also sometimes included in this grouping, although they are not technically benthic macroinvertebrates (Resh and Rosenberg, 1993). [2, 3]

Benthic macroinvertebrates are utilized in biomonitoring because they function as "indicator species" of water quality conditions. An indicator species is defined here as, "a

[2] Nectonic organisms are those that can swim freely in the water column, unrestricted by the current.
[3] The non-scientific name of Veliidae and Gerridae is waterstrider.

species (or species assemblage) that has particular requirements with regard to a known set of physical or chemical variables such that changes in presence/absence, numbers, morphology, physiology, or behavior of that species indicate that the given physical or chemical variables are outside its preferred limits" (Resh and Rosenberg, 1993, p. 40).

Table 1: The advantages and disadvantages of aquatic macroinvertebrates as bioindicators of stream health

Advantages	Disadvantages
They are everywhere and are affected by perturbations in all waterways.	Quantitative sampling requires large numbers of samples, which can be costly.
The large number of species offer a spectrum of responses.	Factors other than water quality can influence organism distribution and abundance.
Most are sedentary in nature which allows spatial analysis of disturbances.	Difficulties may occur in data interpretation or comparison due to seasonal variation.
They have long life cycles which allow for the temporal examination of perturbations.	Inclination of some macroinvertebrates to drift may offset the advantage gained by the sedentary nature of many species.
Qualitative sampling and analysis methods are well developed and can be undertaken with simple, inexpensive equipment.	Many methods for analysis available, which could indicate that scientists are not satisfied with the results.
The taxonomy of most groups is well known and identification keys are widely available.	Taxonomy of various groups is not well known.
There are many methods of analysis that have been developed for macroinvertebrates.	Benthic macroinvertebrates are not sensitive to some perturbations, such as human pathogens and trace amounts of some pollutants.
The responses of many aquatic insects to different types of pollution are well established.	
Measures of biochemical and physiological responses of individual organisms to perturbations are under development.	

Note: Adapted from Resh and Rosenberg 1993, and Resh et al., 1996.

Community and Volunteer Biomonitoring

Within the United States, the first community based biomonitoring began in 1922, when a group of anglers decided to form a collective and work together to protect rivers through volunteer stream monitoring. In 1926, the group (named,The Izaak Walton League of America), initiated its first major effort to investigate pollution and water quality. This initiative continued to grow and resulted in the presently very successful monitoring program Save Our Streams, which was founded in 1969 (Firehock and West, 1995).

Early monitoring programs used primarily visual observations; noting clear problems such as trash, strange colours or strong odours. By the 1960s some volunteer groups were measuring water quality through chemical analysis and by the 1970s the use of a basic chemical water monitoring kit was common. In 1976, the first known use of aquatic insects in volunteer monitoring was implemented. The technique looked at the presence or absence of three indicator orders (Plecoptera, Trichoptera, and Ephemeroptera), within riffle habitat of streams. Originally, this was intended to increase public awareness as well as to increase public support for the restoration of waterways (Firehock and West, 1995). A 1998 report stated that at the time 76% of active stream volunteer monitoring groups were using benthic macroinvertebrates as part of their monitoring (USEPA 1998, as cited in Nerbonne and Vondracek, 2003). As time passed, volunteer monitoring programs worked with the Department of Natural Resources and the Environmental Protection Agency, and began to collect data with the intent to use it to help guide decision makers at the government level.

As the presence of volunteer monitoring groups expanded in the United States and the data that they produced increased, there became more and more of a concern regarding the reliability and validity of the data collected (Engel and Voshell, 2002; Penrose and Call 1995). The US Environmental Protection Agency has decided that data from volunteers can and should be used in reports that are compiled by states to report on current environmental conditions. Some actions that can assist in the collection of more reliable data include placing an emphasis on training and explaining the rationale behind the monitoring, concentrating efforts on acquiring committed volunteers, and the inclusion of a local professional (Nerbonne and Vondracek, 2003).

Overdevest et al. (2004) discuss the ways in which community based monitoring can be used as a mechanism of adaptive management. In this way the data generated from the community monitoring efforts can be used to track the effects of any current management regime and contribute to the knowledge necessary to make changes to management plans as well as understand the constantly changing conditions. Furthermore, it has been argued that Community Based Monitoring Programs (CBMP) are positive for the overall management of watersheds and general environmental well being. This argument is based on the premise that through participation, volunteers begin to have a deeper understanding of the issues, are more likely to want to initiate changes in policies, and are more likely to educate their neighbours (Overdevest et al., 2004). Therefore, community based monitoring groups can play a fundamental part in watershed management firstly through the generation of data, which can then be used to inform regional decision makers, and secondly as a means to generate a local, collective environmental conscience that can influence the management of watersheds at the grassroots level.

Agencies in Costa Rica

While in Costa Rica, I had the opportunity to visit a number of local environmental agencies. This allowed me to understand the types of stream monitoring programs that were or had been in existence within Costa Rica. The agencies visited include, Nectandra, the Organization for Tropical Studies, Tirimbina, and ANAI. Below is a description of each agency.

Nectandra

Nectandra Institute: carries out educational programs for the general public promoting biodiversity and ecology of cloud forests in Costa Rica. They have recently begun to promote environmental education, conservation and the restoration and sustainable use of water as a resource (Nectandra Institute, 2008). Although at the time of my visit Nectandra had not been conducting stream monitoring, one of Nectandra's employees Randal Varela had recently completed a week long training session with the Stroud Institute to learn about stream biomonitoring with use of the LaMotte Leaf Pack Experiment Kit[4].

Organization for Tropical Studies (OTS)

In 1986, Professor Catherine Pringle from the University of Georgia established the STREAMS project to study the ecology and biogeochemistry of tropical lowland streams in Central America. The project is coordinated out of the Organization for Tropical Studies La Selva Biological Station, which is located in the town of Puerto Viejo, in the province of Heredia. The project encompasses three areas: 1. linkages between stream ecology and biogeochemistry; 2. ecology and natural history of stream communities; 3. water resources conservation and environmental outreach on water quality and quantity. As part of this third area, an adaptation of the *Adopt a Stream* Program (from the United States), was translated into Spanish and adapted for use with students from a Costa Rican high school. The manual consisted of information to start a volunteer monitoring program, sampling procedures as well as instructions for data interpretation. The program was implemented from 1995 to 1996. The project was unsuccessful for a number of reasons. These reasons include a shortage of funding,

[4] The Stroud Water Research Center conducts research in streams, rivers and watersheds throughout the world. The Stroud Water Research Center with LaMotte developed a Leaf Pack Experiment Kit and a Leaf Pack Network. These kits are used to discover and monitor stream aquatic insects. Furthermore, in 1989 the Stroud Water Research Center helped establish the Maritza Biological Station in the Guanacaste Conservation Area of Costa Rica. The station is the Center's headquarters for the study of tropical ecosystems and serves as an information source for Latin American scientists and land managers (Stroud Water Research Center, 2010).

lack of necessary chemicals, and lack of sufficiently trained individuals present in the community to assist with the identification of stream insects.

Tirimbina Rainforest Center

The Tirimbina Rainforest Center is located along the Sarapiquí River, in the town of Sarapiquí, in the province of Heredia. As part of its environmental education program the center occasionally conducts water monitoring consisting, in part, of the collection of aquatic benthic macroinvertebrates with school children. This is not a formal monitoring program but rather a tool for environmental education.

ANAI

ANAI is a grassroots organization located in Costa Rica's Talamanca region. They work from the belief that they should help communities develop the capacity to manage existing or potential environmental activities. Over the last decade, they have developed a very successful stream biomonitoring program in the Talamanca region and beyond which includes fish sampling, macroinvertebrate sampling, as well as habitat assessments. (Asociación ANAI, 2008). It seems that ANAI has the only established, successful community biomonitoring program that currently exists in Costa Rica.

Overall, other than ANAI, it seems that no other monitoring programs exist within Costa Rica. The major weakness of the ANAI program is the reliance on funding and in some cases equipment from the United States. Much of the program relies on international volunteers and interns. In 2008, there was one full time ANAI employee (Maribel Mafla) dedicated to the coordination of the biomonitoring. Maribel Mafla is also authour of the Guía para evaluaciones ecológicas rápidas con indicadores biológicos en ríos de tamaño mediano, Talamanca, Costa

Rica (2005). Maribel, along with some trained volunteers provided consistent technical expertise needed to conduct biomonitoring.

Building Connections to Community Based Monitoring

A significant portion of this project field work involved working with community members within both Peñas Blancas and Volcán subwatersheds. During my first few weeks within Costa Rica I attended various community group meetings where I introduced myself, discussed my research, requested local input and addressed my desire for local field assistants to help with my research. From these introductory meetings I was able to proceed with talking to community members about their watersheds and together we identified various watershed characteristics such as the locations and varying types of agriculture and then developed some preliminary ideas of where biomonitoring stations might occur. An additional outcome from these meetings was the identification of individuals who were interested in working with me in the field. The arrangement was mutually beneficial. I had assistance both for sampling as well as navigation to desired locations and the assistants had the opportunity to gain some financial compensation as well as learn the methodologies of biomonitoring and thus would be equipped to assist in potential future studies. Throughout the course of my field work I had 3 assistants from Volcán, 2 from Altimíra, and 2 from Peñas Blancas. Beyond these formal assistants, with each family I lived with there were always young individuals very fascinated in the aquatic insects and interested in helping. With close observation they assisted me in various ways as we discussed stream ecology, importance of the aquatic insects and overall watershed health.

The project also included my involvement in community educational workshops in each watershed. I presented my work in separate workshops in each subwatershed. In addition to these presentations I conducted a workshop at the Environmental Fair in the Peñas Blancas subwatershed. This presentation involved a field component with a group of school children in the community of Quizzará. As a group, we went to the adjacent Peñas Blancas River and collected a small number of insects. We identified them at the stream bank and based upon the individuals that we found completed a quick assessment of the water quality.

Lastly, through my field research, I became involved in the project "Hacia una red nacional escolar de monitoreo y restauración socioecológica" (Translation: Create a National Educational Network of Socioecological Monitoring and Restoration) coordinated by Professor Álvaro Fernández González of the University of Costa Rica. Through this program I was asked to participate in two presentations for teachers and educational coordinators about my project and ways that biomonitoring programs could be incorporated into environmental educational curriculum. Furthermore, I participated in an additional workshop with this program with that involved in field demonstrations with teachers and students from Costa Rica's central region.

Biological Indices

Biological indices are tools of analysis that are used to determine the significance of the presence or absence of a specific group of biological organisms. Indices for aquatic benthic macroinvertebrates are developed based on the premise that pollution tolerance differs among various benthic organisms. Based upon the knowledge known about the taxa which exist, pollution tolerance scores are developed for each taxon based on the type of pollution. Most oftentimes this pollution is organic in nature (Resh et al., 1996).

The number of indices that exist for aquatic benthic macroinvertebrates is approximately five times more than any other aquatic bioindicator group. Presently, there are about fifty indices in existence and the number is still growing. In recent years, there has been a shift to the development and use of more rapid biological techniques for both the collection and identification of aquatic benthic macroinvertebrates (Mackie, 2001).

It is important to note that many currently used indices have been formulated to detect organic pollution. Although they are able, to an extent, to integrate overall environmental quality, they may not be able to determine the exact cause for change in an aquatic benthic community. Moreover, water quality issues that are of importance to humans (i.e. fecal bacteria) may not be directly reflected in the results of biotic indices, and therefore, decisions regarding human use should not be based upon the results of biotic indices (Jacobsen et al., 2008).

This study analyzed the use and application of three indices within Costa Rica. The three indices are: The Biological Monitoring Working Party – Costa Rica Index (from here on referred to as BMWP-CR), the Hilsenhoff Family Biotic Index (FBI), and a Modified Hilsenhoff Family Biotic Index, modified for Costa Rica (FBI-CR).

The Biological Monitoring Working Party – Costa Rica Index

The British Department of Environment, in a response to criticism regarding their implementation of biological monitoring methods, set up the Biological Monitoring Working Party - a working group that was to recommend a monitoring system to be used in the national river pollution surveys (Hawkes, 1998). The result was the creation of the BMWP Score System. In 2007, the BMWP Score System was modified for use in Costa Rica and from here on will be referred to as BMWP-CR. The Costa Rican government has recently incorporated the BMWP-CR into a newly established law entitled the Law for the Evaluation and Classification of the Health of Shallow Bodies of Water. This recognition defined the BMWP-CR as an official methodology for stream biomonitoring in Costa Rica (Maue and Springer, 2008).[5]

Following the original BMWP Score System, the BMWP-CR functions by assigning a sensitivity value (from 1 to 10) to each family collected. A value of 1 is assigned to families that are very pollution tolerant and values of 10 to those which are sensitive to pollution. The sensitivity values from each family are then summed to produce a final score. Table 2 demonstrates how the BMWP-CR score was generated for monitoring site RPB02a of this research project. As can be seen, the sum of all the pollution sensitivity scores for all taxa present is 75. Next, a categorical scale (depicted in Table 3) is used to determine the classification of the water quality at each site sampled. Therefore, with a score of 75, according to the BMWP-CR, monitoring site RPB02a, from this study can be described as having water of regular quality, eutrophic, medium contamination. It is important to note that the BMWP-CR does not account for the family abundance. For this reason, the application of the FBI (which includes abundance at the family level), was explored

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[5] The BMWP-CR index was published as part of regulation number 33903-MINAE-S and can be found in La Gaceta No. 178, 17 Sept. 2007.

Table 2: Example of BMWP-CR Index Score Calculation for Site RPB02a

Taxa Present (Family level)	BMWP-CR Pollution Sensitivity Value
Baetidae	5
Leptohyphidae	5
Leptophlebiidae	8
Naucoridae	4
Hydrobiosidae	9
Hydropsychidae	5
Leptoceridae	8
Dryopidae	5
Elmidae	5
Chironomidae	2
Simuliidae	4
Corydalidae	6
Perlidae	9
TOTAL	**75**

Table 3: Evaluation of water quality using the biological working party-Costa Rica Index

Water Quality	BMWP-CR	Associated Colour
Waters with excellent quality	>120	Blue
Waters with good quality, no contaminations or obvious distortions	101-120	Blue
Waters with regular quality, eutrophic, medium contamination	61-100	Green
Waters with bad quality, contaminated	36-60	Yellow
Waters with bad quality, very contaminated	16-35	Orange
Waters with very bad quality, extremely contaminated	<15	Red

Hilsenhoff Family Biotic Index

In a 1972 paper, Chutter outlines the development of a biotic index for aquatic insect communities of riffle habitat, within streams and rivers of South Africa. The index was intended to measure water quality in terms of organic pollution. Subsequently, in 1977, William L. Hilsenhoff developed and proposed the use of a modified version of Chutter's index in Wisconsin for the evaluation of organic pollution in streams (Rosenberg and Resh, 1993). This species level index (known as the Hilsenhoff BI) uses only insects, amphipods, and isopods because they are abundant and easily collected from the majority of streams. These organisms were also selected based on a number of other advantages previously outlined in Table 1.

In 1988, Hilsenhoff developed a modified version of the Hilsenhoff BI. This adapted biotic index allowed for a more rapid evaluation of macroinvertebrate samples. Consequently, through developing pollution tolerance values for families, instead of for species as in the Hilsenhoff BI, the Hilsenhoff Family Biotic Index (FBI) was developed. Family-level tolerance values were derived by comparing the occurrence of each family with the average Hilsenhoff BI score of streams in which they occurred in the greatest numbers (Hilsenhoff, 1988). Therefore, family-level tolerance values are inclined to be a weighted average of tolerance values of species and genera within each family.[6]

In order to calculate the FBI, species are assigned pollution tolerance values of 0 to 5. A value of 0 is assigned to those species found only in unaltered streams of very high water quality. Conversely, a value of 5 is assigned to those species known to occur in severely polluted or disturbed streams. The values of 1-4 are assigned to those species that are found in streams with intermediate degrees of pollution or disturbance. Once the FBI is calculated, the scale depicted in Table 4 is then used to determine the classification of the water quality at each site sampled.

The FBI is calculated as follows:

$$FBI = \sum(n_i\, a_i)/N$$

Where n_i represents the number of individuals in each family, a_i represents the tolerance value assigned to the family, and N is the total number of individuals in the sample. It is important to note that unlike the BMWP-CR the FBI accounts for abundance of individuals.

[6] The data that was analyzed for this is from a stream study throughout Wisconsin that included more than 2000 stream samples (Hilsenhoff 1988).

