SHANA LYN UDVARDY
Water basin conservation in northwestern Ecuador: a baseline study of four rivers in the pilot area of the Choco-Andes Conservation Corridor.
(Under the Direction of RONALD C. CARROLL)

The goal of this study was to address applied conservation ecology needs on the water basin scale within the Choco-Andes Conservation Corridor pilot area in northwestern Ecuador. The immediate conservation priority in this region was to describe baseline conditions of stream health prior to the development of a second crude-oil pipeline for the country. This study presents data on the density, biomass, diversity and trophic structure of benthic macroinvertebrates at riffle and bank habitat types from 4 rivers within the pilot region of the Choco-Andes Conservation Corridor. The objectives of the study are: (1) to understand local and regional influences on river health; (2) to document baseline data of 4 rivers prior to the development of a crude-oil pipeline; and (3) to provide assessment protocols and recommendations to the Maquipucuna Foundation.

INDEX WORDS**:** Tropical Montane Cloud Forests, Choco – Andes Conservation Corridor, Ecuador, Maquipucuna Foundation, OCP crude – oil pipeline, stream ecology, aquatic macroinvertebrates, biomass, water basin, baseline data

WATER BASIN CONSERVATION IN NORTHWESTERN ECUADOR: A BASELINE STUDY OF FOUR RIVERS IN THE PILOT AREA OF THE CHOCO-ANDES CONSERVATION CORRIDOR.

by

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CHAPTER 1

CONSERVATION OF TROPICAL MONTANE CLOUD FORESTS: THE ROLE OF STREAMS AND RIVERS IN LANDSCAPE MANAGEMENT

Introduction

This paper describes tropical montane cloud forests (TMCFs) in northwestern Ecuador and addresses how riparian areas are integral to conservation efforts to conserve some of the last remnants in the Tropandean ecoregion. The study of riparian areas can help to link terrestrial, aquatic and socioeconomic components in the landscape. Making a connection between aquatic, terrestrial and socioeconomic interfaces helps to bridge conservation theory and practice. As an example of the integral role of streams and rivers in conservation, I describe how this baseline research of rivers in the pilot area of the Choco-Andes Conservation Corridor in northwestern Ecuador became a priority for the Maquipucuna Foundation (a local NGO) and how basic research can help managers to connect social and ecological needs.

A regional description of Tropical Montane Cloud Forests

Depending on the latitude, the elevation of TMCFs in the Tropandean ecoregion is between 800 and 3,500 m.a.s.l and precipitation averages above 2,500 mm annually (Mittermeier et al. 1997). The large biomass of epiphytes, ferns and mosses is an easi ly identifiable characteristic of the forest structure. The presence of persistent and frequent fog distinguishes TMCFs from their montane rain forest counterparts. Depending on specific forest characteristics, fog (horizontal or “occult” precipitation) can add approximately 200 mm of water annually to the hydrologic input. Considering TMCFs exist on different size mountains, elevational ranges, and latitudes, it is not surprising that the presence of fog is the only environmental factor that is shared (Bruijinzeel and Veneklass 1998).

The Tropical Andes region is considered one of the 25 global Hotspots for conservation and research due to the level of plant and animal species diversity, of endemic species and the degree of threat (Mittermeier et al. 1998). The Tropical Andes Hotspot ranks first, of the 25 global hotspots, for both species diversity and endemism of vascular plants, amphibians, and birds. A total of 677 birds are endemic to the Tropical Andes, almost 3 times higher than Mesoamerica. However a better comparison may be with its neighbor, the Choco-Darien Western Ecuador Hotspot just west of the 1,000m topographic contour line (Table 1.1). For vascular plants, the Tropical Andes hotspot has 44% endemic species while the Choco-Darien Western Ecuador Hotspot has 25%.

A large portion of the Tropical Andean endemism is found in pockets along the eastern slope of the Andean Mountain range that runs north – south through Colombia, Ecuador and Peru. Cloud forest ridge areas are one of only four area types in Latin America known to hold high concentrations of endemic species. These areas can exist at scales as small as 5-10km^2 (Gentry 1992).

Cracraft and Grifo (1999) plotted a species diversity index against a threat index and found Ecuador to rank the highest compared to a total of 20 South American countries. The species index included plants, butterflies, birds and mammals and the threat index included: level of human population growth; percent land area disturbed; percent cropland; and percent forest loss per year.

In South America, remnant fragments of TMCFs are rapidly on the decline. The Food and Agriculture Organization (FAO) data from 1994 estimates annual tropical deforestation at 0.8% (Tinker 1997, Doumenge et al. 1995). This seemingly low percentage equals close to 14 million hectares annually and current estimates increase this to over 15 million hectares annually (Singh et al. 2001). The world extent of montane forests has the highest percentage of loss at 1.1% annually compared to 0.6% for rain forests (Tinker 1997). Estimating the extent of remaining tropical montane cloud forests has been a difficult endeavor due to the heavy cloud cover. Nonetheless, the World Conservation Monitoring Centre (WCMC) conducted a global study on the distribution, status, values and threats to TMCFs and found the highest concentration (46%) of TMCFs in Latin America with the majority in Venezuela, Mexico, Ecuador and Colombia (Aldrich 2000). Of the 160 sites in South America, 76 of these are under protection. In Ecuador, an estimated 11,200,000ha of cloud forest exist and of this, just under 8% (1,488,700 ha) is protected (Brown and Kappelle 2002). Based on FAO data from 1991, Ecuador lost 53.60% of forested land from 1950 – 1992 (Koopowitz et al. 1994).

However, It has been postulated that 90% of the original TMCFs in the northern Andes have been lost (Hamilton et al. 1995). Analysis of the Andean forests in Bolivia and Ecuador by the IUCN and a local non-governmental organization has three major summary points: 1) only small patches of native montane forests remain; 2) these patches are likely to be destroyed completely due to colonization; and 3) the institution in charge of management of these areas is ineffective in protecting them (Doumenge et al 1995).

Factors influencing the decline of remnant patches of TMCFs:

The primary force behind the conversion of TMCFs is the colonization of land by people and their subsequent land-use practices. Given the average fertility rate, population pressures in TMCFs can be expected to continue to rise. According to Fischer & Heilig (1997) the world's population is growing by approximately 80 million people annually (surprisingly less than it was 10 years ago at 85 million annually). This rate of growth is expected to decrease by year 2050 to 50 million people annually. However, in 2050 we will have reached a world population of approximately 9.3 billion people (Fischer & Heilig 1997).

It is important to stress the influence of human populations in order to fully understand how to implement conservation objectives. With respect to population pressures in Ecuador, if we look at both rural and urban populations among provinces in the sierra region, we see the highest population for both rural and urban categories in the Pichincha province (Figure 1.2). This, of course, is not surprising considering the Capital city Quito is located here. However, what is surprising is the co-existence of dense human populations and of a high degree of plant and animal diversity and endemism. One hypothesis suggests this co-existence may be attributed to the predictable eco-climatic condition that has protected relict species through periods of stress and that this may have also meant predictable conditions for agriculture (Fjeldsa et al. 1999).

The main land-use practices contributing to the loss of TMCFs are deforestation for wood and charcoal and agricultural uses, particularly grazing (Ataroff & Rada 2000, Hamilton et al. 1995). In Ecuador, heavy deforestation for pastureland is the main driving force (Sarmiento 2000b, Rhoades et al. 1998). This rapid expansion of pastureland is attributed directly to colonization in the region. The change from forest to pasture has been appropriately described as a “mediterranized” landscape (Ellenberg 1979). In addition to the lowered plant diversity and structure, this Mediterranean-like landscape is a concern because of the resulting impacts on ecosystem function.

The primary functions of an ecosystem are energy flow, nutrient cycling, and water flux (Jordan and Medina 1977). Key functions of the terrestrial – aquatic interface include nutrient capture and recapture and energy and nutrient retention. These functions can be disrupted through the alteration of plant structure and phenology (Silver et al. 1996). In broad terms, the removal of native vegetation to crop and/or exotic pasture grasses may impact: 1) water flux; 2) nutrient cycling; 3) meteorology; and 4) habitat connectivity (Table 1.2).

A comparison of water dynamics of deforested and forested lands in an Andean cloud forest in Venezuela indicates the potential for negative hydrologic effects once native vegetation is converted to agricultural uses (Table 1.3). Compared to forested conditions, areas of pasture land will have increases in transpiration rates, in surface runoff, and in retention of water in the upper soil horizon. The latter affect may cause ‘slumping’ of grasses that have clumped roots as is the case with the *Setaria* grass, a common exotic in Ecuador.

In addition to the production of charcoal and agricultural practices, the network of roads has also contributed to the loss of TMCFs. Roads increase the instability of the steep slopes in the Tropandean ecoregion as they tend to be poorly designed, have no infiltration, and have little forest cover (Sarmiento 2000b). These characteristics increase the potential for landslides, which are naturally stimulated by tremors. Poorly designed roads (no drainage ditches) in a region that receives high levels of precipitation, from 1500 to 3000 mm annually, is in effect, a landslide ready to happen (Young 1994). The additional impacts from roads on slope stability is a serious concern considering the ‘footslopes’ of the Andean *cordilleras* are classified as having a high potential for soil erosion (De Koning et al. 1999).

The relative impact of vegetation changes can be gauged by landscape topography. Considering the role trees play in maintaining soil structure, infiltrating precipitation, and regulating runoff, the consequence of the deforestation on slopes can contribute to a multitude of disturbance linkages. Figure 1.3 illustrates how a change on the landscape can lead to a linkage of disturbances (DOA 1998). For example, a change in land or corridor use, such as deforestation of a stream buffer can cause extreme and rapid runoff events. Increases in runoff will cause an increase in soil erosion and result in an increase in sediments to the stream. In turn, the change the quantity of runoff and sediments to the stream will increase the streams’ energy, which in effect causes stream bank erosion and sedimentation. The previous fluvial geomorphology changes will then lead to hydrological changes in the stream, for example, increase in stream turbidity or “flashy” stream flow. This change in stream hydrology can cause changes in stream function due to modification of habitat by sedimentation. Lastly, the changes in stream function can lead to changes in population dynamics of aquatic organisms and lower water table elevations.

Riparian conservation on the water basin scale

Given this review on the current status, population and land-use pressures of TMCFs it is evident why conservation biology has been termed the “crisis discipline” (Meffe & Carroll 1997). That is, we cannot afford to wait while we gain complete knowledge because doing so would compromise the previous efforts. The current status of TMCFs is clearly in a crisis situation. The concern is over the loss of high levels of endemism and biological diversity, of ecosystem goods and services, and of local cultures and livelihoods associated with the TMCFs in the Tropandean ecoregions.

It has been suggested that the world’s remaining closed forests remain intact because they lack commercially valuable species, they are located in remote regions or they are protected as a national park or sanctuary (Singh et al. 2001). However, the remnant TMCFs will remain intact only if local people can gain monetary, social or cultural leverage for maintaining them in this way (Sierra 1999). Conservation of TMCFs via the protection and management of riparian areas on the water basin scale is a pro-active approach for local communities because the inhabitants receive direct ‘rewards’ from the goods and services these riparian areas provide to its inhabitants (Figure 1.4). Water basin goods include fresh water for drinking, irrigation, and industry, fuel wood, game, livestock forage, recreation and medicines from plants. For example, Tropandean mountains could provide from 30-60% of downstream freshwater (Liniger & Weingartner 2000). While water basin services include erosion control, maintenance of water quality, stream flow stabilization, buffer system for drought conditions downstream, and habitat for floral and faunal species diversity (Ataroff & Rada 2000, Bruijnzeel & Hamilton 2000). Many of these services are associated with the forested headwaters that function to stabilize soils, retain and delay runoff, and purify the water (Schreier 2000).

There are advantages and disadvantages to using the watershed scale as a conservation and management approach (Table 1.4). It may appear at first glance that disadvantages outweigh advantages. However, watershed scale conservation and management is effective because it allows for 1) a cost-benefit analysis which can help prioritize funds, 2) information for local municipalities to help with decision making, and 3) a useful measure of sustainability (Estrada & Posner 2001).

Although there is no silver bullet to end the destruction of TMCFs, working on the water basin scale allows for pro-active practices that include: 1) socioeconomic incentives for local communities, 2) legal framework, 3) water-taxes, 4) protected areas, 5) sustainable livelihoods, 6) ecotourism, 7) networks, and 8) financial mechanisms (Fewerda et al. 2000). Haines and Peterson (1998) also stressed the importance of education to "help citizens understand their interaction with their life support systems" and identified six important areas: 1) human reproduction and population growth; 2) carrying capacity of humans; 3) connectedness (shared ecosystems); 4) time scales and lags (of anthropogenic degradation); 5) hierarchical controls (humans within the biome); and 6) local empowerment. The influence of education is demonstrated by a study done by Becker (1999) in which the author found that an Ecuadorian community began to conserve and manage their forests once they understood the social, economic, cultural and environmental tradeoffs involved with capturing fog for freshwater. Part of the educational component should be the teaching of best management practices (BMPs) such as vegetated buffer strips and fencing off cattle from streams.