Table 4: Evaluation of water quality using the Family Biotic Index
(Hilsenhoff, 1988)

Family Biotic Index	Water Quality	Degree of Organic Pollution
0.00-3.75	Excellent	Organic pollution unlikely
3.76-4.25	Very good	Possible slight organic pollution
4.26-5.00	Good	Some organic pollution probable
5.01-5.75	Fair	Fairly substantial pollution likely
5.76-6.50	Fairly Poor	Substantial pollution likely
6.51-7.25	Poor	Very substantial pollution likely
7.26-10.00	Very Poor	Severe organic pollution likely

A comparison of the BI and the FBI from 60 samples indicated that the use of the BI and FBI yielded slightly different results. Typically, the FBI indicated greater pollution of clean streams by overestimating BI values and then usually denoted less pollution in polluted streams by underestimating BI values (Hilsenhoff, 1988). Moreover, Hilsenhoff (1988) notes that the use of the FBI is valuable for evaluating the general status of organic pollution in streams for purposes such as deciding which streams or watersheds should be studied further. Emphasis is placed on the fact that the FBI is intended more for use as a rapid field procedure. Since it is less accurate and there is a greater possibility that it could lead to incorrect conclusions about water quality, it should not be used as a substitute for the Hilsenhoff BI

The Modified Hilsenhoff Family Biotic Index for Costa Rica

The current index used most predominantly in Costa Rica is the BMWP-CR. However, the fact that the BMWP-CR does not include abundance raises concern that it is possibly not accurately evaluating the health of streams. Therefore, the use of the FBI was considered because, firstly it accounts for taxa abundance, and secondly because it is one of the most commonly used abundance-weighted tolerance indices used in freshwater bioassessments (Barbour et al., 1999). The FBI tolerance scores were developed for taxa as they exist and respond to perturbation within the streams of the Wisconsin area of the United States.

The application of the exact FBI scores could be problematic for two reasons. Firstly, although many of the same taxa exist in Costa Rica as in the U.S., there are a number of taxa within this study's results that are not accounted for within the FBI. Only approximately 45% of the families collected in the dataset were represented in the FBI. Using less than half of the taxa in the analysis may be problematic. Secondly, some taxa respond differently to inputs of pollution in Costa Rica, than in the States. Thus, there is a concern that using the Hilsenhoff published FBI scores would result in only a gross approximation; and consequently, a modified version of the Hilsenhoff FBI was developed solely for the purpose of this study.

Through consultation with Monika Springer and Pablo Gutiérrez Fonseca[7], local experts on the subject, two general changes were made to the Hilsenhoff FBI. Firstly, where the family tolerance values were not scaled correctly for the Costa Rican environment, the values were modified to reflect the fact that some taxa in Costa Rica respond differently in the tropics compared to their counterparts located in the United States. Secondly, those aquatic insects that were collected but did not have values in the Hilsenhoff FBI were provided with scores to reflect

[7] Aquatic Entomologists at the School of Biology, University of Costa Rica.

their tolerance to pollution. Both expert knowledge and the published scores of the BWMP-CR were used as references in the modifications of existing Hilsenhoff FBI tolerance scores and the creation of new tolerance scores for taxa not included in the original FBI. The same equation and classifications utilized to calculate the original FBI is used to determine the modified FBI (refer to the FBI equation expressed above and Table 4).

Although modifications through empirical study or laboratory experimentation are clearly preferred, as Jacobsen et al. (2008) points out, “this is rarely the approach used and researchers often resort to ‘scientific intuition’” (p. 93). Furthermore, Jacobsen et al. (2008) notes that, although the general tolerance of each family does not seem to vary much across regions or continents, the accuracy of individual biotic indices could be improved by adjustments to account for known differences between temperate and tropical regions in family representation (see Table 5 for FBI-CR). Family based biotic indices that have been modified to better represent the region have been developed and applied within Argentina, Colombia, Brazil and Thailand (Jacobsen et al., 2008). A summary of the modifications made to the FBI in this study for the creation of the FBI-CR, including adjustments based on differences between temperate and tropical regions, can be found below in Table 5.

Table 5: Modifications the Hilsenhoff FBI Score SEQ

Family	Hilsenhoff FBI Score	Modified FBI Score for Costa Rica
Athericidae	2	1
Chironomidae*	6 & 8	7
Calopterygidae	5	7
Cordulegastridae	3	2
Corduliidae	5	1
Corydalidae	0	4
Gomphidae	1	3
Helicopsychidae	3	5
Heptageniidae	4	3
Hydropsychidae	4	5
Lestidae	9	6
Libellulidae	9	7
Philopotamidae	3	5
Polycentropodidae	6	3
Tipulidae	3	5
Leptohyphidae	No value	4
Belostomatidae	No value	6
Naucoridae	No value	5
Megapodagrionidae	No value	2
Platysticitidae	No value	1
Polythoridae	No value	0

Family	Hilsenhoff FBI Score	Modified FBI Score for Costa Rica
Calamoceratidae	No value	2
Hydrobiosidae	No value	3
Limnichidae	No value	5
Ptilodactylidae	No value	3
Dixidae	No value	4
Hidracarina	No value	4
Lutrochidae	No value	3
Oligochatea	No value	10
Sphaeridae	No value	6
Hydraenidae	No value	3
Staphylinidae	No value	7
Gomphidae	No value	3
Hirudidae	No value	10
Euthyplociidae	No value	2
Scirtidae	No value	7
Ecnomidae	No value	2
Dytiscidae	No value	7
Stratiomyidae	No value	9
Lampyridae	No value	7
Physidae	No value	10
Planorbidae	No value	7
Ancylidae	No value	5
Hydrophilidae	No value	7
Blaberidae	No value	2

*within the Hilsenhoff FBI there are different scores between Blood-red Chironomidae (score of 8) and Other (including pink) Chironomidae (score of 6). Within the identification process, this distinction was not made. Because both exist within the samples, a score of 7 was given to all Chironomidae.

Summary

The use of aquatic benthic macroinvertebrates is predominant within biological monitoring because they function as a good indicator of stream health and water quality. Moreover, due to low cost and relative ease of use benthic macroinvertebrates are popular as an indicator group for community organizations conducting stream assessments. In Costa Rica, there is one community based monitoring group, ANAI that conducts biological monitoring with aquatic insects. Biological indices are tools used in biomonitoring to analyze the presence or absence of indicator taxa. This study includes the analysis of three major biological indices, the BWMP-CR, the FBI and the FBI-CR. Section 4 (Costa Rican Context) will discuss water monitoring and management within the Costa Rican context.

[10] This statistic is from 2000, (FAO, 2007).

Costa Rican Context

Introduction

In the previous section biomonitoring and its application to water monitoring was discussed. This section will discuss water management in Costa Rica. In particular, this section will provide an overview of the role that agriculture has on water management issues in Costa Rica as well as the use of aquatic benthic macroinvertebrates to measure stream health within Costa Rica.

Costa Rica: Water & Agriculture

Despite its mere size of 51,100 km^2, Costa Rica is considered the most biodiverse country in the world. It is the only piece of land where flora and fauna of both the northern and southern hemisphere co-exist (Rodriguez, 1993). It is also a country rich in microclimates, with altitudes ranging from sea level to more than 4000 meters above sea level (Rodriguez, 1993). This unique geographical position has enabled Costa Rica to be host to 205 species of mammals, 845 species of birds, 160 species of amphibians, 218 species of reptiles and 1013 species of fresh-water and marine fish. This list only includes those species that have been discovered and does not include the even greater number of insect species present throughout the country and the 10,000 vascular plants that have been discovered; accounting for roughly 4% of the total number of plant species worldwide (Boza, 1993).

Water is an integral part of the biodiversity in Costa Rica as well as all life on Earth. In the past, water has been viewed as an endless resource in many regions of the world, including Costa Rica. It is now apparent that human actions have led to the mismanagement of this precious resource. The Costa Rican landscape has a long history of degradation, with most negative impacts coming from deforestation to make way for cattle ranching and large scale agriculture. According to Schrier (2003) agriculture is the largest cause of water quality deterioration worldwide. The close proximity and abundance of agriculture to the waterways within Costa Rica as well as the pesticide dependence of many forms of agriculture, suggests that there is a need for conservation and restoration measures as well as a means of monitoring for their success.

Leading aquatic scientists Pringle and Scatena (1999) state that "virtually every major watershed in Costa Rica is undergoing degradation because of deforestation and inappropriate land uses" (p. 119). Furthermore, de la Rosa (1999) states that streams and rivers in Costa Rica represent extremely degraded ecosystems. Finding ways to restore and properly manage Costa Rican watersheds is important to the survival of the high rate of the biodiversity, the ecological uniqueness of the country and the continued well-being of the present and future citizens.

Although the management of forests in Costa Rica receives worldwide attention for their apparent success, the management of water resources tends to be far less idyllic. Water resources in Costa Rica are protected under two laws. The first, enacted in 1989, is intended to protect important aquifers, and the other enacted in 1997 to control wastewater and effluent (de la Cruz and Castillo, 2003). Although these laws exist on paper, there are indications that there is little or no enforcement. Ballestero and Reyes (2006) describe the water management of Costa Rica to be:

> characterized by the absence of clear policies, outdated legislation and the lack of, and/or overlaps, in capacities and functions among the leading public, private or external entities . . . water resources administration is highly fragmented . . . (p. 183).

The nature of water resource management in Costa Rica has resulted in the cumulative decline in the quality of water resources.

The impacts of agriculture on water resources within Costa Rica cannot be ignored as agricultural accounts for approximately half of the land in the country (Evans, 1999). Furthermore, in regards to water, agriculture accounts for 54 percent[10] of the water use in the country (FAO, 2007). The expansion of agriculture throughout Costa Rica has caused immeasurable environmental destruction. By 1950, the monoculture form of producing crops had begun to flourish in Costa Rica with primarily bananas (approximately 30,000 ha), coffee (49,000 ha), and sugar cane (22,700 ha), (de la Cruz and Castillo, 2003). With monoculture, there is an increased need for insecticide; in the event that an infestation occurs, farmers are at risk of losing a whole crop. Thus, the intensive use of pesticides became necessary as a means to eradicate pests. The Costa Rican agricultural sector is highly reliant on the use of synthetic pesticides as a method of pest control. Although there are laws regulating the use of pesticides in Costa Rica, due to a lack of implementation and enforcement, these laws are generally not followed (de la Cruz and Castillo, 2003). By the mid 1990s, there were large expansions of the monocrop system of agricultural production. This high amount of rainfall can result in the transport of pollutants through water runoff, as well as contaminants being transported to water through soil erosion. Despite the large amount of pesticides used within the country, any type of national monitoring program does not exist (de la Cruz and Castillo, 2003). Chemicals from agricultural activities are one of the main sources of contamination of both groundwater and surface water in Costa Rica (Ballestero, 2006). Due to a lack of enforcement of the laws as well as any type of monitoring program, the agricultural industry in Costa Rica experiences no incentive to consider the environmental impact of their operations.

According to Ballestero (2006, p. 194), water is virtually free in Costa Rica; and therefore, "the Costa Rican population lacks a proper appreciation of the true value of water". Considering the distribution of water use within the country (29% domestic, 17% industry, 54% agriculture), it is possible that it is not only the Costa Rican population that does not have a true appreciation of water, but also the many large scale (foreign owned) agricultural farms (FAO, 2007). Due to the lack of environmental enforcement, the continual expansion of agriculture[11] and the subsequent chemical application, it is evident to me that the current water resource practices in Costa Rica are not sufficient for successful management of current and future water supply. One positive occurrence is the increased interest in benthic macroinvertebrates as water quality indicators within Costa Rica. This augmented awareness may be an indication of a change in perception towards water management.

Use of Benthic Macroinvertebrates in the Tropics

Within the temperate zones, bioindicators have been used since the early 1900s as a biomonitoring tool within temperate zones (Maue and Springer, 2008). For example, Forbes and Richardson (in 1913), studied the presence of organisms and their tolerance levels to waste decomposition within the Illinois River. Even earlier, in Europe, scientists Kolkwitz and Marsson developed the Saprobien system for the assessment of organic pollution during the years 1908 and 1909 (Cintrón, 2008). Even though bioassessment can be easily used as an inexpensive tool to provide aquatic environmental information at a fraction of the price compared to chemical testing; in general, countries within the tropics have made only limited use of biomonitoring as a technique to assess stream conditions or to provide information on water quality (Jacobsen et al., 2008).

[11] Rapson et al., Unpublished

In the study of aquatic insects, many tropical researchers have difficulty staying current on literature and research. This occurs mostly because research papers are relatively rare, and the literature is widely scattered not only in journals for stream research, but also in journals specializing in tropical research as well as in unpublished reports or grey literature with only local or regional distributions (Jackson and Sweeney, 1995 and Springer, 2008).

A 1995 publication (by Jackson and Sweeney) discusses the results of a survey amongst tropical aquatic benthologists. The purpose of the survey was to gain insight into what the community felt was important to direct future research in the field. The most common recommendation was the need for future studies to incorporate larger scale perspectives (i.e., whole drainage basins or beyond, including estuaries and oceanic connections). This would help to better inform, and thus, increase the success of implementing conservation and management practices. The second was a recommendation that future research involve biodiversity studies including those of taxonomy as well as the study of certain factors such as chemical, physical, geological and biophysical that are important for maintaining biodiversity. Lastly, future research in tropical streams should determine if models describing the structure and function of temperate streams can be used for tropical streams.

Use of Benthic Macroinvertebrates in Costa Rica

For a number of reasons, such as the political stability, small size, large number of conservation areas, as well as its wide range of climates and bioregions, leading to immense biodiversity; Costa Rica is one of the most studied neotropical countries. Included within the Costa Rican biodiversity are aquatic insects. Recently, Monika Springer (2008), attempted to summarize the existing body of knowledge on the aquatic insects of Costa Rica. She notes that although abundant in many aquatic ecosystems, aquatic insects have the highest diversity in clean, high velocity mountain rivers and streams. Additionally, from a taxonomical perspective, the best known orders of aquatic insects in Costa Rica are Trichoptera, Odonata and Plecoptera (Springer, 2008).

Despite the growing interest in the study of aquatic insects (over the last decade), coupled with the importance of aquatic insects in biomonitoring and environmental impact studies, it is difficult to locate scientific publications on the topic. Although there have been many studies on aquatic insects, most of them do not get published in scientific journals. Often, this is because many of the studies in Costa Rica are conducted by foreign and local masters and PhD students. Although they are available in university libraries, the majority of them are not published in peer reviewed journals (Springer, 2008).

There are a number of aquatic insect collections that exist within Costa Rica; however, the most complete is the Museo de Zoología located at the University of Costa Rica. The museum was established in 1992, and currently the collection contains over 300 genera within 95 families and 11 orders (Springer, 2008).[12] At the present time the museum is working on the creation of an online database where people would be able to access information on the existing specimens collected (personal communication, Monika Springer).

Agriculture and deforestation have a significant role in the degradation of water resources within Costa Rica and a change in the current management regime is necessary. An approach such as adaptive management, where monitoring is applied to measure the success or changes occurring within the system, might be useful. Although the use of benthic macroinvertebrates to assess water quality has gained popularity within the tropics and Costa Rica more recently,

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[12] A compete list of the collection can be accessed through http://museo.biologia.ucr.ac.cr

finding this work in published, peer reviewed literature is difficult. The next section outlines the methodologies used in this study.

Methods

One of the primary research objectives of the project was to test components of a community based monitoring program within the Peñas Blancas and Volcán watersheds in south central Costa Rica. For the program to be sustainable, locally meaningful and comparable to other Costa Rican monitoring studies, I modeled my monitoring program after a successful and established ANAI monitoring program within Costa Rica (Mafla, 2005), which has published methods and protocols. This section presents the methods and techniques employed in my field work, including sampling procedures, chemical and visual assessment and biological analysis.

Field Invertebrate Sampling Procedures

The collection of data took place from January 2009 to March 2009. At each site, three major tasks were carried out:

1. The collection of aquatic benthic macroinvertebrates
2. A Stream Visual Assessment (see Table 6 for a list of the components)
3. Chemical analysis (coliform bacteria, dissolved oxygen, nitrate, pH, phosphate, turbidity and temperature)

I adopted the ANAI procedure to collect benthic macroinvertebrates, as well as conduct the Stream Visual Assessment (see Appendix A for an example of the field worksheets).

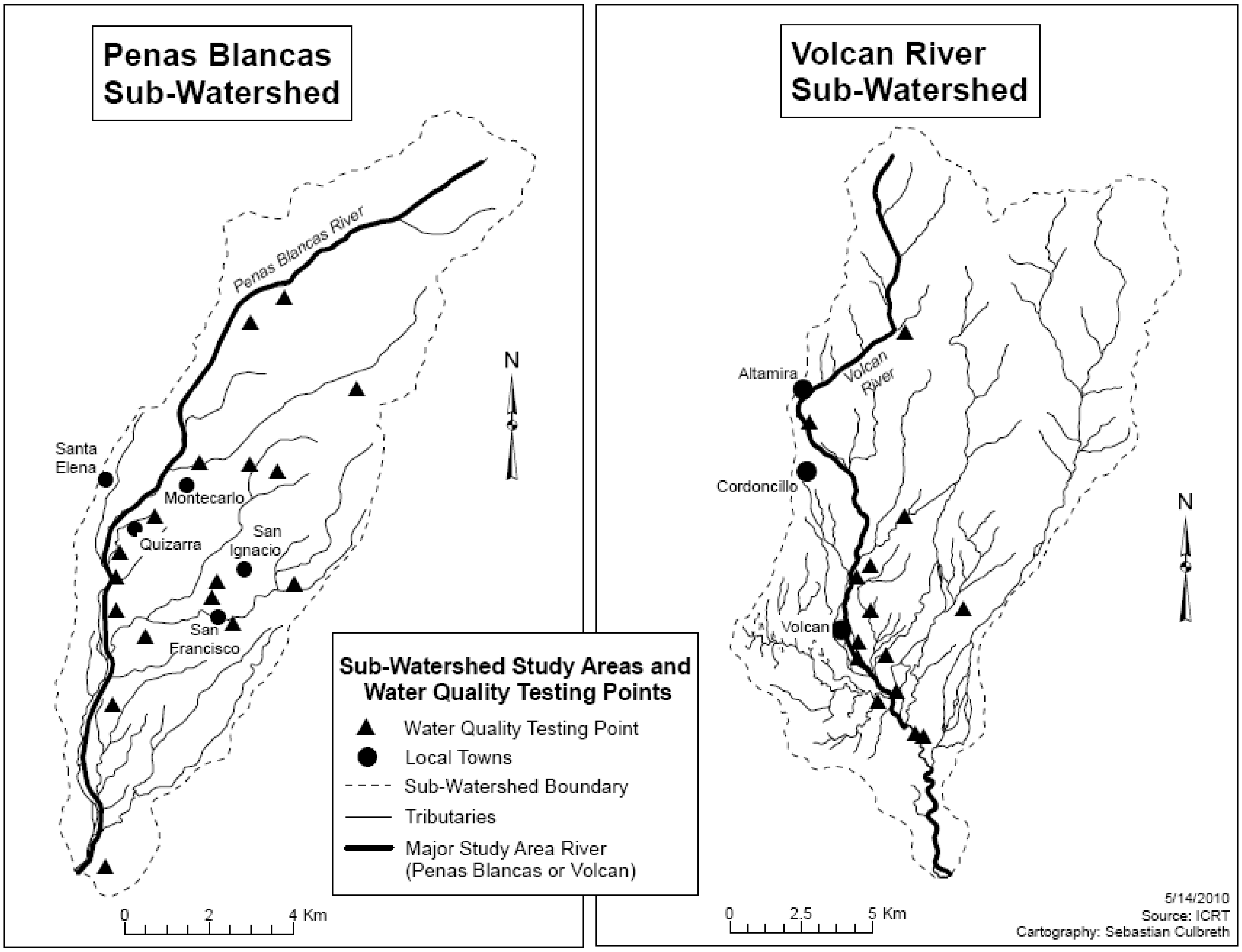
Sampling sites were selected based upon the consultation of members of the community, the identification of any known land-uses of interest, such as intense agriculture or changes in land-use, a section that characterized the study reach, and site accessibility for the researcher and community members (for any potential CBMP in the future). In total, 35 sites were selected for monitoring. Refer to Figure 2 for the location of sampling sites.

In the field, micro habitats were identified as either banks that contained roots, vegetation or submerged objects; substrate areas of glides, riffles and pools; or accumulated organic material such as piles of leaves or small woody debris in glides and riffles. Benthic invertebrates were collected in each microhabitat (30 minutes for each micro habitat) using a D-frame net and hands where necessary.

Site sampling locations were 50m in length, which guaranteed stream reach representativeness and habitat diversity. At each site, sampling began at the downstream end of the 50m reach and proceeded upstream until time requirements for each micro habitat had been met. A D-frame kick net, with a twelve inch rim, depth of approximately six-and-a-half inches, and a mesh size of approximately 500 microns was used for the collection of the benthic macroinvertebrates. In stream, the D-frame kick net was placed (with the opening facing upstream) along the bottom of the watercourse while the rocks or debris in front of the net were lifted and rubbed by hand. Dislodged animals were carried into the net by stream current. Where there were leaf packs, leaves were washed by hand in front of the net, to dislodge and capture animals (Figure 3). Roots that were growing out from the bank were agitated while holding the net downstream to capture the insects that were released.

Collected material was removed from the nets, placed into plastic containers and preserved in 75% alcohol.

Figure 2: Monitoring Site Locations[13]



[13] A map with the Site ID in reference to the location can be found in Appendix G.

Figure 3: In-stream collection of aquatic benthic macroinvertebrates

Assistant Tony Morera, using his hands and the stream current to wash the insects off of a leaf pack.

Lab Invertebrate Processing Procedures

Preserved samples were transferred to a building facility where the macroinvertebrates were separated from the organic material in the sample. This was done by placing small fractions of the sample into a shallow sorting tray, extracting the insects with forceps and then sorting them to order. Sorting was completed for the entire sample. The samples were then transported to the Department of Biology's Entomology Laboratory at the University of Costa Rica in San José. In the laboratory, all organisms were identified to family level using a stereomicroscope with a magnification of 40 times. The taxonomic keys and guides of Mafla (2005), Merritt and Cummings (1996), Roldán Pérez (1996) and Universidad de EARTH (2007) were used as identification aids. Figure 4 provides an example of the types of taxa collected.

Figure 4: Examples of the typical aquatic benthic macroinvertebrates

From top to bottom: Perlidae, Tipulidae, and Corydalidae

Stream Visual Assessment

For each site, a Stream Visual Assessment (SVA) was also completed. A stream visual assessment is useful to characterize and contextualize a stream monitoring site. The visual assessment included the evaluation of fifteen elements, each rated on a scale from 1 (bad) to 10 (good). Using the narrative descriptions and pictures provided in the ANAI field guide pages (see Appendix B); a score that best fits the observations is assigned. A score for each site was calculated as the mean of all of the element scores. Table 6 describes the 15 evaluated elements.

Table 6: Description of stream visual assessment components

Code	Description
A	Water clarity after storm event
B	Sediment accumulation in substrate
C	Riparian vegetation
D	Canopy Cover
E	Amount and depth of pools
F	Channel alteration (i.e. incision)
G	Channel alteration (i.e. canalization)
H	Bank stability
I	Barriers to organism mobility
J	Fishing pressure
K	Solid waste
L	Habitat complexity (fish)
M	Habitat complexity (aquatic insects)
N	Nutrient loading from livestock
O	Abundance of filamentous algae

Chemical Analysis

The chemical analysis was conducted with LaMotte's GREEN Standard Water Monitoring Kit. The kit included tests for coliform bacteria, dissolved oxygen, nitrate, pH, phosphate, turbidity and temperature.

The test for coliform bacteria indicates if there are coliforms above or below 20 coliform colonies per 100mL. The presence of coliform bacteria is an indication of recent fecal contamination. Common sources of this contamination include agricultural inputs, waterfowl deposits, and domestic wastes (Barzilay et al., 1999).

The Dissolved Oxygen (DO) test was conducted by submerging the test tube in the river, ensuring that the tube was full to the top of water. Two Dissolved Oxygen TesTab reagent tablets[14] were then added to the tube. The tube was then capped ensuring no air bubbles. The tablets were then dissolved by gently shaking the tube. After 5 minutes, the colour of the water in the sample was compared to the colours displayed in the Dissolved Oxygen Colour Chart. The test is able to assess concentrations within the range of 0 ppm to 8 ppm. DO is essential to the life of all aerobic aquatic organisms and can be described as the most fundamental parameter of water. Oxygen from the water and photosynthesis by aquatic plants are the most significant sources of DO in water (CCME, 1999). The amount of oxygen required by species is variable depending on the species type and stage of life. DO levels of 5-6 are usually required for growth and activity. Levels below 2 ppm will not support a fish population (LaMotte, n.d.).

The Nitrogen test was conducted by collecting 5mL of stream water in a test tube and adding one Nitrate #1 TesTab reagent tablet.[15] The tube was capped and mixed until the tablet had dissolved. Then a Nitrate #2 CTA TesTab reagent tablet[16] was added. Again, the tube was capped and shaken until the tablet had disintegrated. After 5 minutes, the colour of the water in the sample was compared to the Nitrate Colour Chart. This test was able to detect Nitrate within the range of 0 ppm to 80 ppm. Unpolluted waters tend to have nitrate levels below 4 ppm, and levels above 40 ppm are considered unsafe for drinking water (LaMotte, n.d.). Nitrate can occur

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[14] Each Dissolved Oxygen TesTab contains sodium citrate and 2, 4-Diaminophenol dihydrochloride. Dissolved Oxygen, in a solution buffered by sodium citrate, oxidizes a proportionate amount of 2, 4-Biaminophenol dihydrochloride, producing a coloured solution (LaMotte, n.d.).

[15] Each Nitrate #1 TesTab contains sulfamic acid which destroys any nitrite that will give a positive interference (ibid).

[16] Each Nitrate #2 TesTab contains zinc, which reduces the nitrate to nitrite, and chromotropic acid which reacts with the nitrite for a pink color (ibid).

in waterways naturally as well as through anthropogenic sources. Some natural pathways include wet and dry atmospheric deposition, as well as igneous rocks, volcanic activity, organic nitrogen from soils, as well as the oxidation of vegetable and animal debris. Anthropogenic, point sources of nitrate include agricultural runoff, feedlot discharges, urban runoff, lawn fertilizers, landfill leachate, nitric oxide and nitrogen dioxide from vehicle exhaust, and storm sewer overflow (CCME, 1999).

The test for pH was conducted by filling a test tube with 10mL of water, adding one pH Wide Range TesTab[17], closing the tube and mixing until the tab had dissolved. The colour of the water in the test tube was then compared to the colours on the LaMotte pH Colour Chart. pH is a measurement of the activity of the hydrogen ions in a water sample. The pH scale ranges from 0 to 14. A pH of 7.0 is neutral, whereas an acidic solution is below 7.0, and an alkaline (basic) solution is above 7.0. One unit change in pH corresponds to a tenfold change in the hydrogen ion concentration, and therefore small changes in pH levels can mean significant water chemistry changes. A pH in the range of 6.5 to 8.2 is optimal for most organisms (LaMotte, n.d.). Increased organic matter such as algae and vegetation remove carbon dioxide from the water, and can create a significant increase in pH. Anthropogenic alterations to pH levels in aquatic environments are largely due to the consequences of industrial activities (such as acid rain, or acid mine drainage or industrial waste leachates) (CCME, 1999).

Phosphate was tested by filling the test tube with 5mL of water, adding one Phosphorous TesTab[18], capping the tube and shaking until the tablet has completely disintegrated. After 5 minutes, the colour of the sample was compared to the Phosphate Colour Chart. This test can

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[17] The pH Wide Range TesTab reagent tablets contain mixed pH indicators which are sensitive to pH and undergo specific colour changes with variation in pH (LaMotte, n.d.).

[18] Each Phosphorus TesTab reagent tablet contains ammonium molybdate, which reacts with phosphorus to form a phosphomolybdate complex. This is reduced to a blue complex by ascorbic acid (LaMotte, n.d.).

detect phosphate concentration within the range of 0 ppm to 4 ppm. Phosphorous is a nutrient that when added to an aquatic system causes an increase in plant and algae production. Although an increase in biomass can be positive to a certain extent, excessive increases of phosphorous levels can cause detrimental effects. These include a decrease in biodiversity, a decline in ecologically sensitive species and an increase in tolerant species, an increase in plant and animal biomass, elevated levels of turbidity, and ultimately anoxic conditions (CCME, 1999).

Temperature was measured at each site with a thermometer. Temperature is a very important component of water quality and effects many biological processes. Changes in temperature have substantial effects on biological processes such as photosynthesis, respiration, susceptibility to disease, osmoregulation, uptake of pollutants, and behavioural patterns (such as reproduction, feeding, growth, migration, distribution, predator-prey relationships, and community composition) (CCME, 1999).

Turbidity was also measured. A card with a Secchi disk icon was placed under a graduated cylinder containing stream water. I looked down through the sample water at the Secchi disk icon and compared the visibility of this icon with the examples provided in the LaMotte kit. The degree of "fuzziness" has been calibrated to Jackson Turbidity Units (JTU), which are common units of measurement for water clarity. Turbid waters are a result of suspended or dissolved substances. When there is a higher concentration of suspended sediment, there is also a higher level of turbidity. Sources of sediment leading to turbidity can be natural or anthropogenic. Anthropogenic activities which lead to increased levels of suspended sediment include agriculture, forest harvesting, road construction, dredging, industrial water discharge.

Biological Indices

This study used several indices to evaluate the biological composition of the streams, such as indices of taxonomic richness and composition, functional feeding measures and biotic indices (i.e., indices that summarize abundance and tolerance). For all of the indices used, refer to Table 7.

Taxa richness, the count of different taxa present, is a surrogate for biodiversity (Resh et al., 1995). In this study, taxa richness was expressed at the family level. Increasing diversity correlates with increase in community health and is an indication that habitat and food sources are adequate to support species survival and propagation (Barbour et al., 1999).

Measures of community composition and relative abundance consider how each taxon contributes to the total population of the sample. In a healthy and stable community, the proportional community representation should remain relatively consistent (Barbour et al., 1999).

Tolerance and intolerance measures represent relative sensitivity to perturbation. These measures are often linked to a pollution tolerance index such as the Hilsenhoff Family Biotic Index (refer to the Biomonitoring Section for more details).

Table 7: Description of Indices Used to Evaluate Biotic Composition

(adapted from Resh and Rosenburg, 1993 and Barbour et al., 1999).

Category	Measure	Description	Predicted value response to perturbation
Richness measures	total No. taxa	Measures the overall variety of the assemblage	Decrease
Enumeration measures	number of individuals	Number of all specimen in sample regardless of identification.	Decrease
Composition measures	% EPT	Percent of the composite of Ephemoptera, Plecoptera and Trichoptera	Decrease
	% Chironimidae	Percent of Chironomidae	Increase
	% Dominant Taxa	Is a measure of the single most abundant taxa. The dominance of any one group is of concern.	Increase
Feeding measures	% Collector Filterers	Dominance of collector filterer may reflect organic enrichment	Increase
	% Shredders	Shedder organisms and their food are sensitive to toxins and modifications to riparian zones	Decrease
	%Gatherers	Measures the percent of the population that are Gatherers	Increase
	% Predators	Measures the percent of the population that are Predators	Decrease
Tolerance/Intolerance measures	BMWP-CR	The index summarizes presence/absence and tolerance of families. Several factors are used to predict structure of unimpacted benthic community	Decrease
	Hilsenhoff Family Biotic Index	The index weights the relative abundance of each family in regards to its pollution tolerance.	Increase
	Hilsenhoff Family Biotic Index-CR	Is a modification of the Hilsenhoff Family Biotic Index for Costa Rica.	Increase

Analyses

To analyze the data generated from this project, boxplots and Correspondence Analysis have been used to summarize data and visualize patterns, while t-tests have been used to test hypotheses and determine the significance of any patterns.

Boxplots

Boxplots do not present a whole dataset; however, they do provide a very concise visual summary of important data characteristics. They are useful for displaying the distribution of variables and pinpointing outliers (McGill et al., 1978). Boxplots are useful ways to provide a visual summary of:

- the centre of the data (the median – the center line of the box)
- the variation or spread (interquartile range – the box height)
- the skewness (quartile skew – the relative size of box halves)
- Presence or absence of unusual values ("outside" and "far outside" values), (Helsel and Hirsch, 2002).

Box plots were produced in order to determine the normality of the datasets.

T-test

The t-test is likely the most widely used method for comparing two independent groups of data (Helsel and Hirsch, 2002). This test includes the assumption that the variables being tested are normally distributed (StatSoft Inc., 2010).

T-tests (at a 95% confidence level) were performed to test differences between the watersheds, elevation (high and low) and wetted widths (small and large) for all ten indices (refer to Table 7 for a list of the indices). Furthermore, a t-test was carried out to test for a significant difference between samples collected at wetted widths that were either large or small and at elevation classified as either high or low.

Correspondence Analysis

Correspondence Analysis (CA) is a multivariate descriptive method of analysis that graphically presents the relations between rows and columns in a frequency table as points in a common low-dimensional space (Clausen, 1998). It is considered to be a type of canonical correlation analysis, which assesses the relationship between two sets of continuous variables. However, correspondence analysis is distinct from canonical correlations as it is possible to explore the relationships between two discrete variables. Furthermore, CA can be used as a tool to analyze the association between two or more categorical variables by representing the categories of the variables as points in a low-dimensional space (i.e. a scatter plot). Those categories with similar distributions will be represented as points that are close in space, and categories that have very dissimilar distributions will be positioned far apart (Clausen, 1998).

According to Lebart, Morineau, and Warwick (1984)[19], the following criteria should be satisfied if the advantages of the method are to be exploited to the fullest:

1. The data matrix should be large, making it difficult to discover the structure by means of simple statistical analyses.

[19] As cited in (Clausen, 1998).