The pilot area of the Choco-Andes Conservation Corridor

By embracing the natural and social capital in a water basin, land use managers can move away from the marginalization of mountain societies. Sarmiento (2000b) has found in the Ecuadorian Andes that the mountain societies have been left out of land management policies. He offers a model of mountain verticality to stress the need for integrating Andean belts and the people that live within these areas so as to avoid treating people as an after thought like ‘icing on the cake’. In the Pichinchina province in northwestern Ecuador, it is often the case that small landholders are pushed onto marginal and smaller lands to cultivate their crops or graze the cattle. In these areas, the outcome tends to be low productivity, persistent poverty, and high environmental degradation. In many cases, the ‘colonos’ (or colonizers) do not own the land but work under a landowner from Quito.

The Maquipucuna Foundation is working to make local people integral to their conservation plan through sustainable, economic alternatives to the destructive landuse practices common in the region and through environmental education. The Choco-Andes Conservation Corridor is a major regional initiative first proposed in 1995 by the

Maquipucuna Foundation to link over one million hectares of tropical forests from the Pacific lowlands to the Andean highlands in northwestern Ecuador.

The pilot area of the Choco-Andes conservation corridor is located between 1,000 - 3,000 m.a.s.l in the southern most part of the corridor. It lies within the Pichincha province which has almost six times the average urban and over two times the average rural population of the Sierra provinces due to the location of the capital city Quito within its borders. The pilot area encompasses the Maquipucuna Reserve (5,500 ha) and is surrounded by the Guayllabamba Watershed Protected Forest (14,000 ha).

Although the vision of the Maquipucuna Foundation is based on working with local people, through sustainable, economic alternatives to the destructive land use practices and through environmental education, it has been only recently that riparian conservation issues have been addressed on the water basin scale. These efforts began in 2001 in response to Ecuadorian government's plan for a second crude-oil pipeline within the country (see Chapter 2). The route of the pipeline traverses some of the last remnants of cloud forest within the pilot area of the Choco-Andes conservation corridor. The potential risk to the stream and river health within the pilot areas was evident and the collection of baseline data on river health became an immediate priority due to the lack of data on these rivers (see Chapter 3).

This baseline data allows the Maquipucuna foundation to continue to work with the local people to monitor the health of the streams and rivers on the water basin scale within the pilot area of the Choco-Andes Conservation Corridor and provides the third of five steps I recommend for conservation of riparian areas on the water basin scale (Figure 1.5). The remaining four steps include the assessment of local needs, education and training, analysis of results, and adaptive management. In theory, this conservation paradigm may help to integrate the montane belts ('layers') and the terrestrial, aquatic and cultural components in the pilot area of the Choco-Andes Conservation Corridor so that people are not left out of conservation efforts.

Conclusion

The 'real-time' status of TMCFs is bleak. The annual deforestation rate is 0.8% and population pressures continue to rise. The concern for the conservation and management of these areas lies within the limited TMCFs worldwide, the native biological and cultural diversity and the goods and services they provide. The conversion of TMCFs to pastureland has caused a disturbance regime of negative synergisms that has affected both the terrestrial and aquatic systems. The challenge is to reverse the direction of loss of TMCFs by creating a conservation framework focused on riparian areas on the water basin scale that can provide local people with alternatives to their current land use practices and with education. A critical point of potential contention is the "paradox of management" which suggests that one is more likely to cause or create an effect at a fine scale yet success is more likely to be achieved at a broad scale (Forman 1995). However, I believe the water basin scale meets the balance between being effective at the fine scale (best management practices by farmers) and successful at a broad scale (clean drinking water for the community).

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Table 1.1. Species diversity and endemism of major taxonomic groups for the Tropical Andes and Choco-Darien Western Ecuador Hotspots. Adapted from Mittermeier et al. 1998.

Species	**Tropical Andes**			**Choco-Darien Western Ecuador**		
	Diversity	**Endemism**	**% Endemic**	**Diversity**	**Endemism**	**% Endemic**
Vascular Plants	45,000	20,000	44	9,000	2,250	25
Amphibians	830	604	72.8	350	210	60
Reptiles	479	218	45.5	210	63	30
Birds	1,666	677	40.6	830	85	10.2
Mammals	414	68	16.4	235	60	25.5

Table 1.2. Key ecosystem functions and expected changes due to alterations in plant diversity and structure.

Ecosystem function	Expected changes
Water flux	▪ Loss of moisture inputs from horizontal precipitation. ▪ Changes in infiltration due to clearing will increase runoff
Nutrient cycling	▪ Warmer soil temperatures may effect the ability of microorganisms to decompose organic material.
Meteorology	▪ Direct effect of wind cause physical damage to plants while indirect effects may reduce humidity and therefore increase evapotranspiration rates. ▪ An increase in radiation reaching the soil surface will increase albedo and soil temperatures.
Habitat connectivity	▪ New established pasture grasses act as a barrier to native seed recolonization.

Table 1.3. A Comparison of water dynamics of a forest and Kikuyu pasture from an Andean Cloud Forest in Venezuela. Adapted from Ataroff & Rada 2000.

Forest	Pasture (Kikuyu grass)
▪ Increase in cloud-water capture (equivalent to one month of extra rainfall) ▪ Increase in interception of incoming water ▪ Higher throughflow on a long-term basis (main source of permanent stream flow)	▪ Increase transpiration rates (4 times greater in pasture than in forest) ▪ Increase in surface runoff ▪ Higher retention of water in the upper horizon due to the lower interception and low surface runoff values. ▪ Low moisture in soil in pastureland due to transpiration and soil evaporation

Table 1.4. Disadvantages and advantages of using the watershed scale for sustainable development initiatives. Adapted from Estrada and Posner 2001.

Disadvantages	Advantages
▪ Often, sedimentation problems cannot be addressed through direct incentives to farmers.	▪ Watersheds allow estimation of run-off and soil erosion on a landscape scale (2 criteria for measuring sustainability of mountain production systems).
▪ It is often hard to argue that national funds should pay for incentives to reforest tropical watersheds in private lands.	▪ Negative impacts downstream could be controlled through taxing the upstream activities to fund soil and water management control.
▪ Prioritizing watershed interventions may be of only academic interest.	▪ The cost-benefit ratio of watershed management can help to prioritize funds and attract funding for natural resources management.
▪ Estimated externalities often indicate that improved natural resource management has little perceived economic value.	▪ Small watersheds often approximate municipalities and so often are compatible with local decision-making units.
▪ Some proposed watershed initiative will exacerbate rural poverty	
▪ Resistance to sharing data remains an unfortunate reality in the Andes.	

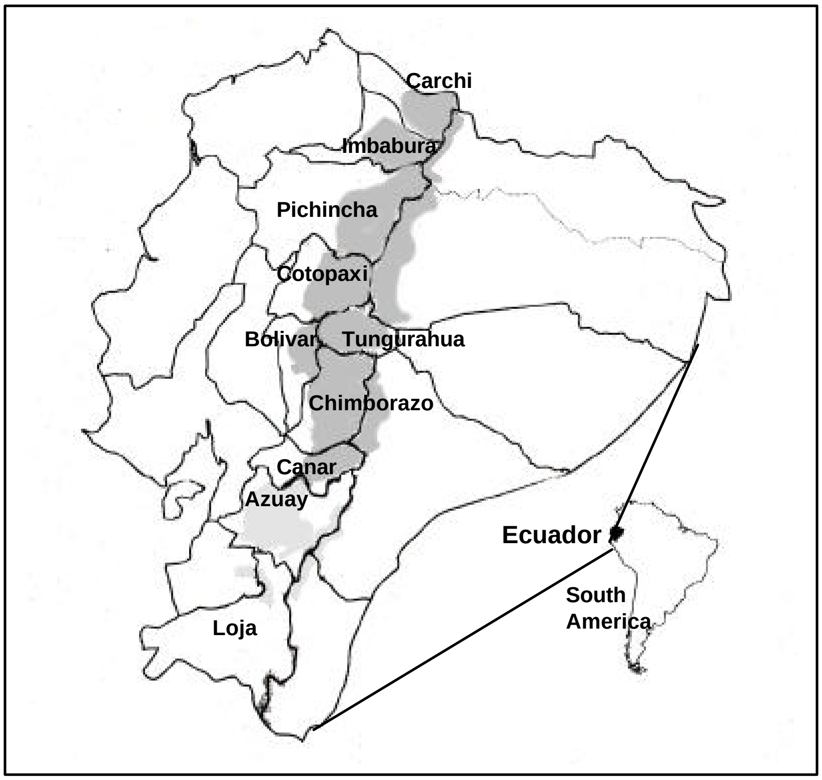

Figure 1.1. Provinces in Ecuador illustrating the montane regions over 3,000 m.a.s.l in gray. Adpated from Borchsenius 1997.

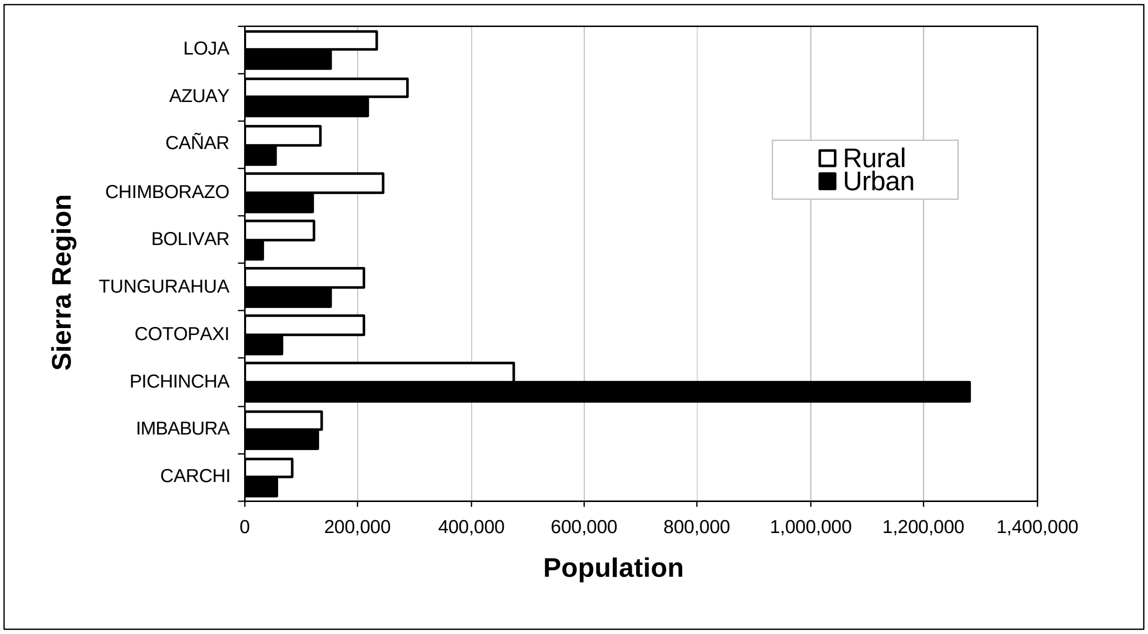

Figure 1.2. Rural and urban population levels for the Sierra Region by provinces. Adapted from Instituto Nacional de Estadistica y Censos 1990.

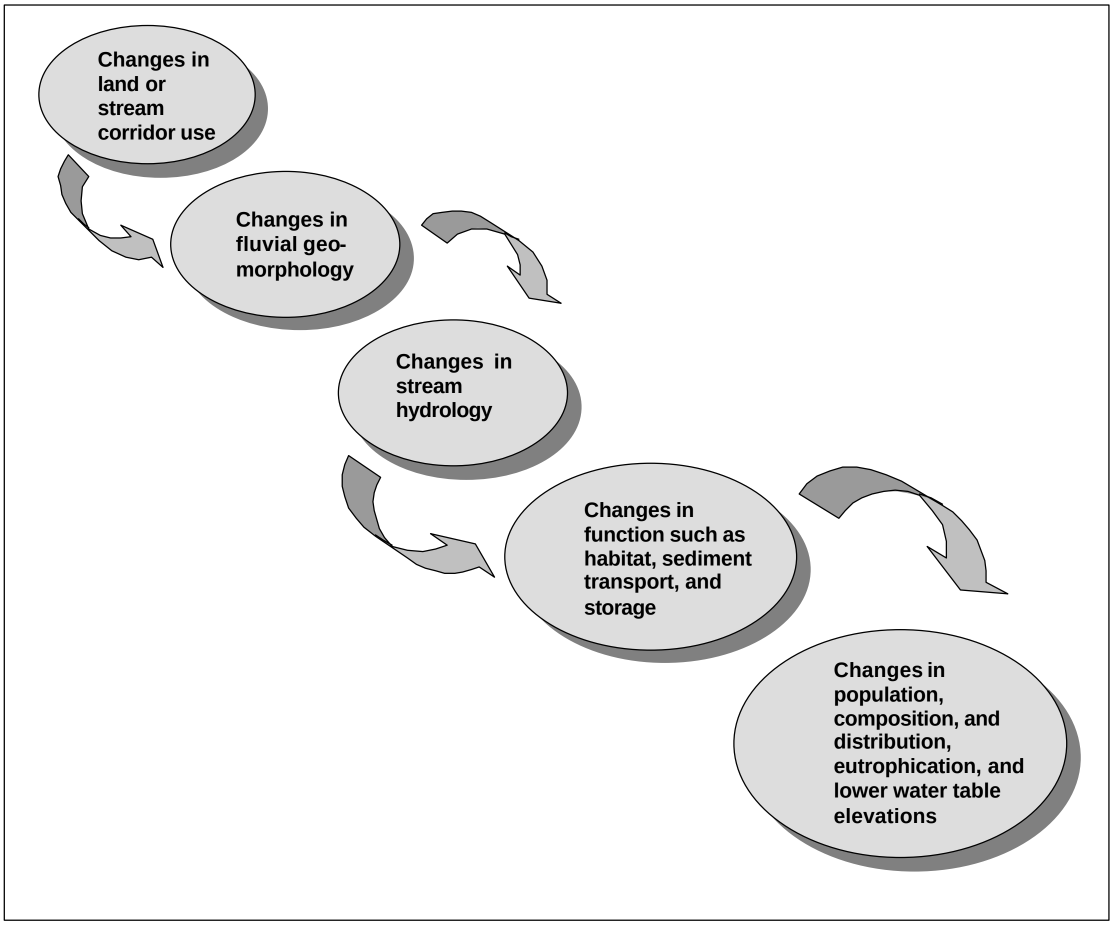

Figure 1.3. Stream disturbance linkages. Adapted after DOA 1995.