2. The variables must be homogeneous, so that it is meaningful to calculate distances between the categories.

3. The method is most suitable for data for which the structure is unknown.

Moreover, when using this tool, it is important to consider that extreme outliers or profile points can pose a problem in CA. If a point is an extreme outlier it can have a dominating effect on the results of the analysis. This is because it can lead to the outlier occupying a position that is at a far distance from the other points, which are thus pressed together. Therefore, outliers are often taken out of the graphical display so that they do not contribute to the formation of the dimensions. This being said, overall, CA is considered to be a flexible method with few assumptions and restrictions. The only restriction is that the data must contain non-negative numbers and no assumptions in regards to the distribution or the nature of the data are made (Clausen, 1998). In this study, CA was undertaken to explore the relationships and patterns of biological composition that exist throughout the study areas.

In this section, I have described the set of methods used to the analyze data such as, boxplots, t-tests, and CA have been used. The ensuing section will present the results.

Results

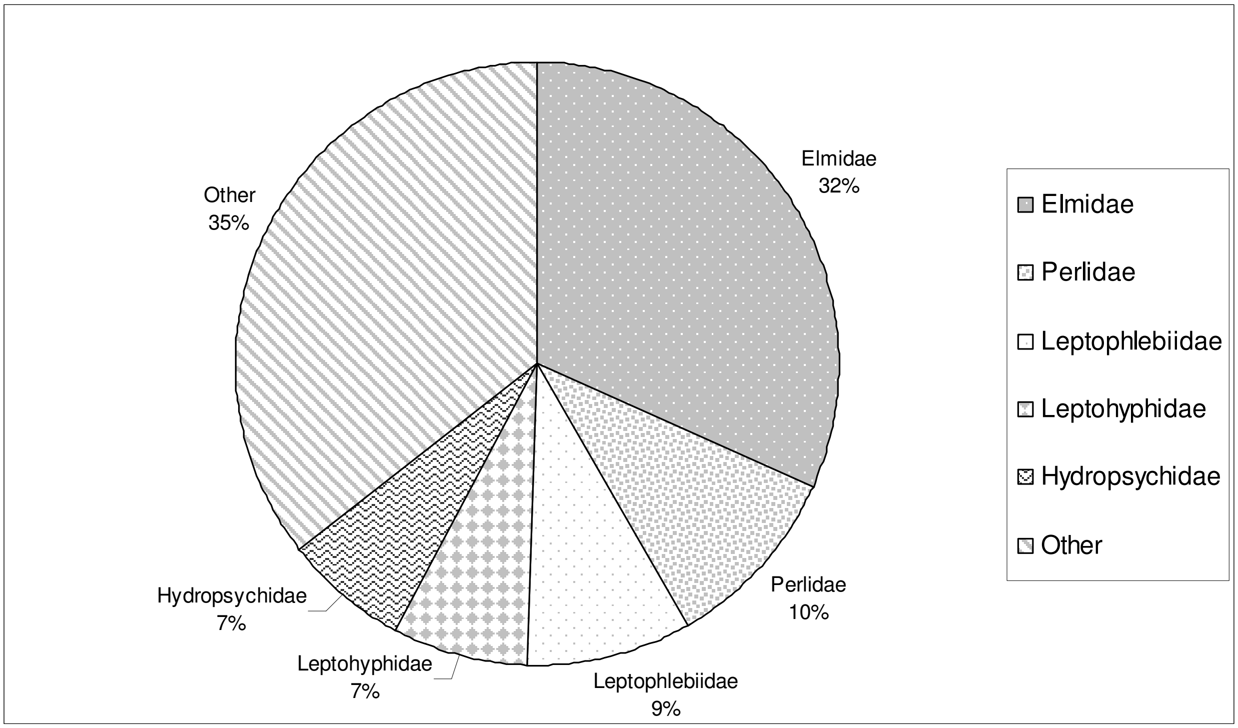
Introduction

This section will outline the results of analyses performed on the monitoring data collected in this study. This includes a general description of the taxonomical data collected, an examination of the SVA results, the chemical analysis, as well as the t-tests performed on the biological indices.

General Taxa Community Composition

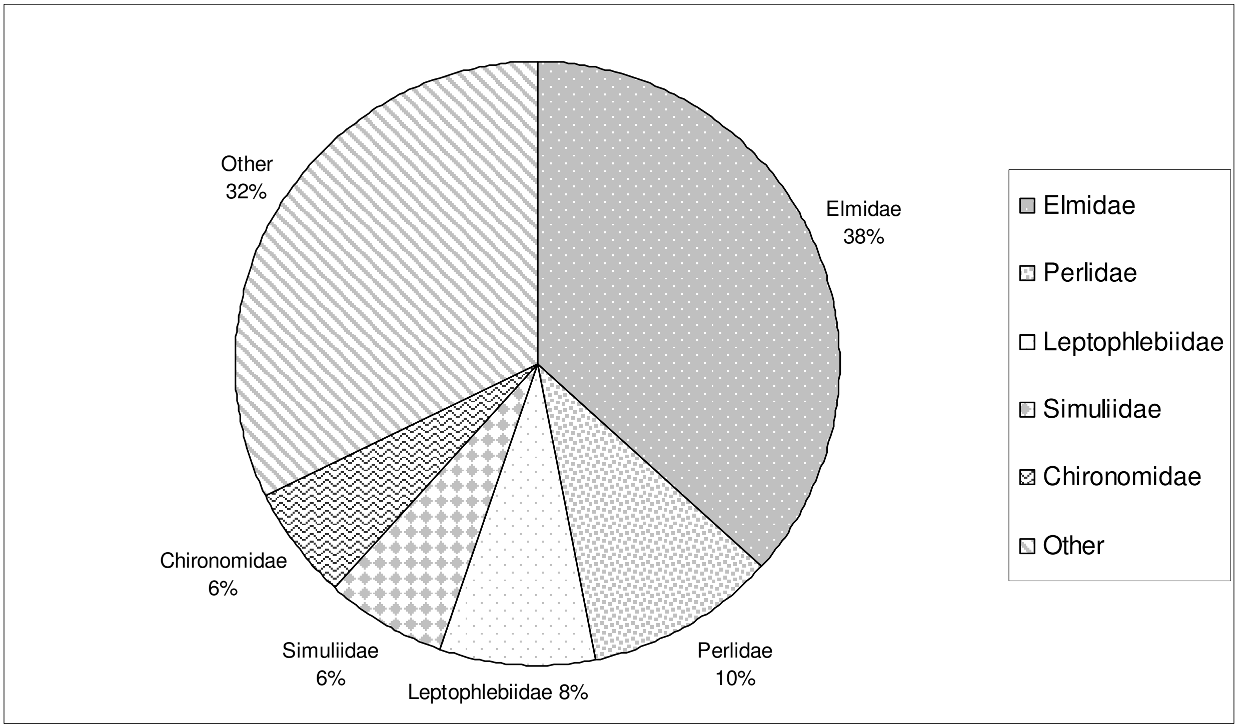
In total, 11,039 individuals from 55 different families were collected, identified and used in the analysis. It was found that the Peñas Blancas and Volcán subwatersheds have moderate biodiversity with family richness ranging from 7 to 26. Appendix C provides a list of the individual taxa collected and used in the analysis. With the data from both subwatersheds combined, taxa such as Elmidae, Perlidae, Leptophlebidae, Leptohyphidae, and Hydropsychidae dominate the biological composition found within the sites (see Figures 5, 6 and 7).

Figure 5: Dominant taxa found in Peñas Blancas and Volcán subwatersheds



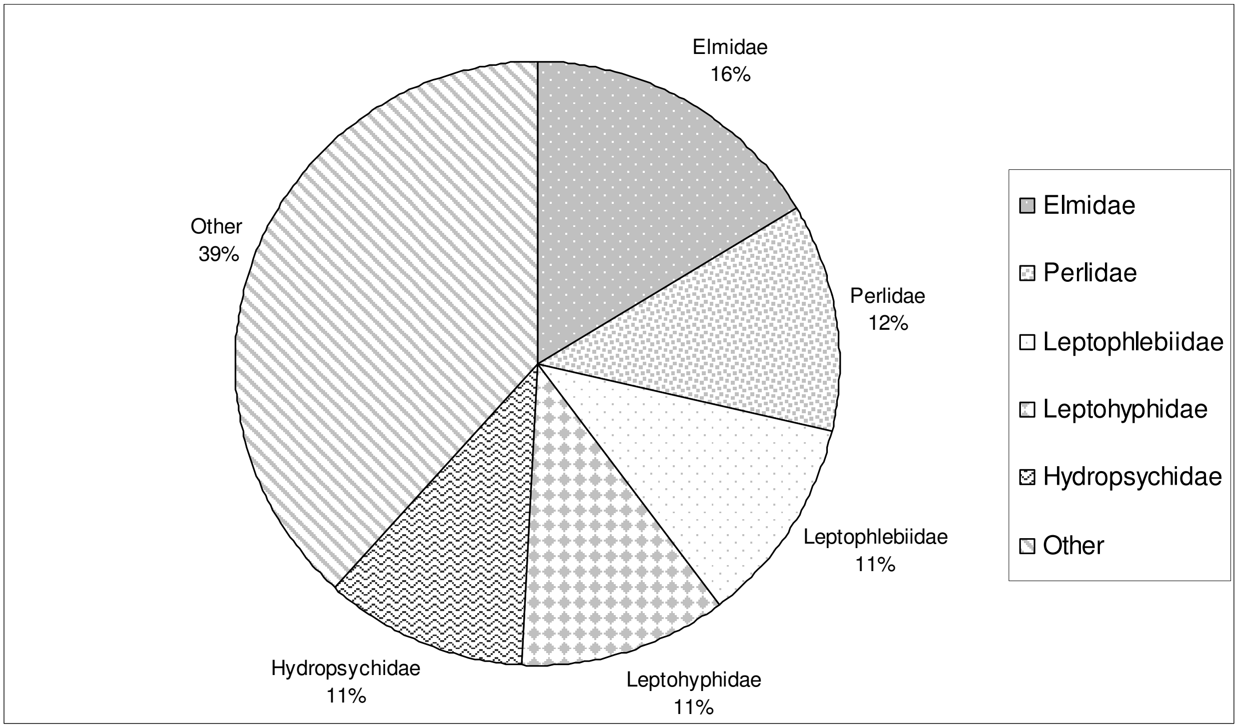
Within the Peñas Blancas subwatershed, the dominant taxa were Elmidae, Perlidae, Leptophlebiidae, Simuliidae, and Chironomidae (see Figure 6).

Figure 6: Dominant taxa found in Peñas Blancas subwatershed



Within the Volcán subwatershed the most predominant taxa were Elmidae, Perlidae, Leptophlebiidae, Leptohyphidae, and Hydropsychidae.

Figure 7: Dominant taxa found in the Volcán subwatershed



Stream Visual Assessment Protocol

The scores for each element within the SVAP ranged from 1 (being bad) and 10 (being excellent). A description of the elements being evaluated can be found in Table 6 of the Methods section. The total SVAP scores for each site ranged from 5.2 to 8.6. The two sites with the lowest scores were RV01 and RCLL02. RV01 is located in the Río Volcán subwatershed, downstream of the town of Volcán as well as a small irrigation dam. RV01 has a representative wetted width of 7.2m (however it becomes wider just downstream), and contains little shade cover. Site RCLL02 is located on Río Calientillo within the Peñas Blancas watershed. The surrounding land-use consists mainly of pasture with cattle in close proximity (cattle were seen in the stream), and coffee farming.

The two sites with the highest totals for the SVAP were site locations RPB10 and RV08. Site RPB10 is located within the Peñas Blancas subwatershed. Of all the sites in the subwatershed, it is located the closest to the headwaters. This site is also located above York University's Las Nubes Reserve. The surrounding land contains forest, and there was virtually 100% canopy cover. There was also a wide variety of in-stream cover providing habitat for both fish and aquatic insects. Site RV08 is located in the Volcán subwatershed on the Río Volcán. Similar to RPB10, RV08 is the closest site to the headwaters of the river. The surrounding land use contains forest in addition to old coffee plantations undergoing natural succession. Appendix E provides a table outlining the scores for each component. Overall, the Río Peñas Blancas subwatershed contains higher average scores for each element. Table 8 summarizes the average scores and standard error for each component evaluated. Both watersheds on average scored the lowest on component "L" (Table 6), which evaluates fish habitat complexity. Another component, which scored lower than 5 within the Volcán subwatershed was component "D", which was a measurement of the amount of canopy cover. Although beyond the scope of this paper due to timing constraints, it would be useful to explore the SVAs further to determine correlations between this type of assessment and a biological assessment.

Table 8: Summary of SVA results

SVA code	RV		RPB	
	$\bar{x}$	SE	$\bar{x}$	SE
SVAP-A Water clarity after storm event	8.06	(0.54)	8.58	(0.15)
SVAP-B Sediment accumulation in substrate	6.91	(0.36)	6.47	(0.16)
SVAP-C Riparian vegetation	6.50	(0.5)	7.00	(0.50)
SVAP-D Canopy Cover	4.94	(0.67)	6.68	(0.37)
SVAP-F Amount and depth of pools	7.06	(0.54)	7.45	(0.37)
SVAP-G Channel alteration (i.e. incision)	7.97	(0.37)	6.18	(0.56)
SVAP-H Bank stability	6.81	(0.55)	7.32	(0.35)
SVAP-I Barriers to organism mobility	8.63	(0.60)	9.37	(0.29)
SVAP-J Fishing pressure	8.19	(0.50)	9.61	(0.20)
SVAP-K Solid waste	7.44	(0.68)	8.63	(0.42)
SVAP-L Habitat complexity (fish)	4.81	(0.28)	4.24	(0.25)
SVAP-M Habitat complexity (aquatic insects)	6.56	(0.47)	6.42	(0.26)
SVAP-N Nutrient loading from livestock	7.25	(0.66)	8.89	(0.42)
SVAP-O Abundance of filamentous algae	7.56	(0.27)	7.45	(0.50)
SVAP - AVG	7.00	(0.24)	7.42	(0.17)

Chemical Analysis

The results of the chemical analysis are presented in Table 9. Overall, DO measurements ranged from 3 ppm to 6 ppm, turbidity ranged from 0 JTU to 20 JTU, phosphates from 1ppm to 4ppm, nitrates from 0 ppm to 3 ppm, pH from 6.5 to 8 and temperature from 14°C to 27°C. From the data set, there are a few results that could be indications of impairment; these are summarized below. Further investigation could be conducted to determine if these are readings taken during extreme conditions or if they are typical characteristics (and therefore possible indication of impairment) of the sites. For DO, there was one site (RA02, in the Volcán subwatershed) that scored 3 ppm, which is relatively low. The average score for turbidity was 2.85 JTU. Most sites had readings of 0 or 5 JTU. However, one site, (QP01), had a reading of 20 JTU, while four sites (RV01, RV04, RV06, RA02) all located in the Volcán subwatershed, had readings of 10 JTU. In terms of nutrients, the average phosphate level was 2.64 ppm; three sites (RV04, RV05 and RPB01) scored 4. For nitrate, all scores were 0 ppm or 1 ppm except for QP01, which had a reading of 3 ppm. The average pH score was 7.86. RPB05 had a pH value of 6.5, which was well below the average. The average temperature reading was 20.85°C. RV02 displayed an elevated temperature value of 27°C, while four sites (RV02, RV01, RV03, QM03 and QC01), had temperature readings of 24°C.

Table 9: Summary of chemical data

Site ID	Watershed ID	DO (ppm)	TURB (JTU)	P (ppm)	N (ppm)	pH	TEMP (°C)*
RV01a	RV	4	10	3	1	7.5	24
RV02a	RV	5	0	2	1	8	27
RV03a	RV	5	0	3.5	1	8	24
RV04a	RV	4	10	4	1	8	ND
RV05a	RV	4	0	4	1	8	ND
RV06a	RV	4	10	2	1	8	ND
RV07a	RV	4	0	2	1	7.5	18
RV08a	RV	4	0	2	1	7.5	ND
RA01a	RV	4	5	3	1	8	22
RA02a	RV	3	10	3	1	8	22
QM01a	RV	4	0	2	1	8	22
QM02a	RV	4	0	3	1	8	ND
QM03a	RV	4	5	3	1	8	24
QP01a	RV	4	20	2	3	7.5	22
QC01a	RV	4	0	3	1	7	24
QJ01a	RV	4	0	3	1	8.2	20
RPB01a	RPB	4	0	4	0	8	ND
RPB02a	RPB	4	0	3	0	8	ND
RPB03a	RPB	6	5	2	0	7.5	ND
RPB04a	RPB	4	0	3	0	8	ND
RPB05a	RPB	4	5	3	0	6.5	20
RPB06a	RPB	4	0	2	0	8	18
RPB07a	RPB	4	0	1	0	8	18
RPB08a	RPB	4	5	2	0	8.2	ND
RPB09a	RPB	4	5	1.5	0	8	ND
RPB10a	RPB	4	0	2	0	8.3	ND
RPBITA01a	RPB	4	0	3	0	8	14
RPBITA02a	RPB	4	0	1.5	0	8	14
RPBITA03a	RPB	4	0	3	0	8	ND
RCTE01a	RPB	5	5	3	0	8	ND
RCTE02a	RPB	4	0	2	0	8	22
RCTE03a	RPB	4	0	3	0	7.5	ND
RCTE04a	RPB	6	0	3	0	8	18
RCLL01a	RPB	4	0	3	0	8	22
RCLL02a	RPB	4	5	3	0	8	22

Note: *Due to equipment failure, temperature data was not obtained at all sites.
TURB =Turbidity, P=Phosphates, N=Nitrates
RV=Río Volcán, RPB=Río Peñas Blancas, RA= Río Angel, QM= Quebrada Mora, QP = Quebrada Peje, QC = Quebrada Casa, QJ = Quebrada Jesus, RPBITA = Río Peñas Blancita, CTE = Río Caliente, RCLL = Río Calientillo

Biological Indices

Results of the biological indices were compared to determine whether there were significant differences in the results and thus biotic composition based upon 3 criteria: subwatershed (Río Peñas Blancas and Río Volcán), elevation (high and low) and wetted width (small and large). Table 10 provides a description of the monitoring sites as they pertain to these classifications. Table 11 provides the mean and standard error of the index results based upon the same three classifications. Please refer to Appendix D for the full results of the biotic indices.

Table 10: Description of sites sampled

Site ID	Watershed ID*	Elevation	Wetted Width
RV01a	RV	428	7.2
RV02a	RV	450	8.1
RV03a	RV	508	9.7
RV04a	RV	640	7.8
RV05a	RV	827	12.4
RV06a	RV	910	15
RV07a	RV	1090	11
RV08a	RV	1311	8.4
RA01a	RV	374	7.8
RA02a	RV	504	8.6
QM01a	RV	370	11.1
QM02a	RV	405	4.4
QM03a	RV	475	6.4
QP01a	RV	388	7.3
QC01a	RV	502	4.7
QJ01a	RV	655	7
RPB01a	RPB	575	25
RPB02a	RPB	589	15.1
RPB03a	RPB	680	12.5
RPB04a	RPB	721	12
RPB05a	RPB	724	14.1
RPB06a	RPB	763	14.5
RPB07a	RPB	892	10.5
RPB08a	RPB	1030	9.5
RPB09a	RPB	1190	9.9
RPB10a	RPB	1223	6
RPBITA01a	RPB	986	9.8
RPBITA02a	RPB	1117	6.8
RPBITA03a	RPB	1348	5.2
RCTE01a	RPB	629	15
RCTE02a	RPB	701	6.8
RCTE03a	RPB	722	8.6
RCTE04a	RPB	1019	5.4
RCLL01a	RPB	725	6.1
RCLL02a	RPB	897	4

Note: RV=Río Volcán, RPB=Río Peñas Blancas, RA= Río Angel, QM= Quebrada Mora, QP = Quebrada Peje, QC = Quebrada Casa, QJ = Quebrada Jesus, RPBITA = Río Peñas Blancita, CTE = Río Caliente, RCLL = Río Calientillo.

Table 11: Summary of biological indices: Mean and standard error

	Watershed				Elevation				Wetted Width			
	RV		RPB		Higher Elevation		Lower Elevation		Smaller Wetted Width		Larger Wetted Width	
Indices	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
BMWP-CR Scores	91.25	(8.13)	124.11	(6.98)	131.17	(4.10)	85.71	(8.29)	106.76	(8.99)	116.35	(6.61)
FBI Scores	3.59	(0.15)	3.43	(0.19)	3.50	(0.08)	3.51	(0.24)	3.72	(0.12)	3.48	(0.09)
Mod FBI Scores	3.97	(0.19)	4.11	(0.22)	3.73	(0.09)	4.37	(0.27)	4.13	(0.15)	3.73	(0.11)
%Chironomidae	5.37	(1.67)	7.81	(3.21)	3.12	(0.53)	10.47	(3.68)	6.33	(1.50)	3.84	(1.39)
%EPT	63.50	(4.00)	44.73	(3.96)	50.26	(3.86)	56.53	(5.19)	52.75	(4.68)	56.98	(3.47)
CA1	-0.42	(0.32)	0.12	(0.19)	0.47	(0.22)	-0.76	(0.21)	-0.31	(0.29)	0.01	(0.24)
CA2	-0.04	(0.37)	-0.09	(0.16)	-0.05	(0.19)	-0.08	(0.34)	-0.35	(0.27)	0.21	(0.27)
Richness	15.69	(1.27)	21.00	(0.99)	21.89	(0.62)	15.06	(1.28)	18.29	(1.27)	19.53	(1.18)
%Dominant	33.70	(3.28)	35.01	(3.66)	36.00	(3.42)	32.73	(3.58)	34.76	(4.29)	32.49	(2.24)
Abundance	167.44	(28.35)	440.00	(67.61)	409.89	(71.84)	215.35	(42.50)	326.29	(84.38)	305.76	(41.15)

Statistical analysis (t-tests) demonstrated differences in biological composition at the watershed level. The Peñas Blancas and Volcán subwatersheds demonstrate differences according to four indices: BMWP-CR, %EPT, Richness and Abundance (see Table 12).

Furthermore, t-tests ($\alpha=0.05$) performed on the 10 indices revealed significant differences in biological composition according to elevation (site locations categorized as either high or low), in five indices: BMWP-CR, Mod FBI, Richness, Abundance and CA1 (see Table 12). An additional t-test showed that the elevations of the sample sites within the Peñas Blancas subwatershed were significantly higher than the elevation of sample sites in the Volcán subwatershed ($P=0.007$, 95%). Thus, although there are biological composition differences on a watershed level, because the Peñas Blancas subwatershed is significantly higher in elevation than the Volcán subwatershed, it seems that the underlying driver of this biological difference may be elevation.

Table 12: T-test results of biological indices

	Watershed	Elevation	Wetted Width
BMWP-CR Scores	**4.47E-03**	**7.29E-11**	0.71
FBI Scores	0.52	0.97	0.08
FBI-CR scores	0.63	**0.04**	0.58
%Chironomidae	0.51	0.06	0.85
%EPT	**2.11E-03**	0.34	0.87
CA1	0.16	**2.99E-04**	0.33
CA2	0.89	0.93	0.15
Richness	**2.51E-03**	**7.41E-05**	0.77
% dominant	0.79	0.51	0.90
Abundance	**1.07E-03**	**0.03**	0.82

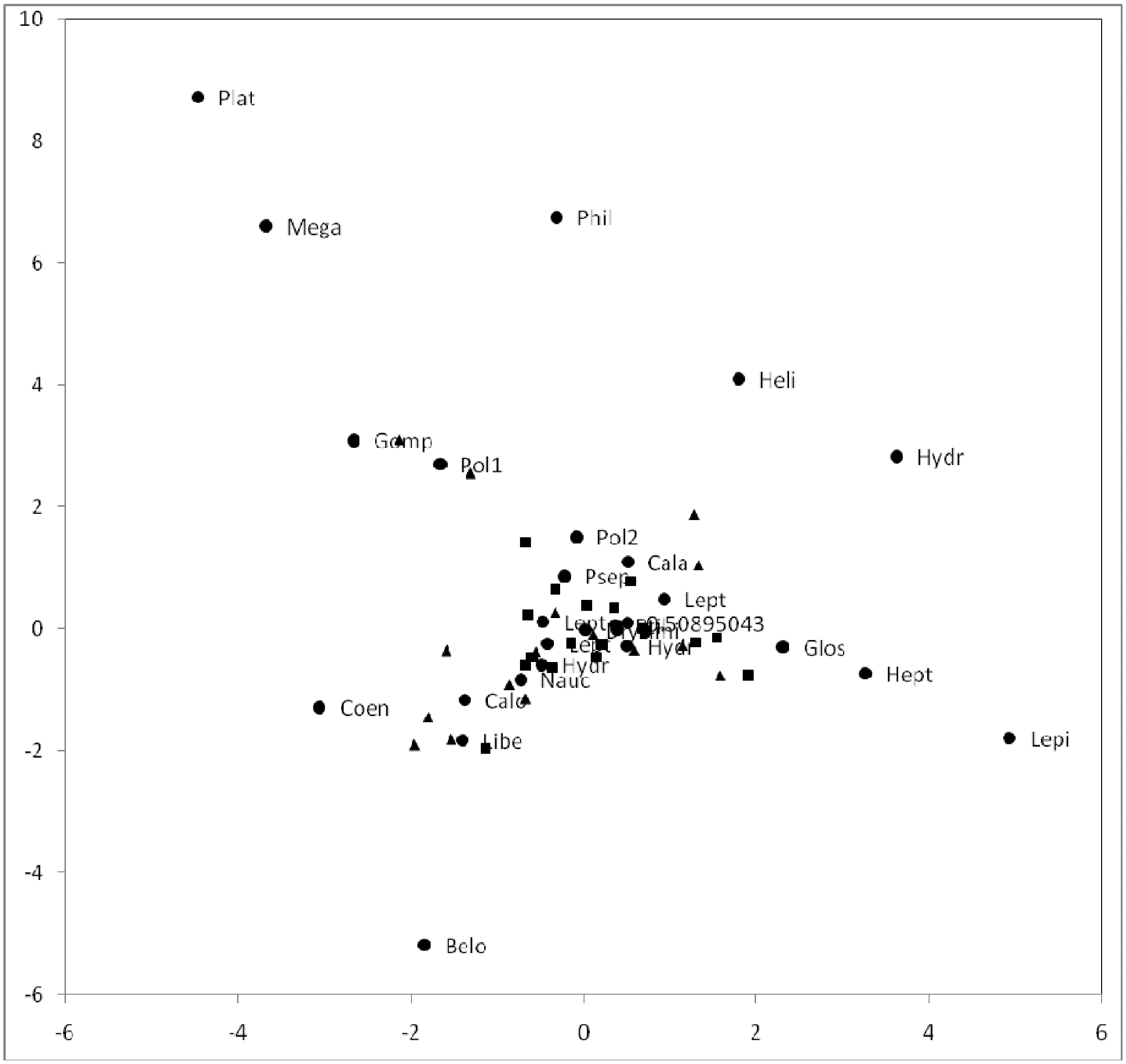
Note: t-test results by factor and biological index. Significant results at α=0.05 are shown in bold typeface. The critical p-value, Bonferroni corrected for 24 tests, is 0.0021.

Oftentimes, wetted width and elevation are correlated. This is because generally, as elevation increases, stream width tends to be smaller. Conversely, the lower in a watershed that a river is located the more likely it is to be wider relative to other streams in the same watershed. T-tests revealed that no significant differences in biological composition exist when comparing the index results of each monitoring site as divided into large and small wetted widths. A separate regression analysis of elevation against wetted width resulted in a R^2 value of 0.0086. This indicates that the two elements are not correlated. Therefore, the differences in biological composition that were seen in elevation are not a result of both elevation and wetted width. Therefore, elevation, independent of wetted width, is a significant factor driving biological composition.

Correspondence Analysis

Figure 8 depicts a bi-plot of the CA ordination, which compares sites by elevation. The difference across the X-axis can be seen quite clearly. The right side of the bi-plot X-axis has a very high number of high elevation sites from the Peñas Blancas subwatershed. These sites are being dominated by Lepidostomatidae, Heptageniidae, Glossosomatidae and Hydroptilidae. These species are characteristic of high gradient, fast flowing and cold water streams. They are generally scrapers and shredders. Conversely, the left side of the bi-plot is clearly dominated by lower elevation sites from the Volcán subwatershed. The species composition at these sites are being influenced predominately by Coenagrionidae, Libellulidae, Gomphidae, Polythoridae, Megapodagrionidae, Belostomatidae and Platysticitidae. These species are generally predators and are characteristic of slower moving streams with warm temperatures.

Figure 8: Ordination Bi-plot Comparison of Elevation



Note: Correspondence analysis ordination of log-transformed sites-by-taxa (CA1 by CA2) data. Triangles represent sites from the Volcán subwatershed; squares represent sites from the Peñas Blancas subwatershed. Hyd1=Hydrobiosidae, Hyd2=Hydrophychidae, Hyd3=Hydroptilidae, Lep1=Leptohyphidae, Lep2=Leptoplebidae, Pol1=Polythoridae, Pol2= Polycentropodidae, Baet=Baetidae,Hept= Heptageniidae, Belo=Belostomatidae, Nauc=Naucoridae, Calo=Calopterygidae, Coen=Coenagrionidae, Gomp=Gomphidae, Libe=Libellulidae, Mega=Megapodagrionidae, Plat=Platysticitidae, Cala=Calamoceratidae, Glos=Glossosomatidae, Heli=Helicopsychidae, Phil=Philopotamidae, Dryo=Dryopidae, Elmi=Elmidae, Psep=Psephenidae, Ptil=Ptilodactylidae.

Discussion

Prior to this project, virtually no stream water quality data existed for the Peñas Blancas or Volcán subwatersheds. Baseline data is useful to characterize the state of a watershed and identify any areas of potential environmental concern. Through York University's ongoing research and involvement in the study area, watershed management decisions are being made and implemented within both subwatersheds (such as reforestation efforts in Volcán). The baseline water quality data provided through this project will be useful to better inform these current (and potential future) environmental management decisions. Moreover, continued monitoring baseline data is crucial so that as new management practices are implemented, there is data to compare in order to evaluate change.

Application

The implementation of ANAIs SVAP as well as the adapted benthic monitoring methodology is very useful on both a local (and potentially national level). On a local level, the protocols are useful due to the fact that they are low cost, do not require much equipment and are not very labour intensive. On a national level, it is useful for monitoring programs to be using the same collection and evaluation protocols so that results can be compared and larger scale patterns or conclusions can be made.

The analysis of biotic indices provided in this study is useful on a local level, as it provides an indication of which indices may be the most sensitive to detect changes or differences in biotic composition. The biotic indices along with the SVA and chemical data can provide insight for the identification of priority areas for management. For example, from the SVAP results, it can be seen that watershed management efforts should be put towards riparian vegetation and increasing canopy cover in the streams and rivers.

In addition, much of the information from this project (from the training of locals and the selection of sites to the adaptability of the ANAI protocols), can be used as part of a Community Based Monitoring Program.[20] In fact, recently, through the program "Hacia una red nacional escolar de monitoreo y restauración socioecológica[21]" (coordinated by Professor Álvaro Fernández-González of the UCR), a site set up in this study was used by a group of students and teachers from the Volcán area to conduct monitoring. One of my field assistants (Tony Morera) was able to assist the group in the location of the site as well as the methodology of collection.

Of Interest

In terms of the analysis of biological indices, CA Ordination typically a powerful index (as demonstrated by Kilgour et. al, 2004) did not distinguish a significant difference between the two subwatersheds. Although this finding is likely dependent on this particular data set, further study is desired to determine if this pattern holds.

To detect biological effects, it seems that the use of indices that responded to both elevation and watershed differences would have the maximum power. A t-test revealed that the sample sites within Peñas Blancas were located at significantly higher elevations than the sampling sites within the Volcán subwatershed. Therefore, the differences that were detected between watersheds seem to be driven by elevation. This suggests that those biological indices that demonstrate differences in both 'elevation' and 'watershed' analysis might be the indices that would have the maximum power to detect biological differences or changes within these two subwatersheds. These indices were BMWP-CR, Richness and Abundance.

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[20] Appendix F provides recommendations for the implementation of a CBMP within the Peñas Blancas and Volcán watersheds.
[21] Translation: A national schools network of socioecological monitoring and restoration.

Overall, the sites located within Peñas Blancas subwatershed are located at a higher elevation than those in the Volcán subwatershed. As a result, it can be assumed that the dominant (but not sole) factor driving the watershed differences is elevation. Therefore, if differences related only to elevation need to be detected, then those indices that responded only to elevation should be used. The two indices that responded to differences in elevation, but not watershed differences, are the FBI-CR and CA1.

Summary

Overall, the two subwatersheds are dominated by Elmidae, Perlidae, and Leptophlebidae. The SVAs and chemical analysis revealed some interesting results and patterns. A full analysis of these results was beyond the scope of this report, but should be included in future analyses. The biological indices revealed that elevation seems to be the factor that influences changes in biological composition throughout the subwatersheds. All of the methodologies used in the study could be used in the application of a Community Based Monitoring Program. The following section outlines the conclusions of this project.

Conclusions

The results presented in Section 5 support the overall conclusion that taxa, such as Elmidae, Perlidae and Leptophlebiidae, dominate the biological composition throughout both subwatersheds. Although there are differences in biological composition between the subwatersheds, it appears that these differences are being influenced by elevation.

Based upon this study, there are a few indices that suggest they would be well-suited to analyze data that would result from a community based monitoring program within the Peñas Blancas or Volcán subwatersheds. To detect biological effects, the use of indices that respond to both elevation and watershed differences would have the maximum power. These indices were: BMWP-CR, Richness and Abundance. However, a more selective index that may detect biological differences related only to elevation would be the FBI-CR or CA1.