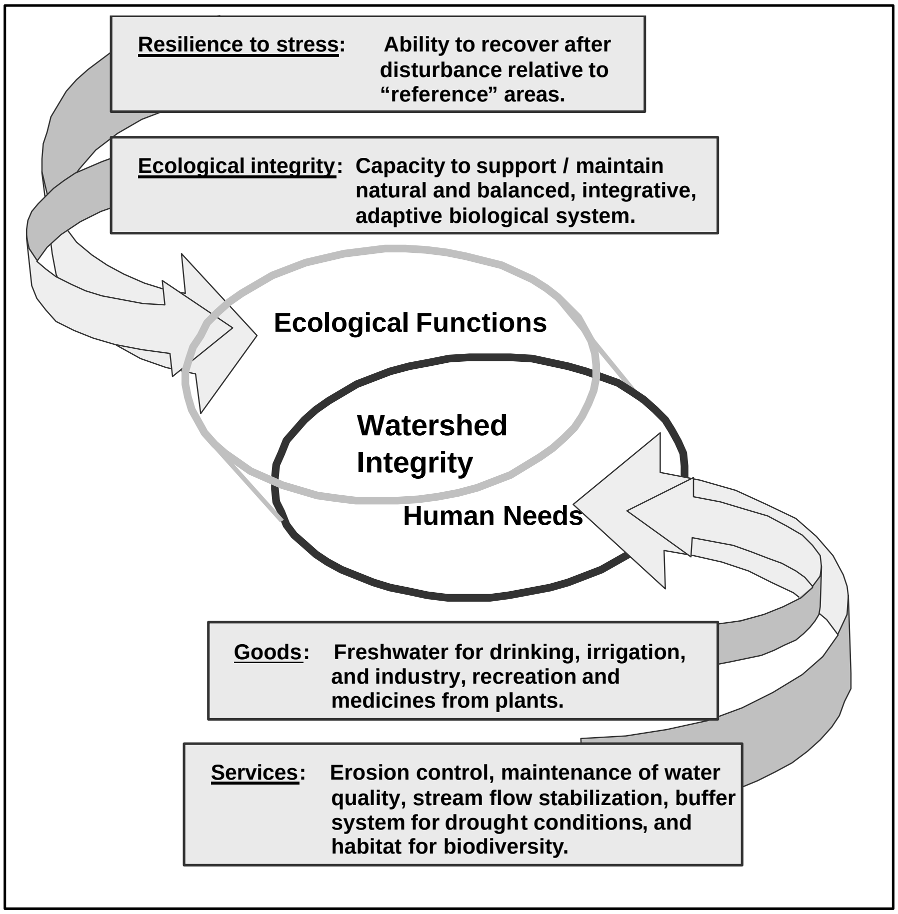

Figure 1.4. Watershed conservation provides both human needs and ecological functions. Adapted from Meyer 1997.

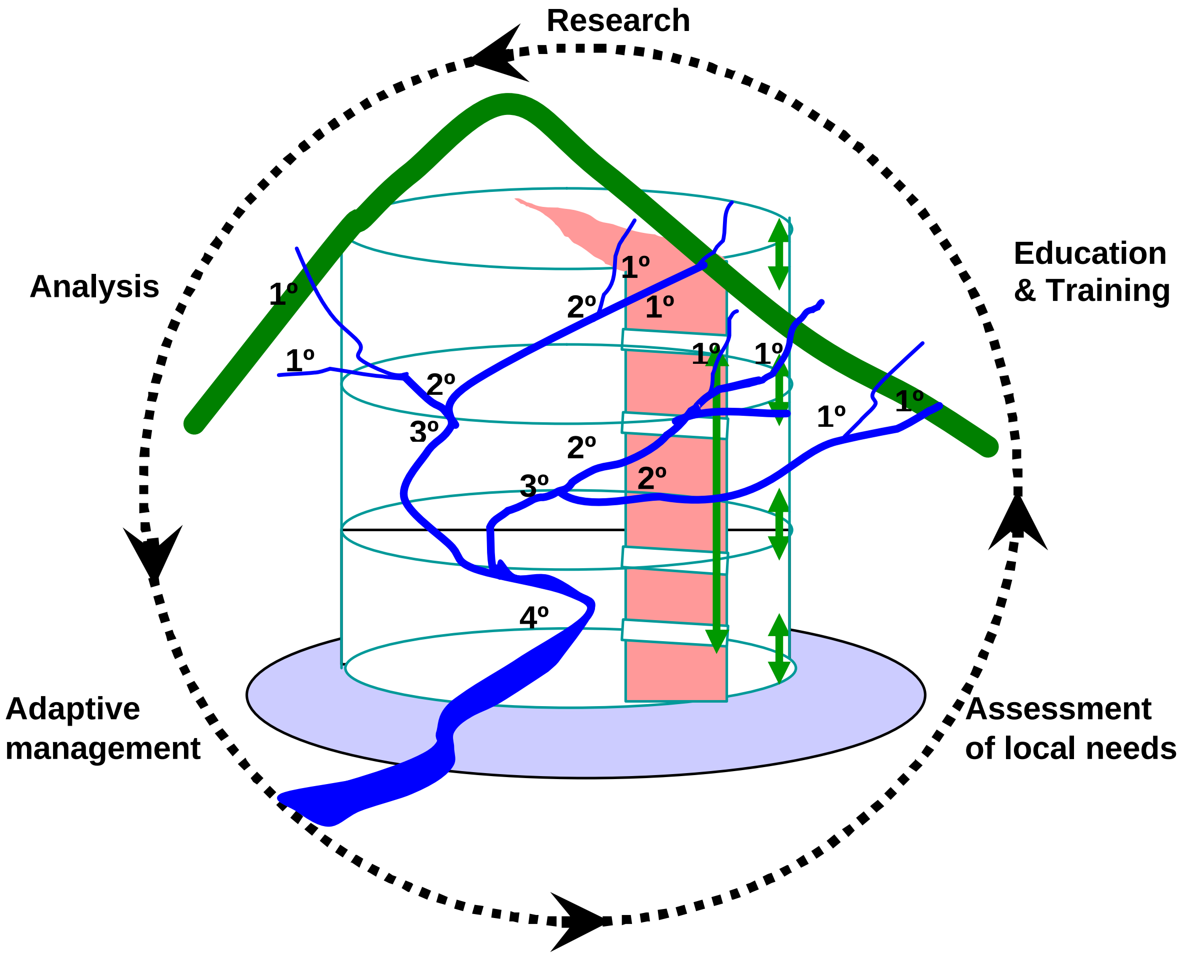

Figure 1.5. A model of how 5 conservation processes which focus on riparian areas within a water basin can help to integrate the montane belts ('layers') and the terrestrial, aquatic and cultural components in Tropical Montane Cloud Forests so that people are not left out of conservation efforts (like 'icing on the cake'). Stream order nomenclature illustrates how streams of equal order move to the next order when they merge (Strahler 1964). Adapted after the schematic diagram of the culinary methaphor of verticality by Sarmiento, F.O. 2000b.

CHAPTER 2

A BACKGROUND TO THE DEVELOPMENT OF THE OCP CRUDE – OIL PIPELINE, ECUADOR

Introduction

It is important to place the development of the OCP crude – oil pipeline in an historical context to understand the roles of the interested parties including governmental and non – governmental agencies, private companies, and local people and researchers. The concession of the second crude – oil pipeline for Ecuador presented a huge conservation challenge to the local Ecuadorian NGOs, particularly the Maquipucuna Foundation, because the proposed route would cut through the last remnant patches of protected forests in the pilot area of the Choco – Andes Conservation Corridor. The implications of a crude – oil pipeline in these patches were daunting as the risks to ecological integrity - - particularly for streams and rivers - - were quickly understood to be potentially high due to environmental and human causes. This paper presents a general background of the crude – oil pipeline including a description of the risk analysis and a summary of analysis on the route selection to set the stage for why a baseline study of rivers within the pilot area of the Choco – Andes Conservation Corridor was an immediate priority for the Maquipucuna Foundation (see Chapter 3).

Background

On February 15, 2001, the Ecuadorian government officially awarded a 20 year build, own, operate, transfer (BOOT) concession to the Crude Oil Pipeline consortium (Oleoducto de Crudos Pesados, S.A., [OCP]) to build a pipeline from Nueva Loja in the Amazon rainforest to Esmeraldas on the Pacific coast. The 500 km OCP pipeline follows the same route as the 30-year-old government built pipeline, Trans Ecuadorian Pipeline System (SOTE), except for a 180 km deviation. The OCP pipeline diverges ~25 km southeast of Quito and cuts a northwestern path through some of the last remnants of intact cloud forest in the Pichincha province, northwestern Ecuador. Here, the pipeline passes through the pilot area of the Choco-Andes Conservation Corridor and the Mindo Important Bird Area (IBA) (Figure 2.1).

The Choco-Andes Conservation Corridor is an initiative being led by an Ecuadorian NGO, the Maquipcuna Foundation, to conserve land and implement sustainable projects from the foothills of the Andes mountain range to the mangrove ecosystems on the Pacific coast. The pilot area for the Choco-Andes Conservation Corridor includes the Upper Guayllabamba river watershed (UGRW) and the Mindo - Nambillo (MN) protected cloud forest. The Mindo IBA encompasses 170,000 hectares of cloud forest near the town of Mindo and is the first for South America. It is home to 450 bird species of which 30 are endemic and 12 have a threatened or near-threatened status (Unwin 2001). Much attention has focused on the Black-breasted Puffleg hummingbird, (*Eriocnamis nigrivestis*) because it is globally rare and Critically Endangered (Szabo 2002). The region has steep elevational gradients ranging from approximately 1200 – 3400 m.a.s.l. Similar to the Tropical Andes Hot Spot - -

considered one of the top five areas critical for conservation in the world - - it has high plant and bird diversity and endemism (Mittermeier et al. 1998).

The OCP pipeline will facilitate the transport of an estimated 450,000 barrels per day (bpd) of heavy crude oil. Although the pipeline has been promoted as an economic boost for the country, little financial gain will benefit Ecuadorians. OCP ltd. will receive 80% of the earnings from the sale of the petroleum while Ecuador will receive 20%. This is 12.5% less than a contract with Texaco – Gulf in 1992. Additionally, none of the 80% earning will go to Ecuadorian companies but rather to seven international companies that form the OCP ltd. consortium. These companies and their percent of the consortium are as follows: Respol – YPF of Spain and Argentina (25.69%); Perez Companc of Argentina [purchased by Petrobas of Brazil] (15%); Occidental Petroleum of the United States (12.26%); Agip Oil of Italy (7.51%); Techint (an engineering and pipeline construction company located in 10 countries) (4.12%); and Kerr McGee of the United States [purchased by Porenco of France] (4.02%). The project was originally projected to have a lifespan of 20 years however recent estimates of the petroleum reserves suggest a more limited lifespan. The existing reserves hold an estimated 1,200 million barrels, which is estimated to last for approximately 5 – 6 years (Koczy 2002).

The impetus behind the development of second crude – oil pipeline is Ecuador's 16 billion dollar foreign debt which is a legacy of aggressive lending practices by the World Bank during the 1980's and 1990's. Of the 20% revenue Ecuador will receive from the operation of the OCP pipeline, 70% of this revenue will go toward paying off the foreign debt. The remaining 30% will be applied to domestic spending for education and social security services.