The CA demonstrated that many high elevation sites from the Peñas Blancas subwatershed are dominated by Lepidostomatidae, Heptageniidae, Glossosomatidae, and Hydroptilidae. These species are characteristic of high gradient, fast flowing and cold water streams. They are generally scrapers and shredders. Conversely, the biotic composition of lower elevation sites from the Volcán watershed are being influenced predominately by Coenagrionidae, Libellulidae, Gomphidae, Polythoridae, Megapodagrionidae, Belostomatidae, and Platysticitidae. These species are generally predators and are characteristic of slower moving streams with warm temperatures. Beyond these findings, this work provides baseline data and has provided a pilot CBMP as well as some training for locals within the Peñas Blancas and Volcán subwatersheds.

Further Study

Further study could include an exploration into the relationships between the results of the Stream Visual Assessment, chemical analysis, elevation and wetted width. In particular, it would be interesting to determine if biological index scores could be determined based upon the scores of the SVAP, if sites with impaired chemical analysis results also scored poorly with the biological indices or the SVAP. Moreover, since the results of this study found that the biological composition of aquatic benthic macroinvertebrates within the Peñas Blancas and Volcán watersheds are being significantly influenced by elevation, it would be of interest to look at land use change in comparison to elevation, to see if any land use patterns might provide additional insight into this relationship. Looking to the use of the data generated by Aileen Rapson et al. (Unpublished) on forestation trends in the Peñas Blancas subwatershed may be of use for this.

Due to the lack of environmental enforcement, the continual expansion of agriculture[22] and the subsequent chemical application, it is evident to me that the current water resource practices in Costa Rica are not sufficient for successful management of future water supplies. There is a need for change. A potential option for change is the implementation of a framework such as adaptive management, where monitoring is applied to measure the success or changes occurring within the managed systems. One step towards the implementation of an adaptive management approach would be the implementation of a CBMP.

Therefore, it is hoped that the information collected for this project will be useful and utilized to help inform the creation of a Community Based Monitoring Program within the Peñas

[22] Rapson et al., Unpublished

Blancas and Volcán watersheds. The value of this type of initiative will be primarily realized locally at the community level, although there is hope that decision makers will make use of the data derived from a Community Based Monitoring Program to make better informed choices that impact the Costa Rican landscape.

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Appendix A - ANAI Field Worksheets

EVALUACIÓN RÁPIDA DE QUEBRADAS Y RÍOS BASADA EN MACROINVERTEBRADOS

Fecha: ________________ **Río / quebrada**: _________________________ **Cuenca:** ______________________
País: ______________ **Código de sitio**: ___________________ **GPS o Lat/Long**: _________________________
Descripción del trayecto: ____
____
Nombres de las personas que hacen la muestra: ____
____
____

Hora inicial: __________ **Temperatura inicial:** __________
Hora final: __________ **Temperatura final:** __________

RESULTADOS
Puntaje: ________________________
Bioclase: ________________________

Orden	Familia	Total	GENERO	Total	Puntaje BMWP	Hábitat
						A B C D E F G H
						A B C D E F G H
						A B C D E F G H
						A B C D E F G H
						A B C D E F G H
						A B C D E F G H
						A B C D E F G H
						A B C D E F G H
						A B C D E F G H
						A B C D E F G H
						A B C D E F G H
						A B C D E F G H
						A B C D E F G H
						A B C D E F G H
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						A B C D E F G H
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						A B C D E F G H
						A B C D E F G H
						A B C D E F G H
						A B C D E F G H
						A B C D E F G H
						A B C D E F G H
	Total:					

Sitios de Muestras:
A: ______________________ F: ____________________
B: ______________________ G: ____________________
C: ______________________ H: ____________________
D: _____________________
E: ______________________

Observaciones:
Odo: Odonata **Col**: Coleoptera
Dip: Diptera **Crus**: Crustacea
Ephe: Ephemeroptera **Meg**: Megaloptera
Ple: Plecoptera **Lep**: Lepidoptera
Tric: Trichoptera **Hem**: Hemiptera

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SVAP-TAL Evaluación de Hábitat

Código del Sitio: ____________________________ País: _______________________ GPS Waypoint # __________ N: ____________________

Nombre del Río: ____________________________ Cuenca: _____________________ EPE: ____________________ W: ______________________

Descripción del trayecto: ____

____

____

____

Fecha: **Día:**_______ **Mes:**_____________ **Año:** __200__

Hora de Evaluación: _______________

Nombres de participantes: ____

____

____

Tiempo actual:	Tiempo en las ultimas 24 horas:	Dibujo del sitio:
Tormenta (mucha lluvia) Lluvia Lloviznas Nublado Sol/ parcialmente nublado	Tormenta (mucha lluvia) Lluvia Lloviznas Nublado Sol/ parcialmente nublado	

1. Descripción de vegetación ribereña:

Margen derecha: _________________________________ Margen Izquierda: _________________________________

____

____

____

2. Presencia de usos de ser humanos?

Lavar ropa ____, Pescar ____, Bañar _____, Casas de habitación cerca _____, Animales domésticos ____, Comunidad _____, etc, _______

____

____

3. Contaminación de origen humano? (bolsas de plástico ____, basura: ____, tubos de drenaje ____, cloro____, fumigación en el área ____, Pañales desechables ____, basura en bolsas _____, bolsas plasticas ____, latas ____, etc. ______________________________

____

____

____

Resultados	
Puntaje promedio:	Clase:

Comentarios:

____

____

____

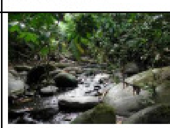
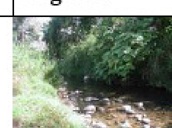
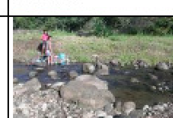
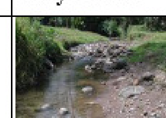
____

____

____

____

____

Clase	**Excelente**	**Bueno**	**Regular**	**Pobre**	**Muy Pobre**
Rango de puntajes	 **9.6 = 10**	 **7.7 = 8.5**	 **6.1 = 7.0**	 **3.1 = 5.3**	 **1.0 = 2.2**

Nota: si un resultado cae entre las clases, el Encargado determina según su criterio profesional en que categoría ubicarlo.

Programa de Biomonitoreo The Nature Conservancy DOROTHY ANN FOUNDATION The J.M. Kaplan Fund

RESULTADOS										
									COMENTARIOS	
A										
B										
C										
D										
E										
F										
G										
H										
I										
J										
K										
L										1 2 3 4 5 6 7 8 9 10 11 12 13
M										1 2 3 4 5 6 7 8 9
N										
O										

Appendix B - SVAP Field Guide

Evaluación Visual de Ríos y Quebradas adaptado a Talamanca
-Conociendo la salud de los ríos- CUENCAS PEQUEÑAS <10Km²

Los ríos o quebradas son el hogar de muchos animales. Un río en buen estado puede adoptar muchas formas vivientes y además sirve como un lugar agradable para los seres humanos. Para saber si un río está en buen estado tenemos que fijarnos en las características que pueda tener. Esta es una manera de evaluar un río pequeño o quebrada aplicando altos puntajes (9.6 a 10) para ríos o quebradas que tienen condiciones sanas, y bajos puntajes (de 2.2 a 1) para ríos o quebradas en mal estado. Cada cuadro describe un aspecto del río o quebrada y tiene un rango de posibles condiciones presentes.

Lea cuidadosamente las descripciones y de un puntaje (1 a 10) a las condiciones que observa en su río o quebrada. Escribe los resultados en un papel aparte.

A. APARIENCIA DEL AGUA

* Muy clara * Un día después de una lluvia se pone completamente clara.	* Puede ser turbio por varios días después de una tormenta.	* Muy turbio por mas de una semana después de lluvias. Y/O * Malos olores de origen orgánico en todas las pozas.	* Turbio todo el tiempo. Y/O * Fuerte olor de químicos, aceite, aguas negras, otros contaminantes, líquidos en todo el trayecto.
10	**7**	**3**	**1**

(**Turbio** significa que no se puede ver el fondo del río, el agua no está clara)

(B). SEDIMENTOS

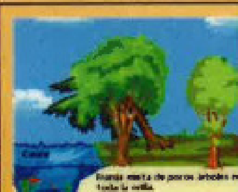
Ejercicio:

1. Busca una sección de la quebrada o río donde el agua corra rápido (raudal) y con piedras.
2. Remueve las piedras con tu pie rápidamente y después saca tu pie.
3. Cuenta los segundos en que queda una nube de sedimentos en donde estaba el pie.

 El agua se mantiene clara. No hay disturbios de agua.	 2 segundos mientras se aclara el agua	 5 segundos mientras se aclara el agua	 8 segundos mientras se aclara el agua	 Las piedras están completamente cubiertas por sedimentos finos. No se aclara el agua.
10	**7**	**5**	**3**	**1**

(Sedimentos son pedacitos de tierra muy pequeños suspendidos en el agua o pegados a las piedras)

(C). ZONA RIBEREÑA (evalué primero una orilla y después la otra, sume y divida en 2)

				
10	7	5	3	1

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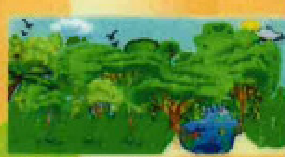
(D). SOMBRA (Cobertura Boscosa)

(Evalúe primero una orilla y después la otra, sume y divida en 2)

 100% del cauce con sombra	 Superficie del agua Sombreado en un 75%	 Superficie del agua sombreado 50%	 Superficie del agua sin Sombra
10	7	3	1

(E). POZAS

 Abundancia de pozas de por lo menos 1 metro de profundidad en promedio.	 Presencia de pozas pero no abundancia. Menos diversidad en profundidad.	 Presencia de pozas pero no son profundas.	 Ausencia de pozas. Las antiguas pozas están llenas de sedimentos.
10	7	3	1

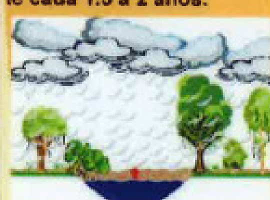
(F). CONDICION DEL CAUCE

 Cauce natural. No hay incisión ni sedimentación.	* Evidencia de alteración en el cauce pero se esta recuperando. * Poca incisión (que se esta haciendo cada vez más profundo). * Se observa sedimentos.	* El cauce esta alterado (puede ser canalizado) * Exceso de incisión. Esta naturalmente muy profundo.	 *El cauce esta canalizado *Mucha incisión
10	7	3	1

(La palabra "cauce" se refiere al lugar donde corre el agua en condiciones normales)

(G). ALTERACION HIDROLOGICA (desbordes)

(Las inundaciones (desbordes) son buenas para el ecosistema por que traen nutrientes a la tierra alrededor del río).

Desbordes ocurren 1 o varias veces durante la época 	Desbordes ocurren solamente **cada 1.5 a 2 años.** 	Desbordes ocurren solamente **cada 3 a 5 años.** 	A pesar de fuertes tormentas no hay desbordes. El cauce esta canalizado. 
10	7	3	1

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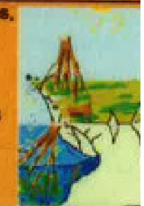
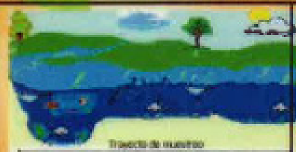
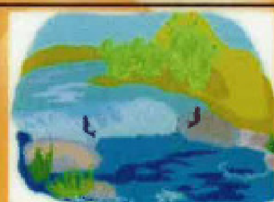
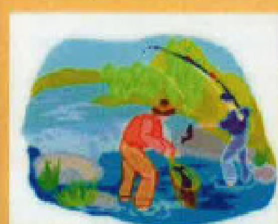
(H). ESTABILIDAD DE LA ORILLA (Evalué primero una orilla y después la otra, sume y divida en 2)

*Las orillas están Estables: Raíces de árboles protegen las orillas 	* Moderadamente estables: Menos que el de las orillas están tegidas por raíces de árboles 	* Poco inestaBles: Erosión en las curvas y algunos árboles esta cayendo al 	* Orillas inestables, erosionadas * Árboles maduros caídos en el agua. 
10	7	3	1

(I). BARRERA AL MOVIMIENTO DE PECES.

 No hay barreras al movimiento de peces en todo el río o quebrada	 Obstrucciones provisionales hechos por el ser humano que inhiben el movimiento de peces. (Estas barreras son arrastradas después de una crecida).	 Alcantarillas o puentes. (Son pequeños, principalmente para los puentes en la región).	 Represas o desviaciones de agua en cualquier parte del río. (Hidroeléctricas)
10	7	3	1

(J). PRESION DE PESCA

 Nadie pesca aquí!!!!	 * La pesca es poco frecuente con arbaleta y/o cuerda. * No usan redes	 * Se pesca con frecuencia con arbaleta, cuerda y/o atarraya. * No usan redes agalleras * Usan venenos 1 vez al año.	 * Pesca indiscriminada. * Frecuentemente usan venenos para la captura de camarón. *Se usan trasmayo para pescar
10	7	3	1

(K). PRESENCIA DE DESECHOS SÓLIDOS (Basura)

No hay evidencia de basura de usos humanos	Presencia de desechos sólidos (ejp: bolsas en los árboles después de una inundación)	Presencia de desechos sólidos dentro del cauce (1 o 2 tipos)	Presencia moderada de deshechos sólidos dentro del cauce (mas de tres tipos)	Abundancia de basura en todo el trayecto
10	7	5	3	1

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(L). REFUGIO PARA PECES DENTRO DEL RIO O QUEBRADA

Mas de 7 tipos de refugios	6 o 7 tipos de refugios	4 o 5 tipos de refugios	2 o 3 tipos de refugios	0 o 1 tipo de refugio
10	7	5	3	1


Varios troncos en diferentes sitios y de diferentes tamaños


Ramas de arboles o arbustos caídas dentro de agua, de diferentes tipos y tamaños


Plantas inclinadas sobre el agua Sacate y hojas sumergidas en el agua. En diferentes sitios


Alfombra de raices dentro del agua pueden ser de árboles o plantas a la orilla de río.


Raíces gruesas en diferentes sitios


Plantas creciendo dentro del agua.

Pozas aisladas del cauce principal.


Hojas en el fondo en diferentes estados de descomposición


Orillas socavadas o cuevas en algunas partes


Piedras de todos los tamaños

OTROS!!!!! <u>RAPIDOS PEQUEÑOS</u>

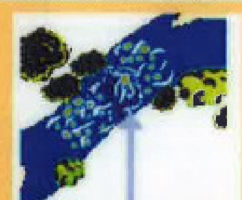
(M). REFUGIO PARA INSECTOS (Bichos)

5 o mas tipos	3 o 4 tipos	1 o 2 tipos	0 o 1 tipo
* Hábitat listo para la colonización por insectos (ramas etc. tienen bastante tiempo en el agua).	* También puede tener hábitat potencial, por ejemplo árboles inclinados sobre la quebrada.	* El fondo del río cubierto en sedimentos o hábitat no presente por alta velocidad del agua.	* Habitas no presentes
10	7	3	1

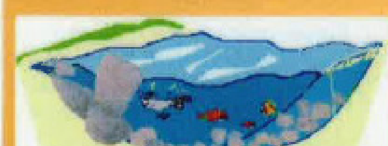

Troncos y ramas caídos dentro del agua de diferentes tipos y tamaños


Plantas creciendo dentro del agua. buchones, lirios, zacate con hojas en el agua


Hojas en el fondo en diferentes estados de descomposición


RAPIDOS PEQUEÑOS con paqutes de hojas


Alfombra de raices dentro del agua pueden ser de árboles o plantas a la orilla de río.


Piedras de todos los tamaños

Otro???

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(N). PRESENCIA DE ESTIERCOL

No hay estiércol o evidencia de animales cerca del río, o quebrada (cerdos, vacas, caballos perros, entre otros).	 Ganado en la zona ribereña. Pero no tienen acceso directo al río.	 Estiércol en la quebrada o ganado dentro del río. Aunque este el paso obstruido, el alambre esta muy cerca del río.	 Mucho estiércol en el río o tuberías que descargan aguas negras al río.
10	7	3	1

(O). Aumento de nutrientes de origen orgánico "Produce algas".

 No hay algas filamentosas. El agua esta totalmente clara.	 Crecimiento moderado de algas filamentosas en sitios de aguas lentas.	 Abundancia de algas filamentosas, especialmente en áreas con sol.	 Exceso de algas filamentosas en todos los sustratos fijos (piedras, troncos etc..)
10	7	3	1

(**Algas** : Lama verde (MOJO) o cubierta resbalosa que crece sobre las piedras o troncos que están dentro del agua)

¡¡¡YA TERMINO!!!!

Ahora suma los puntajes y divide entre 15. Después ubica el puntaje en los rangos abajo.

RANGO DE PUNTAJES	CLASE
9.6 a 10	Excelente
7.7 a 8.5	Bueno
6.1 a 7.0	Regular
3.1 a 5.3	Pobre
1.0 a 2.2	Muy Pobre

¿COMO ESTA TU QUEBRADA O RIO?

Nota: Si un resultado cae entre las clases, El Biólogo determina según su criterio profesional en que categoría ubicar.

Gracias!