Risk assessment

The sustainability of the pipeline both economically and environmentally has been questioned by national and international organizations. The risk assessment by ENTRIX, Inc., a professional environmental consulting firm, reports a varying degree of environmental risks. The 30 km (from east to west, km 250 – km 280) length of OCP pipeline, which crosses through the IBA and MN protected cloud forest region, is considered to be high risk (Figure 2.1). It is of critical concern because it ranked 3E on the risk analysis matrix for three (geotectonic, seismology and for volcanism) of the five categories (floods and tsunamis), indicating catastrophes such as landslides, earthquakes and volcanic eruptions are probable (can occur once every 10 – 100 years) and could have serious consequences (Table 2.1). Geotectonic risk is due to the steepness of slope (> 65%) a characteristic that increases the probability of landslides, particularly in light of the rainy season when annual precipitation can be more than 2000 mm per year and the soil is a highly erodable of volcanic origin. Additionally, the steep slopes will be particularly vulnerable in an el Nino year. The seismological risk is based on the 60% probability of an earthquake, similar to that which occurred in the zone in 1906 (Ms 8.1), occurring in the coming years (ENTRIX 2001). The risk of volcanic activity is high due to the proximity of both the Pululahua and Guagua Pichincha volcanoes that have a potential to impact the pipeline from km 233 – km 255.

The facilities that support the pipeline (camps, platforms, helipads, etc.) are outside of the protected area. Therefore, the greatest risks and impacts within the conservation area are related to the construction and operation of the OCP in the pressure reduction station in the Chiquilpe zone. Major impacts to river quality include:

1) magnitude and frequency of direct habitat destruction due to construction (e.g. bridges, hill fortification, etc.); 2) degree of sedimentation (landslides and soil erosion); 3) degree of increase of total suspended solids (hydrostatic tests); 4) size and range of oil spills due to both environmental (seismic activity, landslides, etc.) and human causes (pipeline failures, terrorism, etc.).

The combined factors of high average annual precipitation (rainy season from November to May), unstable volcanic soils and steep slopes are a cause for concern regarding the potential size of disturbances within the MN protected cloud forest. Although scientist predicted 2002 to be an el Nino year, they did not expect it to have the degree of severity as the 1997 – 1998 El Nino. Nonetheless, the bare volcanic and highly erodable soil left after the pipeline has been buried 3m underground poses a high level of risk of river sedimentation due to soil erosion. Within the TMN protected cloud forest, the widths of vegetation clearings along the pipeline are approximately 7m (Figure 2.2), while outside this zone are approximately 20m (Figure 2.3). In February of 2002, OCP’s environmental licenses was suspended for excessive erosion at Guarumos, the working area in the MN protected forest. Estimated rates of soil erosion once vegetation has been removed are very high and range from 75 – 470 tons/hectare/year (ENTRIX 2001). The extreme change in soil erosion rates is obvious when compared to the range estimated under natural conditions, from 0.5 – 3.2 tons/hectare/year. Although approximately 75% of the pipeline was completed as of July 2002, revegetation by the Ecuadorian NGO Jatun Satcha had not yet begun. The increase of sediments in streams impacts habitat, stability of stream banks (due to steep average channel gradients characteristic of mountain streams and rivers), and can cause an increase in stream bank erosion due to the potentially high yields of sediments being transported (Wohl 2000).

The history of oil spills from the SOTE pipeline raises major concerns for the future operation of the OCP pipeline. The SOTE spilled more than 16.8 million gallons of oil over its 30 year operation (Kimberling 1991). During the week of July 16 2001, 1,000,000 liters of crude oil spilled from the SOTE into the Andean forest just east of Quito. In just three years, a total of 23,100,000 liters of crude oil have spilled from 14 SOTE pipeline failures since 1998 (Economist 2001). A small oil spill is considered by ENTRIX (2001) to be less than 4,000 liters and a large spill anything over this (Table 2.1). However, the range of the maximum volumes of potential oil spills in the area of concern is from 76,900 – 424,000 liters, magnitudes higher than what is considered to be a small spill (calculated by using the lengths of the pipeline from the point of spill to the nearest control station and the area of the pipeline [r= 40.6 cm]).   The heated crude oil (80°C) flows through the pipeline at a velocity of 250 m^{-s} (Koczy 2002). Also of concern is the high pressure within the pipeline, especially in the crossing over the Andes. The pressure is 37 times that of a pressure reduction station. In case of a rupture, an explosion and fires will follow and a minimum of 200 – 300m of pipeline would be destroyed.

Although there is a paucity of data on effects of oil spills in Neotropical streams, evidence from studies done on macroinvertebrates in North America suggests that there is an immediate lowering of diversity and richness and that recovery is slow (Lytle & Peckarsky 2001). In addition, changes in the richness and density of macroinvertebrates have been reported after one year from the time of oil spill when oil sorption and coating of substrates act as barriers to successful colonization (Poulton et al. 1998). Although advances have been made in cleaning up crude – oil spills, Vandermeulen and Ross (1995) found that cleanup activities can pose additional impacts to freshwater environments and these activities are expensive.

ENTRIX, ltd. is the same firm that wrote the Environmental Impact Assessment (EIA) for Enron's controversial Bolivia- Brazil pipeline. Similar to the scenario in Ecuador, the Bolivia – Brazil pipeline was built in the Chiquitano dry forest in Bolivia rather than along an existing road around the forest (Worldtwitch 2001). Generally, the EIA for the Ecuadorian OCP pipeline has been criticized by the environmental NGO's for failure to identify the conservation importance of the ecoregion and failure to address secondary impacts that would result from the construction (LeastImpact 2001).

Route selection

A total of five NGO's reviewed the EIA during the 28 day review period and concluded that there was not sufficient information in the EIA to make a decision regarding the best route and that the southern route, although considered technically and economically viable by the government, was not considered by OCP (Fundacion Natura et al. 2001). However OCP, Ltd. argued that the southern route would cross between 20 – 30 kilometers of primary forest while the northern route would cross ~13.5 km with the most sensitive area measuring 3.5 km (PlanetArk 2001). Yet the southern route would essentially follow the same transect as the SOTE. In addition, the Ecuadorian Geophysical Institute stated that the volcanic and seismic activity is similar for both routes (Worldtwitch 2001).

The same group NGOs stated that the presence of the SOTE proved to have evidence of high alteration, fragmentation and loss of natural habitats therefore suggesting that these types of effects could be expected in the northern route and a least impact route would take advantage of the SOTE as it has already undergone such impacts. Although the Northern route is 40 km shorter then the southern route, the NGO group found that the analysis of the costs for each route were not adequately analyzed particularly considering the potential costs to future conservation and tourism (in the northern route). They stated the need for an equal review of the routes in order to select a route with least impact (environmental and social risks and lowest costs for mitigation) throughout the projects life.

The group computed the total land lost by the right of ways (ROW). In the 9m wide ROW for the protected area the land loss is equivalent to a total of 17.2 hectares while the total impact on mountainous forests is 960.9 hectares. Their concluding remarks state that EIA does not distinguish between restoration and revegetation nor is there a plan for revegetation which should include species and age class of seedlings.

Due to the conflict surrounding the compliance issues, Dr. Robert Goodland, a tropical ecologist, was selected by a coalition of US and Italian NGOs and Trade Unions to assess the OCP pipeline project (Goodland 2002). Although the World Bank Group (WBG) is not involved in financing the project, OCP ltd. must be in compliance with the WBG policies because it is stipulated in the contract by its funders, a consortium of international banks led by Westdeutsche Landesbank of Dusseldorf (WestLB). Goodland found OCP, ltd. to be in non-compliance with the WBG policy on environmental assessment for the following 6 areas: (1) the sectoral, regional, and cumulative environmental assessment was not conducted; (2) failed to achieve independence of the environmental impact assessment because the president of Entrix (the company hired to conduct the EIA) is also the environmental coordinator of OCP, ltd.; (3) failed to have an independent panel of environmental and social experts; (4) unsatisfactory systematic analysis of alternatives to ensure the least impact route is chosen; (5) Terms of Reference (TOR) were unavailable to the public before the EIA process began; and (6) did not identify, analyze or quantify the impacts on natural habitat.

In addition, Goodland findings demonstrate that OCP ltd. was not in compliance with the WBG's policy on natural habitats. Of the seven non-compliances, the most critical to the Mindo region is the fact that the Global Environmental Facility (A World Bank group) has financed the Choco – Andes Conservation Corridor project which is being bisected by the pipeline.

The Ecuador EcoFund

The high level of international and national attention given to the development of the OCP crude – oil pipeline and particularly to the route selection through the Mindo Imporant Bird Area may have stimulated the establishment of the Ecuador EcoFund. The EcoFund was established by the OCP, Ltd. consortium in January of 2003 to be administered by a group of Non – Governmental, Ecuadorian Organizations for the development of environmental programs, training, scientific research and other conservation projects in Ecuador. The 20 year fund is designed to invest more than US $20 million into environmental related programs in Ecuador.

In summary

In light of the political processes behind the development of the OCP crude – oil pipeline presented above, it is evident that pressure applied by the international and national agencies on the Ecuadorian government to avoid impacts to the last remnants of cloud forests in Ecuador had little influence on their goal for economic gain. Given this now historical context, the role of science is clear. Basic data on stream health in this case, provides conservationists with a baseline to which restoration efforts can target in case of an oil spill or other disturbance from the operation of the crude – oil pipeline.

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Table 2.1. This matrix lists the probability and level of consequence of physical risks to the OCP pipeline for the Mindo Nambillo protected forest (ENTRIX 2001).

Probability		**A**	**B**	**C**	**D**	**E**
5	Very probable - more than once per year					
4	Once every 10 years					
3	Probable - Once every 10 - 100 years					**3E** - MN protected forest
2	Once every 100 - 1000 years					
1	Improbable - less than once every 1000 years					
Consequences		**Not important**	**Limited**	**Serious**	**Very serious**	**Catastrophic**

Table 2.2. The maximum potential volume of an oil spill within the Mindo Nambillo protected forest is listed in liters for each of the sensitive areas.

m^3	**Liters**	**Site**
77	76,900	Below Cerro Castillo & Loma La Bola
184	183,900	Below Cerro Campanarío & Cerro La Bola
235	235,000	Below Loma La Bola & Cerro Campanarío
424	424,000	Below Alambi river & Cerro Castillo
Type	**Spill size**	**Volume (liters)**
Type I	Small spill	< 4,000
Type II	Large spill	> 4,000

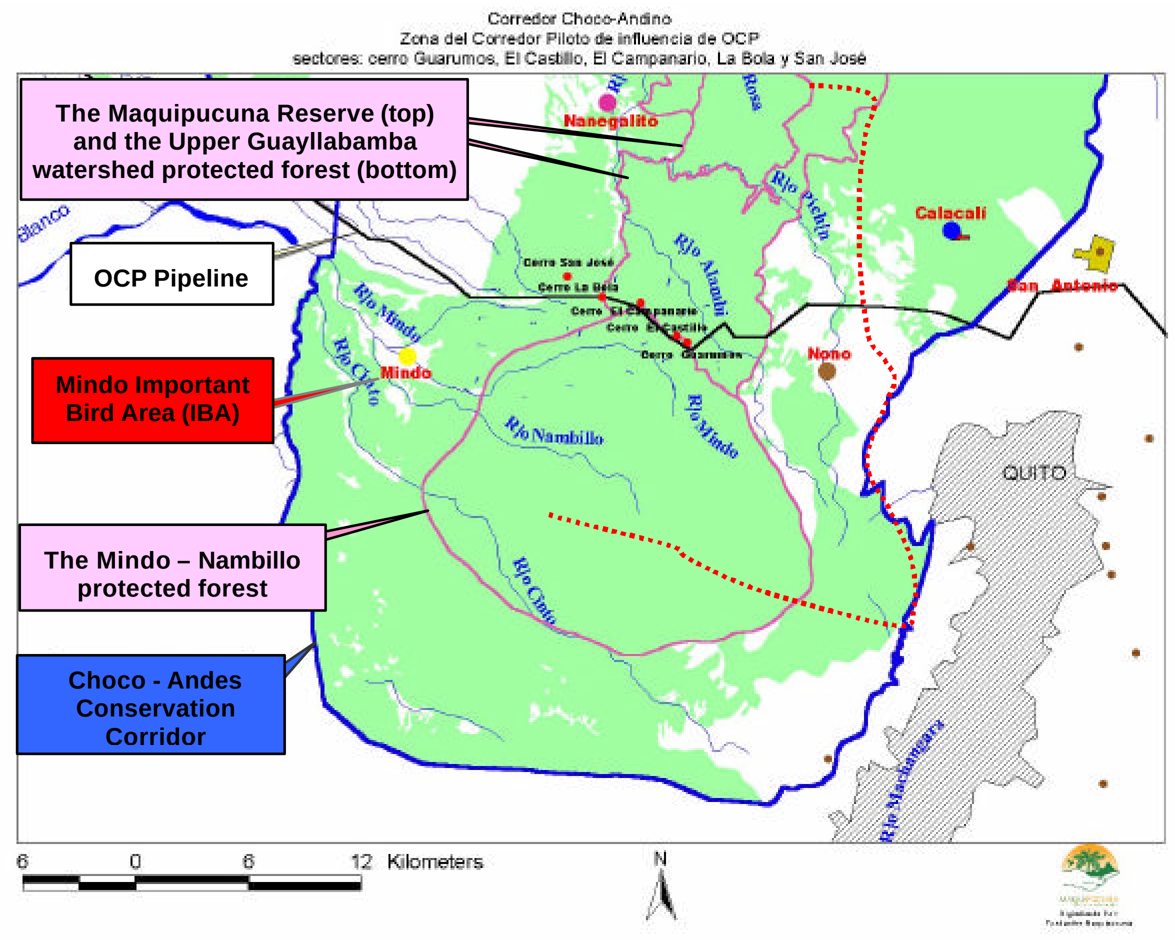

Figure 2.1. Map of the study area illustrating the OCP pipeline route which follows the ridgeline (**—**) and the conservation areas: the Maquipucuna reserve (top, —) and the Upper Guayllabamba river watershed protected forest (bottom, —); the Mindo Important Bird Area (IBA) (**…**); the Mindo – Nambillo protected forest (—); and the Choco-Andes conservation corridor (**—**).

Figure 2.2. Photograph of the 7m wide clearing for the subterranean crude oil pipeline within the Tandayapa-Mindo-Nambillo protected forest (west of the Alambi river, site 1).

Figure 2.3. Photograph of the 20m wide stretch of devegetated land under which the OCP pipeline was buried at 3m in depth (east of the Pichan river, site 2).

CHAPTER 3

A STUDY OF FOUR RIVERS IN THE PILOT AREA OF THE CHOCO – ANDES CONSERVATION CORRIDOR, NORTHWESTERN ECUADOR.

Introduction

Much of the research in tropical aquatic ecology has been conducted in the lowland rainforest ecoregion and the majority has been conducted on fishes. Freshwater fishes provide a clear example of the latitudinal trend in diversity because the highest diversity in the world, more than 5,000 species, exists in South and Central America compared to 1,050 species in North America and 360 in Europe (Lundberg et al. 2000). The Amazon basin alone provides habitat for more than 3,000 of these species (Lowe and McConnell 1986). The high diversity in fishes has been argued to be a result of the high degree of heterogeneous food sources as a result of both regional (long historical evolutionary change) and local (high degree of nutrients from flooding and allochthonous material) factors (Covich 1988).

However, little is known about the biodiversity of tropical stream macroinvertebrates and of the studies done, the majority have been located in the lowland ecoregion. There is a paucity of data on stream macroinvertebrates from mid-altitude, cloud forest ecoregions; however a few studies have recently been conducted in Ecuador (Jacobsen 2003, Jacobsen 2000, Thom 2000, Jacobsen and Encalada 1998, Jacobsen et al. 1997).

Although the latitudinal trend in diversity has not been clearly established for stream macroinvertebrates (Covich 1988), we do know they generally show a trend of low family diversity and high species diversity (Jacobsen et al. 1997). This is in line with the theory in tropical ecology in which generally, there are more species within tropical guilds. Stated in another way, the species are "tightly packed" (Terborgh 1992).

The lack of a transparent latitudinal trend in diversity for macroinvertebrates may be due to many contributing factors that include the lack of data, the lack of taxonomic resolution due to the difficulty of identification, and the variability in sampling methodologies such as issues regarding scale (stream order), design (e.g. rocks vs. multiple micro-habitat types) and sample size (e.g. sub-sample vs. full sample) (Jacobsen et al. 1997, Covich 1988).

In addition to understanding the latitudinal trend, there are numerous justifications as to why research in the tropics, particularly in the midaltitude range, should focus on stream macroinvertebrates. The importance of macroinvertebrates as indicators of stream health has been established by numerous studies particularly form Europe and the United States (Barbour et al. 1992, Hilsenhoff 1988, and Lenat 1993).

The importance of streams as providers of human services (potable water, trout farms, ecotourism, etc.) in mid-altitude regions is increasing as human disturbances associated with agriculture, deforestation and infrastructure development increase. These anthropogenic disturbances coupled with natural disturbances (landslides, droughts, spates, etc.) will alter and potentially degrade the integrity of stream attributes and processes (food sources, water quality, habitat structure, flow, and biotic interactions) (Karr 1991). Furthermore, stream assessments in tropical, mid-altitude ecoregions are critical while reference conditions still exist so that scientists and land managers have a baseline to which they can restore streams and rivers to.

The primary objective of this study was to provide baseline data on stream health prior to the operation of the OCP crude – oil pipeline. Lytle and Peckarsky (2001) noted that it is rare to have pre – spill data on stream biota and therefore rigorous studies on the effects of oil spills are often difficult. These authors did not have baseline data for their 2 year study of macroinvertebrates in a small trout stream in central NY after a 26, 500 liter diesel fuel spill. Instead they used sites upstream as reference conditions to compare to the impacted sites below. From the first sampling date in the fall of1997 they found an approximately 90% reduction in invertebrate density and almost a 50% reduction in richness. After one year, their data show almost a complete recovery for both.

In addition to collecting baseline data, objectives of the study include: (1) increase the understanding of local and regional influences on river health; (2) provide assessment protocols for future assessments and monitoring in the pilot area of the Choco – Andes Conservation Corridor; and (3) provide recommendations on future research and monitoring to the Maquipucuna foundation.

Methods

Regional description

This study was conducted in the pilot region of the Choco - Andes Conservation Corridor. The Choco – Andes Conservation Corridor is a strategic conservation ecology project being led by the Maquipucuna foundation with the efforts from governmental and non-governmental organizations to connect patchy habitats along a

185 kilometer long corridor (~1,000,000 ha) from the central highlands of Ecuador to the shores of the Pacific Ocean. The pilot region is 75,000 hectares of lower and upper montane cloud forest at altitudes ranging between 1,200 and 3,500 m.a.s.l. with an annual average rainfall between 2.0 – 2.5 m falling generally during the months from December through April.

The corridor's pilot scale was selected as a testing ground because of its close proximity to the Maquipucuna Reserve and the capital city Quito and due to the large extent already under protected status as reserves or parks (almost half the pilot area). In addition to the Maquipucuna reserve, these areas include the Guayllabamba and Mindo Watershed Protective Forests, the Pululahua and Cedros Reserves, and the Mindo Important Bird Area (IBA) (Figure 3.1). The Mindo IBA, the first for South America, includes 170,000 hectares of cloud forest in which an estimated 450 bird species (30 of these are endemics) have been recorded for the area (Unwin 2001). The region is known for its high plant and bird diversity and endemism and is comparatively similar to levels found in the Tropical Andes Hot Spot. The Tropical Andes Hot Spot is considered one of the top five areas critical for conservation in the world (Mittermeier et al. 1998) and ranks first of the 25 global hotspots for both species diversity and endemism of vascular plants, amphibians, and birds. Gentry (1992) found that high levels of plant endemism exist at small scales (5 – 10 km^2) and in sensitive areas, such as along ridges of cloud forests, precisely the type of habitat through which the Ecuadorian government granted a 7 – 20 m right-of-way for the development and maintenance of the OCP crude-oil pipeline. The OCP pipeline will facilitate the transport of an estimated 450,000 barrels of heavy crude oil per day from the Amazon to the Pacific coast.

Study design

I conducted a bioassessment of 4 rivers using a reference condition approach within the pilot area of the Choco-Andes conservation corridor in northwestern Ecuador during the dry season of 2002 (Figure 3.2). Site locations on the rivers were selected with the objective of understanding what the current physico-chemical and biological conditions were prior to the operation of a crude-oil pipeline. The crude-oil pipeline is designed to have a sub-riparian crossing (3 m in depth) for both the Alambi and Pichan rivers while the Tandayapa and Mindo rivers are potentially affected by the confluences La Bola and El Chaco (Figure 3.2). Physico-chemical and biological data were collected during a 4 day period at each site: from July 04 – 08 at the Pichan river; from June 30 – July 04 at the Alambi; from July 15 – 19 at the Tandayapa; and from July 21 – 25 at the Mindo.

Site descriptions

The Pichan River. The Pichan (Lat. S 0° 01' 36"; Long. W 78° 39' 06") is a third order river with an average width of 3.6 m. The dominant substrate type is sand, gravel and cobble. Land use surrounding the Pichan includes pasture and agriculture. A narrow buffer (~5m) of scrub vegetation separates the pasture/agriculture on the west and the dirt road on the east side. Sampling was conducted below the future sub - riparian pipeline crossing at approximately 2400 m.a.s.l at the 249 km mark along the pipeline. The Pichan flows north through the town of Nono and is the recipient of the towns' untreated sewer wastes. The estimated watershed area for the Pichan is 300 km^2.

The Alambi River. The Alambi (Lat. S 0° 02' 30"; Long. W 78° 34' 28") is a third order river with an average width of 5.1 m. The substrate is predominantly cobble -

boulder (Table 3.1). Although the Alambi is located within the Mindo IBA and the MN protected forest, the predominant land use is pasture for cattle. The predominant use of the river is for trout farms (which exist up and downstream of the study site). Sampling was conducted on private land below the future sub - riparian pipeline crossing at approximately 2000 m.a.s.l. at the 267 km mark along the pipeline. The estimated watershed area for the Alambi potentially affected by the OCP pipeline is 110 km^2.

The Tandayapa River. The Tandayapa (Lat. S 0° 00’ 19”; Long. W 78° 40’ 32”) is a third order river that flows in a northwesterly direction. The study site was located downstream of the La Bola stream, a first order stream that is potentially impacted by the crude-oil pipeline, at 1726 m.a.s.l. The sampling site is approximately 18 km south of the town of Nanegalito and 6 km from the town of Tandayapa. This river is considered the reference condition for this study. The average stream width is 5.8 m and the substrate is predominantly boulder-bedrock. Primary forest is located above the study site within the Bellavista Reserve. Downstream however, the land use is mixed. Immediately downstream (~ 25m) there is a large trout farm and an invasive grass (*Setaria*) for pasture along the riparian border.

The Mindo River. The Mindo (Lat. S 0° 01’ 36”; Long. W 78° 39’ 06”) is a fourth order river that flows in a northwesterly direction. The average stream width is 20 m and the dominant substrate is cobble – boulder substrate. The study site is below the confluence with the El Chaco stream, a first order stream that is potentially impacted by the crude-oil pipeline, at 1618 m.a.s.l. This study site has had little anthropogenic impact since the partial deforestation activities more than 50 years ago. Land use above the study site is protected secondary forest and below is secondary forest and pasture for cattle. Below the sampling site, and closer to the town of Mindo, the river is used predominantly for recreation (river rafting and swimming) by tourists and local people.

Sampling procedures *(Appendix B)*

Physico-chemical. The physical parameters collected include temperature (max, min ºC), velocity (m^{-S}), and pebble count. I used the float method to estimate current velocity over a 10 m reach (Gore 1996). I estimated the distribution of particle sizes (mm) to describe the substrate using the pebble count method as described by Kondolf (1992). I recorded pH, conductivity, dissolved oxygen and temperature data *in situ* at 15 minute intervals over a 4 day period using a YSI sonde and data logger.

Biological. Macroinvertebrates were sampled 1-10 meters downstream of the potential area of impact from the crude-oil pipeline development. For the Pichan and Alambi rivers, the impact area is the future sub-riparian pipeline crossing 3m below the river bed and for the Tandayapa and Mindo rivers the potential impact area is downstream of the first order streams which are in close proximity to the pipeline.

I set five transects at each site at 20 m intervals and along each transect a total of 3 riffle and 2 bank samples were taken for a total of 25 samples per site. Due to time constraints, I randomly selected (using a random numbers table) 2 bank and 3 riffle samples from these 25 samples. I collected samples using a D-ring kick net (500 µm mesh) in a 0.09 m^2 area for 30 seconds. I removed large rocks prior to the kick net collection and hand washed each one to remove all macroinvertebrates. The samples were preserved in 70% ethanol. In the laboratory, each sample was washed through a 500 µm sieve to separate out small particles. All invertebrates were hand-picked from debris using a dissecting microscope at 15x magnification, measured to the nearest size class (mm) and then preserved in 70% ethanol. All non-insect and insect aquatic fauna were identified to genera when possible and to functional feeding groups (FFGs) based on Merritt and Cummins (1996) and Roldán (1988). I calculated biomass by the length-mass model outlined by Benke et al. (1999). Both the Hilsenhoff Family Biotic Index (FBI) (Hilsenhoff 1988) and the North Carolina Biotic Index (NCBI) (Lenat 1993) were used to assign tolerance values (where high values indicate poor water quality). Water quality ratings were based on the mountain ecoregion (Lenat 1993).

I measured waterborne coliforms and fecal coliforms with Coliscan® Easygel®. I stored the water samples in a cooler until they could be added to the EASYGEL solution. A 2.5 mL amount of the stream water sample was transferred into the Easygel bottles. This inoculum mixture was poured into the Coliscan petri dishes. The petri dishes were placed in an incubator (~35ºC) for 24 - 48 hours. At the end of the incubating period, I counted the total number of the purple colonies to measure *E. Coli* (fecal coliform) and the total number of pink and purple colonies for total coliforms. All results were reported as colonies per mL of water.