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Appendix C - Aquatic Benthic Macroinvertebrate Raw Data

Site ID	Watershed ID	Baetidae	Euthyplociidae	Heptageniidae	Leptohyphidae	Leptophlebiidae	Belostomatidae	Naucoridae	Calopterygidae
RV01	RV	0	0	0	10	2	0	1	0
RV02	RV	21	0	0	89	61	0	8	0
RV03	RV	3	0	0	17	4	0	1	0
RV04	RV	14	0	1	36	21	1	0	8
RV05	RV	9	0	0	15	16	0	0	0
RV06	RV	8	0	0	8	5	0	0	0
RV07	RV	27	0	2	16	16	0	8	2
RV08	RV	35	0	1	4	9	0	1	2
RA01	RV	7	0	0	32	88	0	1	2
RA02	RV	2	0	0	3	26	0	0	0
QM01	RV	0	0	0	7	14	0	0	5
QM02	RV	2	0	0	10	5	0	0	1
QM03	RV	5	0	0	10	4	0	0	5
QP01	RV	0	0	0	8	8	0	0	4
QC01	RV	4	0	0	8	9	0	1	2
QJ01	RV	9	0	0	23	5	0	0	1
RPB01	RPB	1	0	0	0	0	0	0	0
RPB02	RPB	10	0	0	16	5	0	1	0
RPB03	RPB	76	0	0	85	55	0	5	2
RPB04	RPB	24	0	0	58	59	4	6	4
RPB05	RPB	46	0	0	41	73	0	0	0
RPB06	RPB	23	0	0	13	32	0	1	10
RPB07	RPB	12	0	0	23	18	0	1	4
RPB08	RPB	49	0	1	17	23	0	0	2
RPB09	RPB	23	0	2	23	13	0	0	1
RPB10	RPB	15	0	1	5	5	0	0	0
RPBITA01	RPB	29	0	1	9	35	0	0	1
RPBITA02	RPB	8	0	0	11	7	0	0	0
RPBITA03	RPB	46	1	6	11	19	0	1	0
RCTE01	RPB	18	0	0	62	80	0	0	0
RCTE02	RPB	3	0	0	16	52	0	1	5
RCTE03	RPB	6	0	0	5	42	0	1	6
RCTE04	RPB	6	0	0	5	42	0	1	6
RCLL01	RPB	10	0	0	11	28	0	2	3
RCLL02	RPB	83	0	1	72	109	0	3	3
TOTAL		634	1	16	779	990	5	44	79

Site ID	Watershed ID	Coenagrionidae	Gomphidae	Libellulidae	Megapodagrionidae	Platysticitidae	Polythoridae	Pseudostigmatidae	Calamoceratidae
RV01	RV	2	0	1	0	0	0	0	0
RV02	RV	0	2	0	0	0	0	0	0
RV03	RV	0	0	3	0	0	0	0	0
RV04	RV	0	0	0	0	0	1	0	0
RV05	RV	0	0	0	0	0	0	1	0
RV06	RV	0	0	0	0	0	0	0	6
RV07	RV	0	0	2	0	0	0	0	4
RV08	RV	0	0	1	0	0	0	0	0
RA01	RV	0	0	0	0	0	0	0	0
RA02	RV	0	1	0	0	1	3	0	0
QM01	RV	2	1	1	0	0	1	0	0
QM02	RV	0	0	1	0	0	0	0	0
QM03	RV	3	0	0	0	0	0	0	0
QP01	RV	0	0	1	0	0	0	0	0
QC01	RV	1	0	1	1	2	2	0	2
QJ01	RV	0	0	0	0	0	1	0	0
RPB01	RPB	0	0	0	0	0	0	0	0
RPB02	RPB	0	0	0	0	0	0	0	0
RPB03	RPB	0	0	0	1	0	2	0	0
RPB04	RPB	4	0	4	0	0	0	0	0
RPB05	RPB	0	0	0	0	0	0	0	2
RPB06	RPB	1	0	1	0	0	0	0	2
RPB07	RPB	0	0	0	0	0	0	0	2
RPB08	RPB	0	0	0	0	0	3	0	1
RPB09	RPB	0	0	0	0	0	0	0	4
RPB10	RPB	0	0	1	0	0	0	0	1
RPBITA01	RPB	0	0	0	0	0	0	0	0
RPBITA02	RPB	1	0	5	0	0	1	0	2
RPBITA03	RPB	0	0	0	0	0	0	0	0
RCTE01	RPB	4	1	1	0	1	0	0	4
RCTE02	RPB	3	0	3	0	0	0	0	8
RCTE03	RPB	1	0	1	0	0	2	0	1
RCTE04	RPB	1	0	1	0	0	2	0	1
RCLL01	RPB	1	0	2	0	0	0	0	0
RCLL02	RPB	0	0	0	0	0	1	0	0
TOTAL		24	5	30	2	4	19	1	40

Site ID	Watershed ID	Ecnomidae	Glossosomatidae	Helicopsychidae	Hydrobiosidae	Hydropsychidae	Hydroptilidae	Lepidostomatidae	Leptoceridae
RV01	RV	0	1	0	0	16	0	0	0
RV02	RV	0	0	0	2	27	0	0	44
RV03	RV	0	0	0	0	9	0	0	1
RV04	RV	0	5	0	5	0	0	0	63
RV05	RV	0	2	1	1	2	1	0	69
RV06	RV	0	2	2	1	10	0	0	95
RV07	RV	0	50	0	2	27	1	0	11
RV08	RV	0	23	0	1	5	0	1	3
RA01	RV	0	0	0	0	68	0	0	1
RA02	RV	0	0	0	0	5	0	0	3
QM01	RV	0	2	0	0	21	0	0	1
QM02	RV	0	0	0	0	10	0	0	0
QM03	RV	0	0	0	0	6	0	0	0
QP01	RV	0	0	0	0	93	0	0	0
QC01	RV	0	0	0	0	6	0	0	0
QJ01	RV	0	1	0	0	25	0	0	5
RPB01	RPB	0	0	0	0	0	0	0	0
RPB02	RPB	0	0	0	6	29	0	0	3
RPB03	RPB	0	0	0	19	32	0	0	24
RPB04	RPB	0	0	0	4	21	0	0	11
RPB05	RPB	0	1	0	2	15	0	0	83
RPB06	RPB	0	0	0	4	27	0	0	7
RPB07	RPB	0	0	0	0	18	0	0	8
RPB08	RPB	0	1	0	1	31	0	0	28
RPB09	RPB	0	6	0	3	26	0	2	27
RPB10	RPB	0	2	0	0	21	0	4	7
RPBITA01	RPB	0	2	0	0	22	0	0	17
RPBITA02	RPB	1	4	0	3	32	0	0	18
RPBITA03	RPB	0	0	0	4	38	0	1	108
RCTE01	RPB	0	2	1	1	18	0	0	5
RCTE02	RPB	0	0	0	7	19	0	0	14
RCTE03	RPB	0	0	0	0	8	0	0	16
RCTE04	RPB	0	0	0	0	8	0	0	16
RCLL01	RPB	0	0	0	3	4	0	0	4
RCLL02	RPB	0	0	1	8	39	0	0	7
TOTAL		1	104	5	77	738	2	8	699

Site ID	Watershed ID	Philopotamidae	Polycentropodidae	Dryopidae	Dytiscidae	Elmidae	Hydraenidae	Limnichidae	Psephenidae	Ptilodactylidae	Scirtidae
RV01	RV	0	0	0	0	3	0	0	0	0	0
RV02	RV	0	0	1	0	18	0	0	4	1	0
RV03	RV	0	0	0	0	7	0	0	0	1	0
RV04	RV	0	0	0	0	27	0	0	4	1	0
RV05	RV	1	1	1	0	18	0	0	1	0	0
RV06	RV	0	0	0	0	65	0	0	0	1	0
RV07	RV	0	1	2	0	107	0	0	1	4	0
RV08	RV	0	1	0	0	47	0	0	0	1	0
RA01	RV	0	0	109	0	14	0	0	4	1	0
RA02	RV	0	0	2	0	13	0	0	0	1	0
QM01	RV	0	0	0	0	9	0	0	2	0	0
QM02	RV	0	0	0	0	12	0	0	1	0	0
QM03	RV	0	0	0	0	6	0	0	0	0	0
QP01	RV	0	0	0	0	0	0	0	0	0	0
QC01	RV	1	0	1	0	28	0	0	2	0	0
QJ01	RV	0	0	0	0	64	0	1	0	4	0
RPB01	RPB	0	0	8	0	4	0	0	0	0	0
RPB02	RPB	0	0	11	0	70	0	0	0	0	0
RPB03	RPB	0	8	0	0	175	0	0	0	1	0
RPB04	RPB	0	0	3	0	73	0	0	0	0	0
RPB05	RPB	1	1	12	0	87	0	0	0	1	0
RPB06	RPB	0	0	21	0	121	0	0	0	4	0
RPB07	RPB	0	0	4	0	139	0	0	1	0	0
RPB08	RPB	0	1	6	0	165	0	0	0	0	0
RPB09	RPB	0	1	2	0	254	0	0	2	0	0
RPB10	RPB	0	0	1	39	254	0	0	0	1	4
RPBITA01	RPB	0	1	1	0	109	0	0	1	1	1
RPBITA02	RPB	0	0	3	0	327	1	0	1	5	1
RPBITA03	RPB	0	0	9	0	1038	0	0	3	8	7
RCTE01	RPB	0	10	1	0	9	0	0	5	2	0
RCTE02	RPB	0	0	8	0	18	0	0	1	2	1
RCTE03	RPB	0	5	2	0	34	0	0	0	5	0
RCTE04	RPB	0	5	2	0	34	0	0	0	5	0
RCLL01	RPB	0	3	2	0	37	0	0	1	1	0
RCLL02	RPB	0	4	9	0	122	0	0	13	1	0
TOTAL		3	42	221	39	3508	1	1	47	52	14

Site ID	Watershed ID	Staphylinidae	Athericidae	Blephariceridae	Ceratopogonidae	Chironomidae	Dixidae	Empididae	Psychodidae	Simuliidae	Stratiomyidae
RV01	RV	0	0	0	0	12	0	0	0	0	0
RV02	RV	0	0	0	0	13	0	0	0	10	0
RV03	RV	0	0	0	0	0	0	0	0	0	0
RV04	RV	0	0	0	0	7	2	0	0	2	0
RV05	RV	0	0	0	0	8	2	0	1	0	0
RV06	RV	0	0	1	0	4	0	0	0	0	0
RV07	RV	0	4	0	0	7	1	0	0	1	0
RV08	RV	0	10	0	1	2	0	0	0	2	0
RA01	RV	0	0	0	0	6	0	0	0	58	0
RA02	RV	0	0	0	0	0	0	0	0	1	0
QM01	RV	0	0	0	0	0	0	0	0	0	0
QM02	RV	0	0	0	0	14	0	0	0	22	0
QM03	RV	0	0	0	0	5	0	0	0	12	0
QP01	RV	0	0	0	0	2	0	0	0	1	0
QC01	RV	0	0	0	0	8	0	0	0	3	0
QJ01	RV	0	0	0	0	16	0	0	0	15	0
RPB01	RPB	1	0	0	0	180	0	0	0	0	0
RPB02	RPB	0	0	0	0	14	0	0	0	51	0
RPB03	RPB	0	4	0	0	29	0	1	1	116	0
RPB04	RPB	0	5	0	0	15	3	2	0	45	1
RPB05	RPB	0	2	1	0	21	5	0	1	5	0
RPB06	RPB	1	6	2	0	12	2	3	2	60	0
RPB07	RPB	5	6	0	0	5	0	1	0	39	0
RPB08	RPB	0	11	0	0	12	4	0	0	3	0
RPB09	RPB	0	8	0	0	8	2	0	0	8	0
RPB10	RPB	0	21	0	0	4	5	0	0	12	0
RPBITA01	RPB	0	2	0	0	4	3	0	0	4	0
RPBITA02	RPB	21	7	0	0	23	0	4	0	27	0
RPBITA03	RPB	0	1	0	0	19	0	0	2	4	0
RCTE01	RPB	0	0	0	2	96	10	1	0	31	0
RCTE02	RPB	0	0	2	0	15	4	0	0	37	0
RCTE03	RPB	0	0	0	0	5	1	1	0	11	0
RCTE04	RPB	0	0	0	0	5	1	1	0	11	0
RCLL01	RPB	0	0	0	0	19	7	0	0	44	0
RCLL02	RPB	0	0	0	0	36	2	0	0	16	0
TOTAL		28	87	6	3	626	54	14	7	651	1

Site ID	Watershed ID	Tabanidae	Tipulidae	Pyralidae	Corydalidae	Perlidae	Hidracarina	Lutrochidae	Oligochatea	Sphaeridae	Hirudidae	Physidae	TOTAL
RV01	RV	0	0	0	0	2	0	0	1	0	0	0	51
RV02	RV	0	0	1	0	6	0	1	0	0	0	0	309
RV03	RV	0	0	0	0	5	0	0	0	0	0	0	51
RV04	RV	0	1	1	3	12	0	0	1	1	0	0	217
RV05	RV	0	0	1	0	12	0	0	0	0	0	0	163
RV06	RV	0	0	0	0	19	0	0	0	0	0	0	227
RV07	RV	0	6	1	0	36	0	0	0	0	0	0	339
RV08	RV	0	2	1	1	21	0	0	0	0	0	0	175
RA01	RV	0	0	0	0	22	0	0	0	0	0	0	413
RA02	RV	0	0	0	1	15	0	0	0	0	0	0	77
QM01	RV	0	0	0	0	9	0	0	0	0	0	0	75
QM02	RV	0	0	0	1	0	1	0	0	0	0	0	80
QM03	RV	0	0	0	0	4	0	0	1	0	0	0	61
QP01	RV	0	0	0	2	0	0	0	0	0	0	0	119
QC01	RV	0	0	1	0	1	0	0	0	0	0	0	84
QJ01	RV	0	1	1	0	65	0	0	0	0	1	0	238
RPB01	RPB	0	0	0	0	0	0	0	2	0	0	98	294
RPB02	RPB	0	0	0	1	33	0	0	0	0	0	0	250
RPB03	RPB	0	0	1	0	72	0	1	0	0	0	0	710
RPB04	RPB	0	1	4	0	23	0	0	0	0	0	0	374
RPB05	RPB	0	1	0	2	33	0	0	0	0	0	0	436
RPB06	RPB	0	0	2	3	37	1	0	0	0	0	0	398
RPB07	RPB	0	29	1	1	34	0	0	0	0	0	0	351
RPB08	RPB	0	1	2	1	58	2	0	0	0	0	0	423
RPB09	RPB	0	0	0	1	62	1	0	0	0	0	0	479
RPB10	RPB	0	6	0	1	66	1	0	0	0	0	0	477
RPBITA01	RPB	0	0	0	4	22	0	0	0	0	0	0	269
RPBITA02	RPB	0	17	0	0	83	0	0	0	0	0	0	613
RPBITA03	RPB	0	3	0	4	158	5	0	0	0	0	0	1496
RCTE01	RPB	0	0	0	2	16	0	0	0	0	0	0	383
RCTE02	RPB	0	0	0	0	30	0	0	0	0	0	0	249
RCTE03	RPB	1	0	0	1	38	0	0	0	0	0	0	193
RCTE04	RPB	1	0	0	1	38	0	0	0	0	0	0	193
RCLL01	RPB	0	0	0	1	11	0	0	0	0	0	0	194
RCLL02	RPB	0	1	0	3	44	0	0	0	0	0	0	578
TOTAL		2	69	17	34	1087	11	2	5	1	1	98	11039