Results

Physico-chemical

Considering the main distinguishing attribute of the tropics as compared to temperate climates is the reduced annual variation in air temperature and light (Hynes 1970, Terborgh 1992, Whitmore 1998) and the increase diurnal flux in air temperature (23 °C – 27 °C), it is not surprising that the stream temperature data from this study reflect a similar trend in that we see the largest °C variation for the diel temperature (average flux is 4.4 °C) then between the 4 sampling days (average variation is 0.31 °C). Stream temperatures at the 4 rivers were negatively correlated with altitude (Figure 3.3). The average water temperature at the 4 sites ranged from 13.6 - 15.2 ºC with the highest maximum temperature detected at the Tandayapa River (18.5ºC) and the lowest minimum temperature at the Alambi River (11.3 ºC) (Table 3.1). A difference of 1 ºC exists between the mean stream temperatures for both the two higher altitude sites and for the two lower altitude sites. The diel stream temperature at the 4 river sites had a 4.0 - 4.8 ºC variation while the variation in stream temperature among the 4 sampling days for the highland sites (Pichan and Alambi) was 0.36 ºC and .81 ºC for the midland sites (Tandayapa and Mindo) respectively.

The Alambi, Tandayapa and Mindo rivers all had similar substrate type composition of gravel, cobble and boulder (Figure 3.4). The composition of substrate type at the Pichan river however was dominated by sand, gravel and cobble. The distribution of particle sizes at the Pichan River shows the highest number of smaller particle sizes within the 2-16 mm range with ~1/4 of the number of particles in the 2 mm size range and, unlike the other 3 rivers, it has no substrate particles over the 256 mm size type (Figure 3.5). The Mindo River has the highest number (> 35%) of particles sizes in the largest size class, more than 256 mm. At all 4 rivers, few pieces of wood were collected.

The current velocities at the Pichan, Alambi and Tandayapa Rivers are all similar ranging from 1.1 - 1.3 m^{-s} (Table 3.1). I was not able to accurately estimate the current velocity at the Mindo river due to the physical difficulty in attempting to traverse a 10 m reach.

The pH values for the 4 rivers ranged from 8.01 – 8.75 where the Pichan and the Tandayapa rivers were more acidic (8.01 and 8.24 pH respectively) with levels of bicarbonates present, then the Mindo and Alambi rivers (8.52 and 8.75 pH) with levels of hydroxides or carbonate alkalinity present (Table 3.1). The degree of alkalinity in rivers can be due to the hydroxides, bicarbonates and carbonates of calcium, magnesium, sodium, and potassium dissolved in the water (Wetzel and Likens 2000).

The Pichan river had the highest specific conductivity with 0.194 (μ S/cm) while the Alambi and Mindo rivers were lower with 0.173 (μ S/cm) and 0.166 (μ S/cm) respectively and the Tandayapa river the lowest with 0.082 (μ S/cm) (Table 3.1).

Biological

Of the 4 river sites, the Pichan River had a significantly higher number of both *E. coli* and of total coliforms, with 28 and 42 colonies, compared to the other three sites which ranged from 0 – 1 and 6 – 14 colonies respectively (Figure 3.6).

A total of 7,970 macroinvertebrates in 91 distinct taxonomic groups were collected from 4 rivers (Appendix A). Total average generic and family richness for the 4 sites was 49 and 34 taxa, respectively. The average generic and family richness for the highland sites (2000 – 2400 m.a.s.l.) was 43 and 33 taxa and for the midland sites (1618 – 1726 m.a.s.l.), 55 and 36 taxa, respectively. The Tandayapa river had the greatest richness with 42 families and 66 genera while the Pichan showed the lowest richness with 30 families and 38 genera (Figure 3.7). The most common taxa were Chironomidae (*Ablebesmyia* spp.), Tricorythidae (*Leptohyphes* spp.), Baetidae (*Baetodes* spp.) and Simuliidae (*Simulium* spp.).

The rank abundance graph, in which the number of individuals per genera is shown, represents a geometric series in which the majority of genera are represented by a few individuals and a few genera are very abundant (Figure 3.8). Rank abundance arrangements have been considered in terms of resource portioning in that the abundance of species is indicative of the relative percentage of occupied niche space (Magurran 1988).The geometric series is the best fit for these data (in this case, genera) from the 4 rivers indicating low evenness and suggesting a niche pre-emption hypothesis. That is, a few genera are dominant and appropriate a large proportion of the resources. Field data collect by Whittaker have demonstrated that the geometric series pattern of species abundance represents species-poor and sometimes harsh environments so that as conditions improve, the pattern will change to depict more evenness such as in the log series (Margurran 1988).

The highest average densities of aquatic macroinvertebrates were found at the Mindo and Tandayapa rivers with 12,733 and 11,977 ind. m^{-2}, respectively, and the lowest at the Pichan and Alambi rivers with 3,022 and 7,533 ind. m^{-2}, respectively (Table 3.3). When considering habitat type for the third order rivers (Pichan, Alambi and Tandayapa), the Tandayapa not only has the highest average densities for riffle and bank habitats, but also has the highest average biomass for these habitats.

By comparing average densities between the bank and habitat types, we see both the Alambi and Mindo rivers had higher average densities of aquatic macroinvertebrates individuals in the bank habitat then the riffle habitat while the reverse was true for the Tandayapa and Pichan rivers (Figure 3.9).

Average biomass of aquatic macroinvertebrates was highest at the Tandayapa river with 4.47 g m^{-2}, followed by the Alambi with 3.62 g m^{-2}, the Mindo with 3.29 g m^{-2}, and the Pichan with the lowest at 0.52 g m^{-2} (Table 3.3). The Alambi and Mindo rivers had higher biomass values in the riffle habitat than the bank habitat and these values were similar at both rivers with 4.37 and 4.68 g m^{-2} respectively (Figure 3.9). However, the Tandayapa river had over 3 x the biomass in the bank as compared to the riffle habitat. While at the Pichan river, both the riffle and bank habitat types had similarly low biomass values (0.48 and 0.57 g m^{-2} respectively).

A further comparison of the 4 rivers by percent taxonomic composition reveals other similarities and differences. At the Pichan river, although we see an abundance of Diptera, Trichoptera and Ephemeroptera, by biomass, Trichoptera and Diptera and Ephemeroptera and Trichoptera are dominant for the riffle and bank habitats, respectively (Figure 3.10).

At the Alambi however, the abundances of Diptera, Coleoptera, Trichoptera, Plecoptera and Ephemeroptera generally reflected the biomass of these orders for both the riffle and bank habitats with Ephemeroptera dominant (Figure 3.11). At the Tandayapa river, Diptera and Ephemeroptera biomass were dominant for both riffle and bank habitats (Figure 13.2). Similar to the Pichan river, the Mindo river biomass was dominated by Diptera and Ephemeroptera and by Trichoptera and Ephemeroptera for riffle and bank habitats, respectively (Figure 3.13).

In comparing the percent composition of Trichoptera taxa from the 4 rivers, the Pichan was the only river which had the same taxa, *Glossomatidae mortoniella*, dominant for both riffle and bank habitats (Figure 3.14). In the riffle habitat, both the Alambi and Mindo had a high percentage of *Hydropsyche smicridea* and *Leptoceridae leptoceris*, while *Hydropsyche smicridea* had the largest composition at the Tandayapa. There was a relatively even distribution of Trichoptera taxa in the bank habitat at the Alambi. The bank habitat for the Tandayapa river however was dominated by *Leptoceridae atanatolica* and by *Leptoceridae leptocerus* at the Mindo river.

The dominant Ephemeroptera taxa at the Pichan river were *Baetidae baetodes and Leptophlebiidae thraulodes* for the riffle *and Leptophlebiidae thraulodes* and *Tricorythidae leptohyphes* for the bank habitat types (Figure 3.15). Both the Alambi and Tandayapa rivers were similar in Ephemeroptera composition for both riffle and bank habitats with *Baetidae baetodes* and *Tricorythidae leptohyphes* dominant. Similarly, *Baetidae baetodes* had the largest composition at the Mindo river.

Percent of non-insect taxa to total insect and non-insect taxa was low at the Pichan river (0.058), and lower still at the Alambi river (0.009), and at the Tandayapa river (0.008), and no non-insects were collected at the Mindo river. For both the riffle and bank habitats, Oligochaeta and Planariidae were dominant at the Pichan river, while Acari and Gammaridae were dominant at the Alambi and Tandayapa rivers.

At all 4 rivers, the shredders had the smallest percent composition of the functional feeding groups ranging in density from 19 g m^{-2} (0.03%) at the Pichan river to 372 g m^{-2} at the Mindo river (13.4%)(Figure 3.16). Filterers and predators each had roughly similar compositions at all four sites. Densities of the filterers ranged from 165 g m^{-2} at the Pichan river to 949 g m^{-2} at the Mindo river and densities for the predators ranged from 119 g m^{-2} at the Pichan to 705 g m^{-2} at the Tandayapa river. Scraper densities ranged from 255 g m^{-2} at the Pichan river to 949 g m^{-2} at the Mindo river. The Gatherers were dominant at the Alambi (41%) and Tandayapa (38%) rivers. The gatherers ranged in density from 99 g m^{-2} at the Pichan river to 1094 g m^{-2} at the Tandayapa river.

At the Pichan river the scrapers were dominant (35%) followed by predators (26%), filterers (23%), gatherers (13%), and shredders (0.03%). At the Mindo river there was a relatively even distribution of functional feeding groups with the scrapers dominant (34%) followed by the filterers and gatherers (19.4%) and the shredders and predators (13.6%).

The Margalef diversity index, which takes into account the sample size, was found to be the highest at the Tandayapa river (9.30) and the lowest for the Mindo river (6.10) (Table 3.2). However both the Alambi and Tandayapa rivers had the highest value for the Shannon – Weiner information theory index (2.51) which weights towards abundance rather then species richness. The largest value for evenness (values from 0 – 1.0 and where 1.0 signifies that all species are equally abundant) was at the Pichan river (0.69) and the lowest was the Tandayapa river (0.60). We should see similar results from the Simpson diversity index which reflects dominance or equitability of a sample (i.e. inverse of diversity, that is, how individuals in a sample are concentrated into a few species) and we do. The Tandayapa river had the lowest value (6.05) and Pichan river had the highest (8.38).

Calculations for the Jaccard and Sorenson similarity measures had comparable results. The Alambi river was most similar and the Pichan was the least similar to the reference river, the Tandayapa.

The Pichan river had the optimal value for the FBI (3.90=Excellent), followed by the Mindo (4.40=Good), the Alambi (4.55=Good), and the Tandayapa (4.82=Good) (Table 3.3).

The Tandayapa river had the most Ephemeroptera, Trichoptera, and Plecoptera (EPT) taxa (20), followed by the Alambi (17), the Mindo (16), and the Pichan (15) (Table

3.3). However, percent EPT was highest at the Mindo river and lowest at theTandayapa river.

Percent abundance of shredders was low at all rivers with the Mindo river having the highest percentage (0.13), the Alambi with the lowest (0.02), and both the Pichan and Tandayapa with the same percentage (0.03). The Alambi river had the highest percentage of Chironomidae to total Diptera (0.72) and the Pichan had the lowest (0.43) (Table 3.3). The results of the percent Hydropsychidae to total Trichoptera showed the Pichan river to have the lowest value (0.01) and the Alambi river to have the highest value (0.65) (Table 3.3). Percent Diptera to total taxa showed the highest value for the Tandayapa river and the lowest value for the Mindo river (Table 3.3). Total values for percent Diptera and percent EPT taxa explained 96% of total taxa for the Mindo river, 93% for the Alambi, 92% for the Pichan and 84% for the Tandayapa.

Significant relationships occurred for regressions of generic (r^2=0.737) and EPT richness (r^2=0.73) with standard deviation of particle size (mm) of substrate at the 4 rivers (Figure 3.17 & 3.18). Comparable to the results from the study by Jacobsen et al. (1997) in which the authors find maximum stream temperature to best explain the variability in faunal composition, maximum stream temperature for this study was relatively good at explaining generic richness (r^2=0.534) (Figure 3.19).

Discussion

How well did the methodologies employed reflect the stream integrity?

Disturbance regimes. Disturbance regimes, particularly high and low stream flows, are understood to play an important role in the structure of stream communities (Reice et al. 1990 and Lake 2000). The disturbance regimes of the wet and dry seasons in the tropics vary in their degree and length of disturbance and have been shown to influence the abundance and composition of stream macroinvertebrates. Jacobsen and Encalada (1998) studied 8 Ecuadorian streams and found that although the number of individuals and species were significantly higher in the dry season than in the wet season, no changes in aquatic macroinvertebrate structure or functional feeding groups were found between the two seasons for the eight Ecuadorian streams they sampled.

Unlike other studies done in the neotropics (Flecker and Feifarek 1994, Jacobsen and Encalada 1998) Melo and Froehlich (2001) found there to be no difference in assemblage structure between the wet and dry seasons. The authors suggest the fauna may have adapted to the dry season low flow and that only the infrequent stress from floods would cause a change in the structure of macroinvertebrates. The data presented by Flecker and Feifarek (1994) from a study at a lowland piedmont site (180 m.a.s.l.) and a highland montane site (2060 m.a.s.l.) in Venezuela suggest that disturbances, such as unpredictable and severe changes in discharge, affect the macroinvertebrate assemblages in Neotropical streams. Their study shows an inverse relationship between rainfall and invertebrate diversity. Jacobsen and Encalada (1998) found similar results in their study in highland Ecuador. The montane area streams are often fast flowing step/pool, therefore it is not surprising that densities of aquatic macroinvertebrates after rainfall are distinctly lower than during the dry season, and that such patterns are not seen in the lowland areas such as the Amazon (Flecker and Feifarek 1994).