Appendix D - Biological Index Scores

site ID	watershed	BMWP-CR	FBI	FBI-CR	%Chironomidae	%EPT	CA1	CA2	Richness	%Dominant	Abundance
RV01a	RV	57.00	4.04	5.14	23.53	60.78	-1.54	-1.81	11.00	31.37	51.00
RV02a	RV	102.00	3.39	3.84	4.21	80.91	-0.33	0.27	17.00	28.80	309.00
RV03a	RV	62.00	3.75	3.90	0.00	76.47	-0.68	-1.15	10.00	33.33	51.00
RV04a	RV	126.00	3.40	3.78	3.23	72.35	0.59	-0.35	22.00	29.03	217.00
RV05a	RV	112.00	3.50	3.74	4.91	79.75	1.28	1.88	20.00	42.33	163.00
RV06a	RV	93.00	3.61	3.70	1.76	68.72	1.33	1.04	14.00	41.85	227.00
RV07a	RV	152.00	2.87	3.14	2.06	56.93	1.15	-0.27	25.00	31.56	339.00
RV08a	RV	141.00	2.88	2.97	1.14	59.43	1.59	-0.76	23.00	26.86	175.00
RA01a	RV	78.00	3.96	4.18	1.45	52.78	-0.55	-0.37	14.00	26.39	413.00
RA02a	RV	90.00	2.57	2.64	0.00	70.13	-1.31	2.54	14.00	33.77	77.00
QM01a	RV	85.00	3.35	3.75	0.00	72.00	-1.59	-0.36	13.00	28.00	75.00
QM02a	RV	61.00	4.65	5.15	17.50	33.75	-0.86	-0.91	12.00	27.50	80.00
QM03a	RV	52.00	4.53	5.00	8.20	47.54	-1.80	-1.44	11.00	19.67	61.00
QP01a	RV	40.00	3.88	4.84	1.68	91.60	-1.95	-1.90	8.00	78.15	119.00
QC01a	RV	116.00	3.96	4.15	9.52	36.90	-2.14	3.11	20.00	33.33	84.00
QJ01a	RV	93.00	3.07	3.53	6.72	55.88	0.12	-0.09	17.00	27.31	238.00
RPB01a	RPB	25.00	0.20	7.91	61.22	0.34	0.68	0.00	7.00	61.22	294.00
RPB02a	RPB	75.00	4.00	4.28	5.60	40.80	0.14	-0.47	13.00	28.00	250.00
RPB03a	RPB	125.00	3.87	3.99	4.08	52.25	-0.32	0.65	21.00	24.65	710.00
RPB04a	RPB	117.00	3.81	4.07	4.01	53.48	-1.14	-1.96	22.00	19.52	374.00
RPB05a	RPB	140.00	3.35	3.64	4.82	68.35	0.54	0.77	22.00	19.95	436.00
RPB06a	RPB	146.00	3.93	4.13	3.02	36.43	-0.36	-0.64	26.00	30.40	398.00
RPB07a	RPB	111.00	3.70	4.04	1.42	32.76	-0.14	-0.23	20.00	39.60	351.00
RPB08a	RPB	141.00	3.39	3.56	2.84	49.88	0.35	0.34	23.00	39.01	423.00
RPB09a	RPB	139.00	3.45	3.56	1.67	40.08	1.55	-0.15	22.00	53.03	479.00
RPB10a	RPB	138.00	3.40	3.79	0.84	26.62	1.90	-0.76	23.00	53.25	477.00
RPBITA01a	RPB	120.00	3.39	3.61	1.49	51.30	0.71	-0.04	20.00	40.52	269.00
RPBITA02a	RPB	153.00	3.60	3.92	3.75	27.57	0.21	-0.25	25.00	53.34	613.00
RPBITA03a	RPB	137.00	3.65	3.74	1.27	26.20	1.30	-0.22	23.00	69.39	1496.00
RCTE01a	RPB	148.00	3.46	4.41	25.07	56.66	-0.67	1.42	25.00	25.07	383.00
RCTE02a	RPB	122.00	3.56	3.85	6.02	59.84	-0.67	-0.59	21.00	20.88	249.00
RCTE03a	RPB	122.00	3.14	3.27	2.59	62.69	-0.65	0.23	22.00	21.76	193.00
RCTE04a	RPB	156.00	3.87	4.17	2.59	62.69	-0.65	0.23	22.00	21.76	193.00
RCLL01a	RPB	113.00	4.14	4.40	9.79	38.14	-0.60	-0.47	20.00	22.68	194.00
RCLL02a	RPB	130.00	3.31	3.71	6.23	63.67	0.03	0.39	22.00	21.11	578.00

Appendix E - SVAP Scores

	SVAP-A	SVAP-B	SVAP-C	SVAP-D	SVAP-E	SVAP-F	SVAP-G	SVAP-H	SVAP-I	SVAP-J	SVAP-K	SVAP-L	SVAP-M	SVAP-N	SVAP-O
RV01a	8	6	3	2	4	3	9	3	5	7	3	7	3	7	8
RV02a	10	10	5	3	1	2	7	4	10	3	5	3	4	9	8
RV03a	10	6	5	2	6	9	7	4	10	8	8	2	3	8	9
RV04a	7	6	7	3	7	6	7	8	10	10	10	5	7	10	9
RV05a	6	6	9	3	8	9	7	8	10	7	6	5	7	3	7
RV06a	7	9	9	6	10	9	9	9	2	7	10	5	7	8	9
RV07a	10	9	8	4	8	9	9	10	10	10	10	5	10	10	6
RV08a	10	9	9	2	10	10	10	9	10	10	10	6	8	8	8
RA01a	8	6	7	7	6	7	10	6	7	7	7	5	7	10	8
RA02a	7	7	7	8	7	7	8	8	10	6	9	5	7	8	7
QM01a	7	6	7	8	5	7	6	7	10	10	9	5	6	6	8
QM02a	10	6	4	8	5	6	5	5	6	8	5	5	8	4	7
QM03a	9	6	9	8	7	8	7	9	10	10	10	5	6	3	8
QP01a	2	6	4	2	8	7	10	4	10	8	3	5	8	9	5
QC01a	8	6.5	5	9	3	7	8.5	8	10	10	4	5	7	3	7
QJ01a	10	6	6	4	5	7	8	7	8	10	10	4	7	10	7
RPB01a	7	6	4	3	8.5	6	7	5.5	10	10	7	5	7	10	6
RPB02a	9	7	2	7.5	7.5	3	5	6	7	7	7	3	7	10	8
RPB03a	9	6	9.5	6	7	8.5	7.5	6.5	10	9	10	5	7	10	6
RPB04a	9	7	9	7	7	8.5	7	8	10	8.5	5.5	5	7	10	6
RPB05a	9	6.5	6	6	8	9	3	8.5	10	10	8.5	3	6	10	6
RPB06a	9	6.5	6	6	8	9	3	8.5	10	10	8.5	3	6	10	6
RPB07a	9	8	7	5	9	9.5	8	7	10	10	9.5	3	4	7	8.5
RPB08a	9	6	6	7.5	8	8	5	8.5	10	10	10	3	7	6	10
RPB09a	9	6.5	10	7	8	7	7	9.5	10	10	10	5	7	10	10
RPB10a	9	7	9.5	9	9	9	5	9	10	10	10	6	7	10	10
RPBITA01a	9	7.5	7.5	8	8	9	10	8	10	10	10	3	4	10	7
RPBITA02a	9.5	7	9	9	8	8.5	4	8.5	10	10	10	5	7	10	9.5
RPBITA03a	9	7	9.5	5	5	8	5	9.5	10	10	10	5	7	10	10
RCTE01a	8	6	7	6	3	6.5	10	6.5	7	10	10	5	7	8	5
RCTE02a	8	6	5.5	7	6	6	7	4	10	10	10	5	7	6	9
RCTE03a	8	6	5.5	9	8	6	9	5.5	7	10	8	3	7	10	9
RCTE04a	8	6	8.5	8	7	6	4	7.5	7	10	10	5.5	7	9	8.5
RCLL01a	8	5	6.5	6	6	7	2	6.5	10	8	5	5	7	9	4
RCLL02a	7.5	6	5	5	3	7	9	6	10	10	5	3	4	4	3

Appendix F - Recommendations for a Community Based Monitoring Program

Application of project to the creation of a Community Based monitoring Program

Who

- Work with existing programs such as the one being coordinated by Professor Álvaro Fernández González from the University of Costa Rica named "Hacia una red nacional escolar de monitoreo y restauración socioecológica"
- Schools are useful as well because many have stereoscopes. A professor of sciences at the high school in Volcán expressed interest in assisting with a biomonitoring program.
- Problem with schools is that there is a high turnover rate of teachers in many of the rural schools. Also, having a supportive principal is needed.
- The ANAI program has many strong components and successes that we can learn from. The first is a dedicated full time person to the program to provide consistent technical expertise. Second they offer resources (such as fieldsheets and field guides) that can be used in the south central region. While conducting my research a visit from ANAI's Maribel Mafla[24] was discussed. She is an excellent resource and if biomonitoring is to be taken up within the subwatersheds of Peñas Blancas and Volcán she should be consulted.
- In addition to the one dedicated expert, the program could look elsewhere for additional support. This could include biology students from the University of Costa Rica. Students in Costa Rica are required to fulfill 300 hours of community service volunteer hours. Perhaps a future biomonitoring program could have students conduct volunteer work with our organization and these hours could be used to fulfill community service hours. Secondly, there are a large number of international interns and students that could work on this project.

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[24] Maribel Mafla is the co-ordinator of the ANAI Biomonitoring program and authour of the Guía para evaluaciones ecológicas rápidas con indicadores biológicos en ríos de tamaño mediano, Talamanca, Costa Rica (2005).

Timing

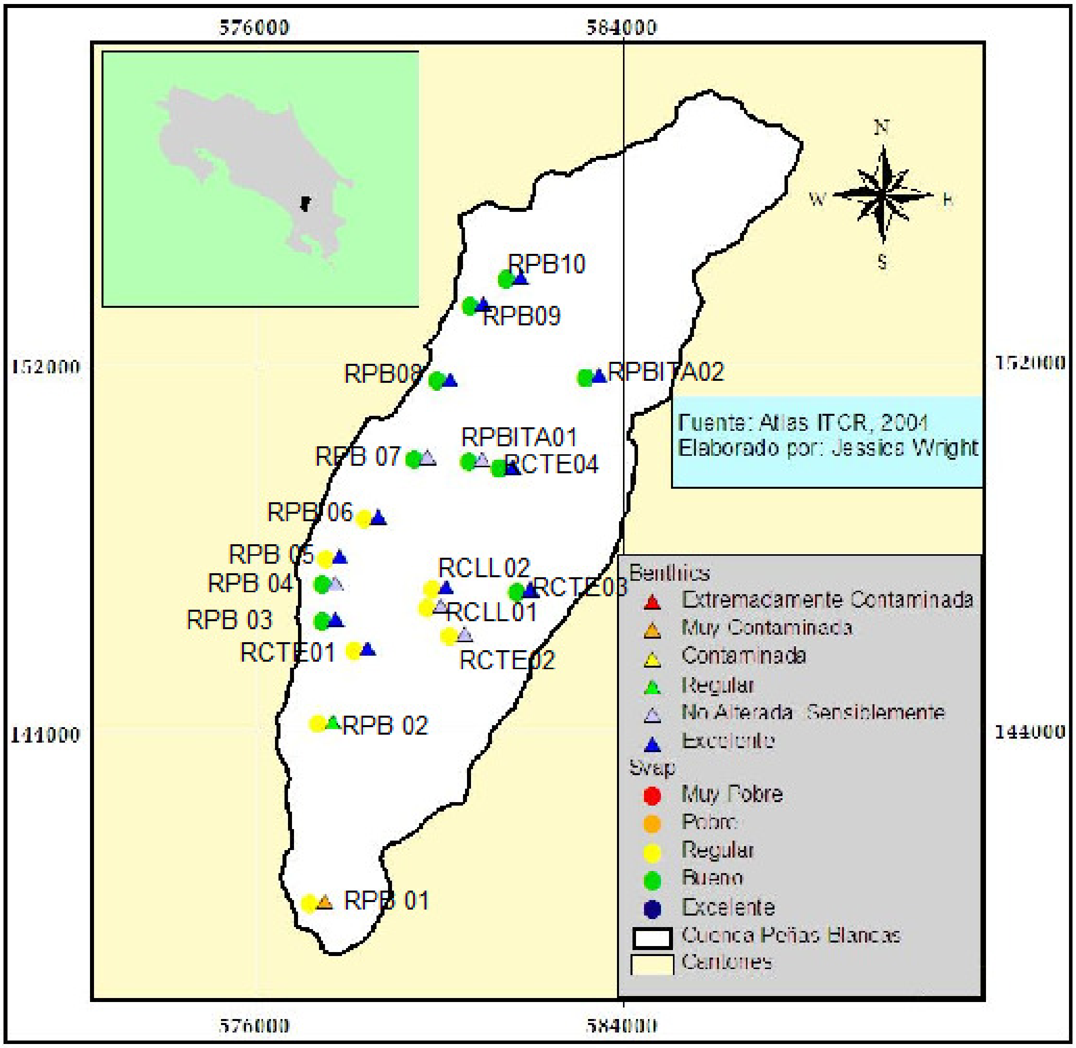
- Do to danger associated with high and fast flowing water; it is not safe to conduct monitoring during the rainy season. I would suggest not long after the rainy season has subsided and then again at the end of dry season. This would provide data for high and low flows.

Equipment

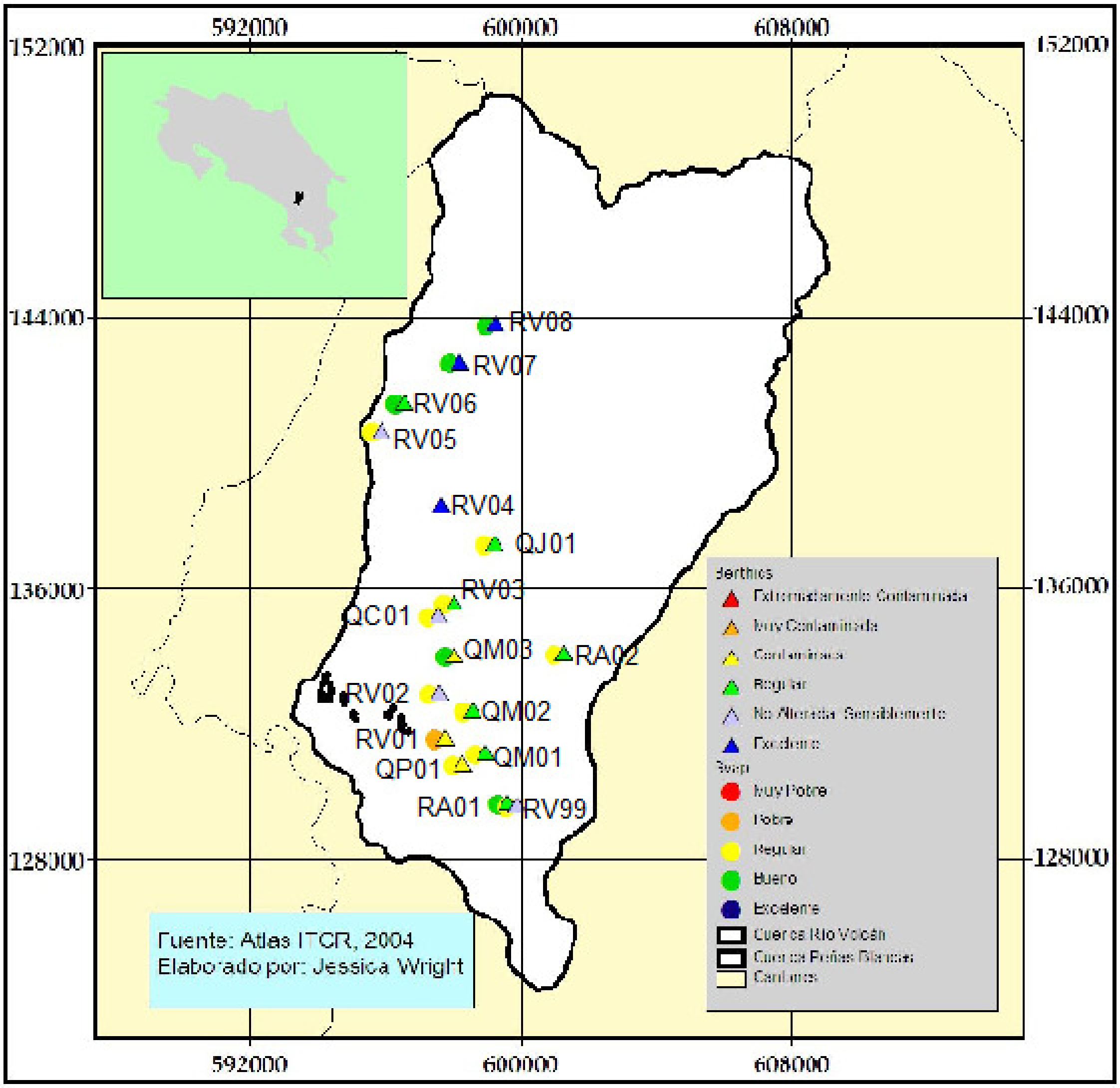
- Colanders can be used as a low-cost alternative to d-nets. Colanders are also beneficial because they do not trap as much detritus as do the smaller mesh size of the D-net.
- Chemical analysis: Low Cost GREEN monitoring kit (ordered through LaMotte). The cost of this kit is $34.00. However you can register your group for World Watershed Monitoring Day and receive a free kit. Instructions come in both Spanish and English. There are tests for pH, DO, BOD, temp, turbidity, N, P and E-Coli. There is enough material to conduct 10 tests with every kit.

Appendix G - Subwatershed Maps of Monitoring Site Locations and Site ID Codes

Monitoring Site Locations and Site ID Codes for Río Peñas Blancas Watershed



Monitoring Site Locations and Site ID Codes for Río Volcán Watershed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600000
608000
152000
144000
136000
128000
RV08
RV07
RV06
RV05
RV04
QJ01
RV03
QC01
QM03
RA02
RV02
QM02
RV01
QM01
QP01
RA01
RV99
Fuente: Atlas ITCR, 2004
Elaborado por: Jessica Wright
Muy Contaminada
Regular
Excelente
Muy Pobre
Pobre
Bueno
Excelente
Cantones