Sampling vs. subsampling. Although all insect and non-insect individuals were counted, it proved to be a time consuming and laborious process. I recommend that a similar study to the one by Doberstein (2000) be conducted to explore how well subsampling at a range from 100 to 1000 individuals compares to whole sample results. However, given the that results of their study found that subsampling significantly decreased the maximum number of IBI classes from 8.2 for fully counted samples to 2.8 for 100-organism sub samples, the chance to significantly reduce time and labor costs does not look promising.

EPT metric. The order Plecoptera presents an exception to the latitudinal pattern of diversity primarily due to the fact that the order is adapted to cool temperatures as evidenced by its' diversity in the temperate regions. Illies (1969) reported that the order Plecoptera is over five times as diverse in the temperate region than in the tropics. Therefore, it may be inappropriate to apply the temperate, EPT metric as and index of stream health in the tropics.

What variables were potentially driving changes in biota in these rivers?

The strength of this study was the physico-chemical variables that were quantified and that then could be related to macroinvertebrate indices. We know that temperature, land use types, and substrate all can have a significant influence on the distribution and composition of aquatic macroinvertebrates (Hynes 1970, Vannote & Sweeney 1980, Covich 1988). Habitat and food quality and availability are second to the range of thermal requirements of an aquatic insect in regulating its abundance (Cummins and Merritt 1996). These variables will be discussed in further depth below.

Altitude. The results for percent Diptera correlated with the data presented by Jacobsen (2003) in which Diptera richness increased with altitude. Generally, there is a negative correlation between family richness and altitude. This trend is shown with data from recent studies in Ecuador including this study, Jacobsen et al. (1997), and Thom (2000) (Figure 3.20).

Temperature. Thermal regimes may be the most important physico-chemical variable to populations at a given geographic range as there is a ‘dynamic equilibrium’ between temperature and individual growth, metabolism, reproduction, emergence and distribution (Vannote & Sweeney 1980). Under harsh thermal conditions, aquatic macroinvertebrates will tend to have low population densities and reduced fecundity. As would be predicted for mid-altitudinal rivers in the tropics, temperature did appear to influence the generic richness of aquatic macroinvertebrates as a negative correlation existed between max stream temperature and generic richness.

Substrate. The standard deviation of particle size of substrate composition positively correlated with both generic and EPT richness. The heterogeneity of stream substratum is potentially important as providing more areas for refuges for prey (therefore possibly explaining lower predation rates in streams with heterogeneous substratum) (Malmqvist 2002). Peckarsky (1979) found that the nature of substrate habitat is initially responsible for attracting particular sizes and assemblages of species and following this, a density-dependent response by macroinvertebrates will achieve an “optimum density”. Huryn and Wallace (1987) found in their study in an Appalachian mountain stream that the functional character of the stream was related to the specificity each of the functional feeding groups had to the distinct mesoscale habitats which included bedrock-outcrop, riffle and pool. A sandy substratum is poor habitat for macroinvertebrates because it is unstable and therefore does not allow for quality food to accumulate nor for attachment sites by the macrofauna (Wallace and Anderson 1996, Zweig and Rabeni 2001). Many studies correlate increasing levels of deposited sediment with lowered richness and density of macroinvertebrates (Melo and Froelich 2001, Zweig and Rabeni 2001). In comparing macroinvertebrate densities found at the third-order rivers in this study, I suggest it is the heterogeneity of larger particle sizes at the Tandayapa river that explains the higher densities in the riffle habitat in this river (Reice 1980).

Substrate and flow are important in considering future risks to stream integrity by potential oil spills from the OCP pipeline due to either natural catastrophes or to human error. Beasley and Kneale (2002) found that the concentrations of polycyclic aromatic hydrocarbons (PAHs) are controlled by the physical characteristics of the stream. Large, fast-flowing streams with gravel or cobble dominated substrates have a high potential for dilution and dispersion and therefore a high potential to mask the true level of PAH contamination. PAHs are the most recalcitrant of the four classes of hydrocarbons and they contain carcinogenic hydrocarbons (up to 0.1% in crude-oil) (Vanloocke et al. 1975).

Scale. Streams and rivers are the “sinks” into which the surrounding landscapes drain (Baron et al. 2002). We know through many studies that the spatial composition of land practices in a catchment strongly influence the structure of lotic macroinvertebrate communities (Allan 1995, Harding, et al. 1998, Sponseller et al. 2001). Sponseller et al. (2001) found water chemistry to be the most strongly influenced by land practices at the catchment scale, temperature and substratum most influenced at the riparian corridor and sub corridor scales, and at the 200m scale, macroinvertebrate indices.

Food quality. Although we know substrate is important to the composition of stream macroinvertebrates, Hawkins et al. (1982) found that canopy type can be more important than substrate type in influencing the total abundance and guild structure of macroinvertebrates. These authors found that most guilds were influenced by the quality of the food available to these organisms and not the quantity. Perhaps the comparatively high values in bank biomass at the Tandayapa river were influenced by the quality of leaf litter deposited from the primary forest upstream of the sampling station.

Trout farms. Concerns regarding the impact of trout farms on river integrity focus on the continuous entry of food wastes as both dissolved nutrients and suspended solids which can then have a significant impact on the faunistic trophic structure (Loch et al. 1996). Recent studies on the influence of trout farms on stream integrity have found a decrease in sensitive taxa (Ephemeroptera, Plecoptera, and Trichoptera) and an increase in pollution tolerant taxa (Isopods, Gastropods, Chironomidae, Simuliidae, Oligochaeta and Pisidium) below the trout farm effluence as compared to above (Brown 1996, Selong and Helfrich 1998, Loch 1996, Boaventura et al. 1997). Greater percentages of collectors and percent Hydropsychidae to total Trichoptera below a trout farm effluence has also been found which suggests these taxa are filling the trophic niche provided by the increase in organic solids (Loch 1996). Selong and Helfrich (1998) found that settling ponds at two farms effectively reduced nutrient loadings downstream. Given these findings, I believe it is probable that the trout farm located on the Alambi river has increased the nutrient levels in the stream and this may be the reason why we see a large percent of gatherers (41%) and of Hydropsyche to total Trichoptera (65%). It is possible that the Tandayapa river was influenced by the trout farm located ~25m downstream from the sampling site through downstream-upstream linkages. Pringle (1997) suggested many ways in which downstream disturbance by humans can change the diversity and abundance of river fauna upstream and cites a case study in Puerto Rico which involved both natural (hurricanes and droughts) and human (dam, fishing and sewage) legacies of impact. It may be that trout farms impact the faunal composition upstream due to the legacy of water withdrawal and nutrient enrichment from food wastes and the stress of these variables particularly during the dry season when water levels are considerably lower.

What indices were most sensitive to environmental change?

The biotic metrics that were most sensitive to environmental change were total richness and total EPT taxa considering the values were highest for the reference condition at the Tandayapa river. The results of the modified FBI calculation contradicted my expectations based on the land use, temperature, substrate and nutrient enrichment variables for the four rivers. This surprising result may be attributed to the fact that in the tropics the macroinvertebrate fauna generally have a lower diversity on the family level and a species diversity while the opposite is true for temperate regions (Jacobsen et al. 1997).

The percent Hydropsychidae to total Trichoptera was sensitive to describing the potential influence of nutrient enrichment through the dominance of the filter feeding functional group.

Temperate vs. tropical: How well does the RCC hold true at this study site?

It has been suggested that the variability in annual stream temperatures in the temperate regions allows for more niches and therefore a coexistence of synchronized life cycles.

It may be that the stability of tropical stream temperatures lowers the probability of a coexistence of synchronized life cycles and therefore increases the competition, “species packing” (Whitmore 1998) and lowers diversity (Jacobsen et al. 1997, Vannote et al. 1980). Indeed, the study by Minshall et al. (1985) fount that midlatitude streams support lower numbers of species but higher densities than do tropical streams.

Melo and Froehlich (2001) studied 10 streams in low-altitude (500 – 800 m.a.s.l.) catchment in Brazil and found the highest richness to be in low ordered streams. This finding contradicts the river continuum concept (RCC) which predicts a higher richness in the mid-sized streams that have more variation in both daily and seasonal temperatures.

The highest percentage of abundance of shredders of the four rivers found in this study was at the Mindo river, which is an open canopy, 4^{th} order river. However, the RCC predicts a high biomass of shredders in small high altitudinal closed canopy streams. My findings however do correlate with those by Hawkins et al. (1982) in which they found no differences in shredder abundance in shaded streams and those with canopies. However, for the third ordered rivers, the percent contribution of shredders was lower (0.02 - 0.03) than the 5 – 7 % Jacobsen and Encalada (1998) found at 2^{nd} and 3^{rd} ordered streams (2600 – 3100 m.a.s.l.) in the Central Valley of the Ecuadorian Andes.

It may be that the long life-cycles and slow colonization characteristics of the shredders is a contributing factor to the low percent contribution (Jacobsen and Encalada 1998, Wallace et al 1986)

The general trend predicted by the RCC for predators did correlate with this study in the overall evenness of the percent composition of abundance for the 4 rivers (14-25%) but these percentages are higher than those predicted for the RCC. Scrapers decrease with an increase in width for the third order streams which also do not correlate with the RCC predictions. Minshall et al. (1985) suggest that any midlatitude and tropical comparative studies should consider the different levels of density-dependent and independent attributes along with the time of year and the width of stream.

What influenced the variability in biomass between the four rivers?

Banks act as debris dams because of the structural nature of the roots of riparian vegetation allow for the accumulation of leaf litter and other detritus even during high flow (Covich 1988). These debris dams provide food and habitat for macroinvertebrates and therefore may explain the difference in biomass values between the 4 rivers.

The Tandayapa river had an extremely high bank biomass in relation to the riffle habitat in that river and in relation to the other three rivers. At the Tandayapa and Mindo rivers, the differences in biomass in the bank habitat can be attributed to the different dominant taxa of Ephemeroptera at each river. The Tandayapa bank habitat was dominated by *Tricorythidae leptohyphes* while the riffle habitat was dominated by *Hydropsychidae smicridea* and *Baetidae baetodes*. At the Mindo river, *Baetidae baetodes* dominated the bank habitat. The second most dominant order in the bank habitat was Diptera (*Chironomidae*) at the Tandayapa river and Trichoptera (*Leptoceridae*) at the Mindo river.

High levels of biomass accrual may also be attributed to either taxa with long life cycles (more than two years) and overlapping cohorts or to certain filter feeding taxa which rely on a ‘subsidized’ food sources and expend little energy in search for food (e.g. black fly) (Huryn and Wallace 2000). Life spans for Ephemeroptera vary with temperature and usually range from three to six months. However, Edmunds and Waltz (1996) noted that the period can be as short as 10-14 days in some Baetidae, Tricorythidae and Caenidae or as long as two years in Hexagenia limbata in cold habitats.

Although both the Tandayapa and the Mindo rivers have high quality habitat above the sampling point, the Tandayapa river is the shortest of the 4 rivers while the Mindo is the longest of the river which may correlate with the food retention ability for each river. As has been found in other studies, lower shading in both the Tandayapa and Mindo rivers is probably the factor stimulating the higher densities at these two rivers (Hawkins et al. 1982).

The low biomass at the Pichan river may have been influenced by the synergy between the physico-chemical mechanisms at work including the narrow and low quality riparian buffer, the land use for cattle pasture and road parallel to the river, the nutrient enrichment from sewage effluent, the low maximum stream temperature (15.8ºC), and the high percentage of fine particle size of substrate (23% in 2 mm size class).

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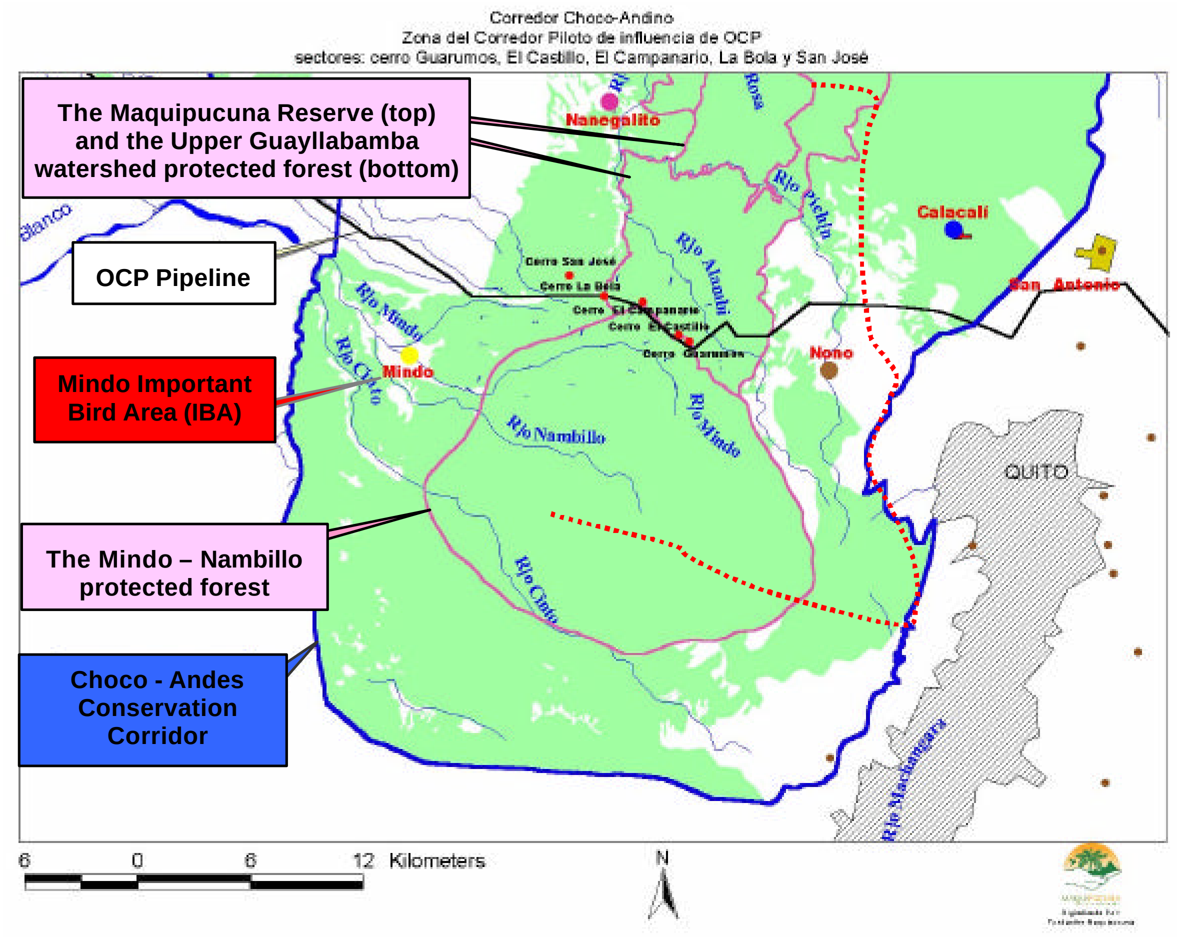


Figure 3.1. Map of the study area illustrating the OCP pipeline route which follows the ridgeline (—) and the conservation areas: the Maquipucuna reserve (top, —) and the Upper Guayllabamba river watershed protected forest (bottom, —); the Mindo Important Bird Area (IBA) (…); the Mindo – Nambillo protected forest (—); and the Choco-Andes conservation corridor (—).

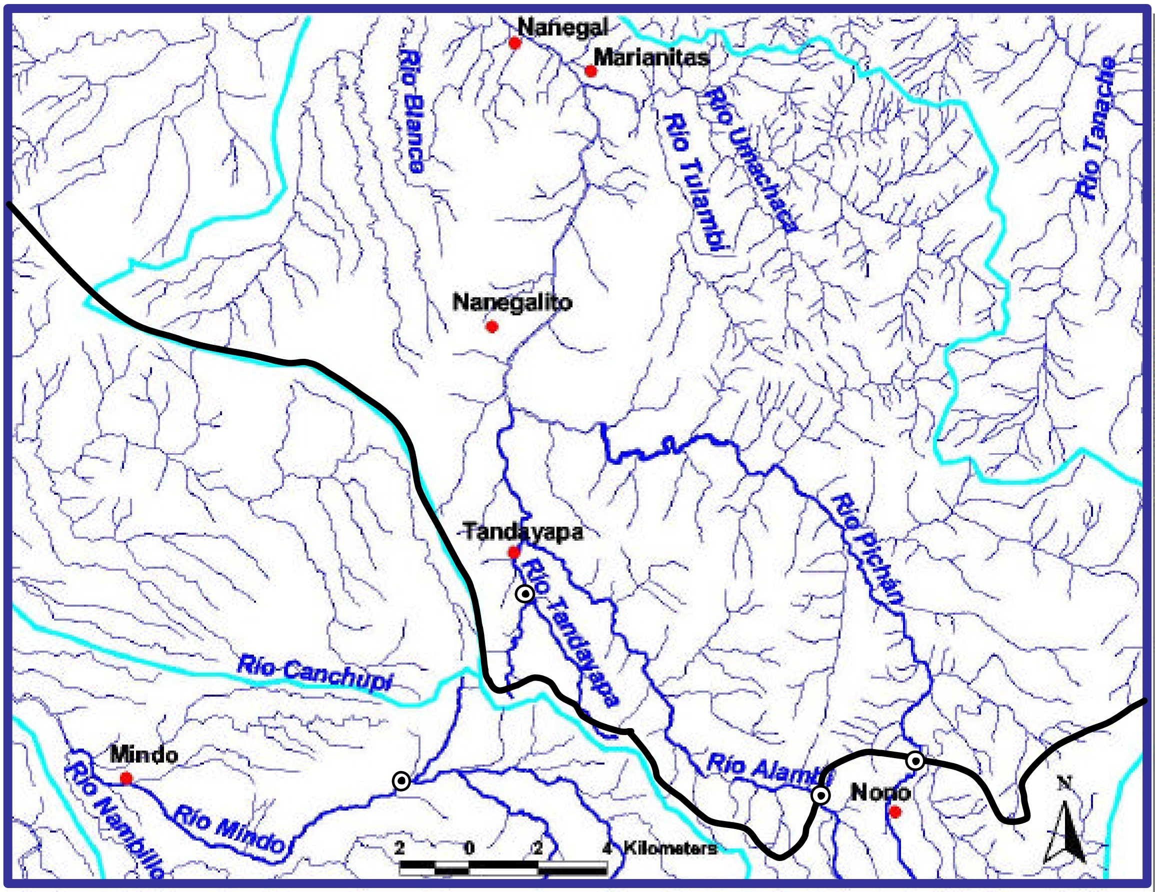


Figure 3.2. Map of the study area depicting the pipeline route (bold solid line), major rivers and streams, towns (solid red circles) and study sites (bull's eye) at the Pichan, Alambi, Tandayapa, and Mindo rivers.

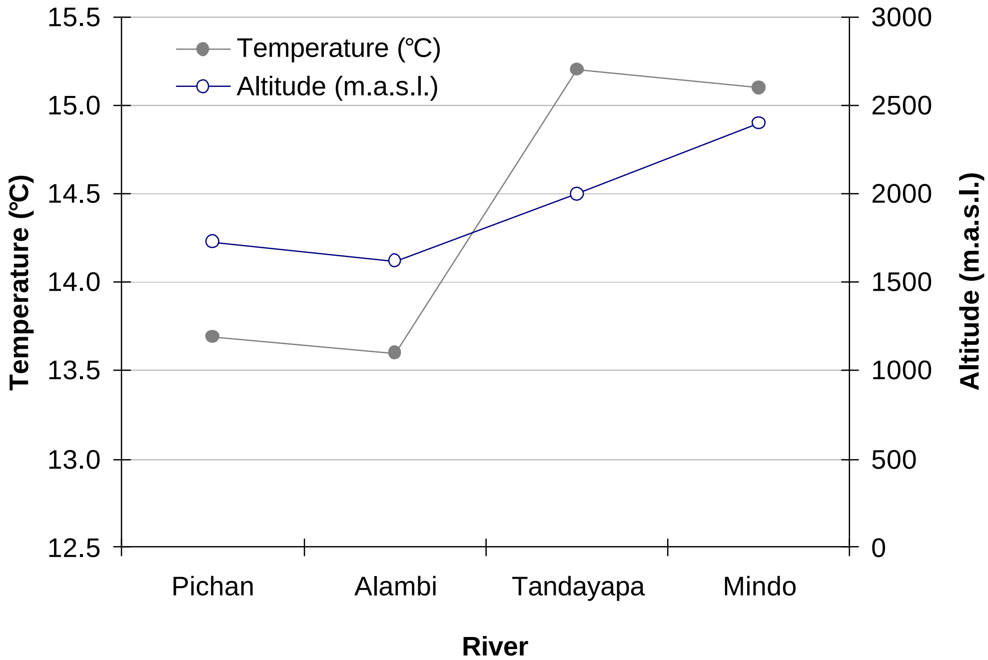


Figure 3.3. Stream temperature (ºC) and altitude (m.a.s.l.) of 4 Ecuadorian Rivers.

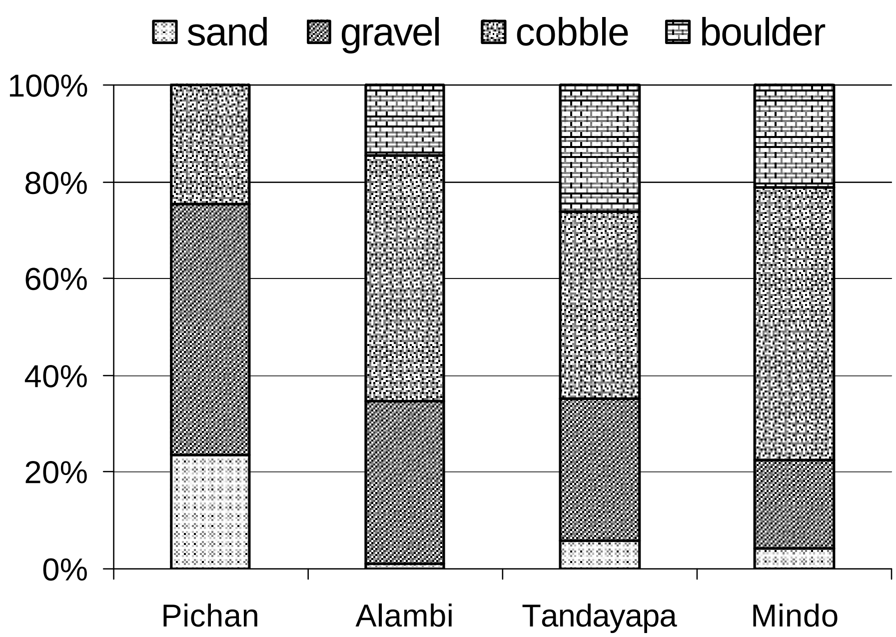


Figure 3.4. Percent type of substrate composition from 4 Ecuadorian rivers.

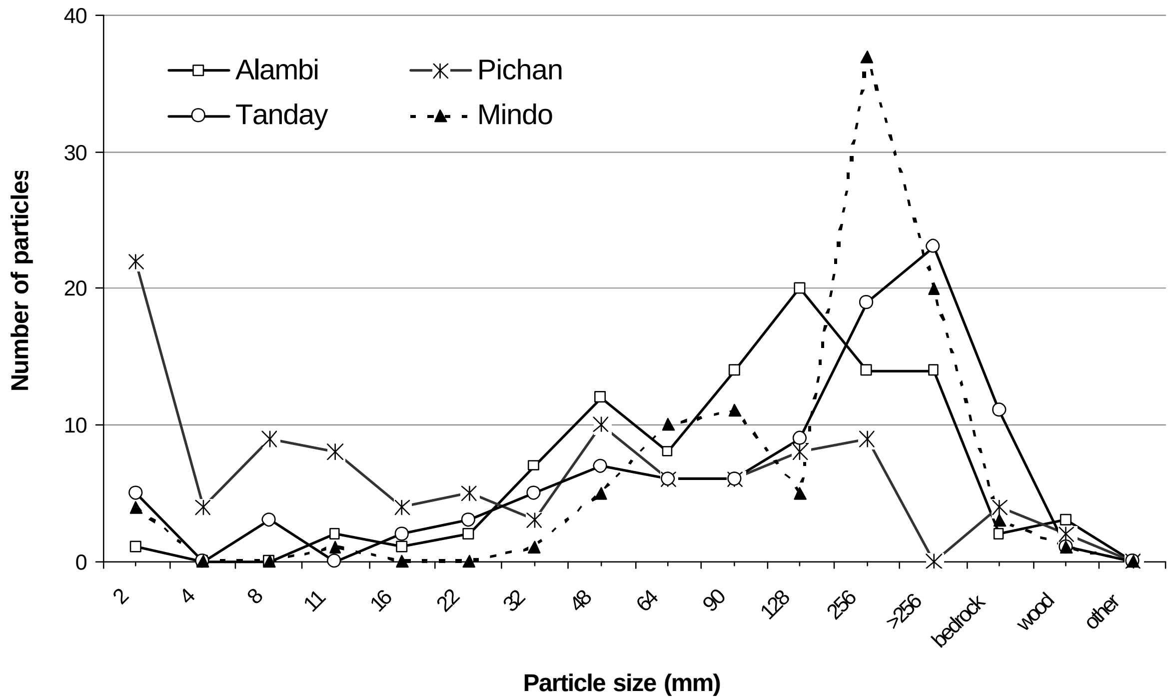


Figure 3.5. Number of particles per particle size class of substrate from 4 Ecuadorian rivers.

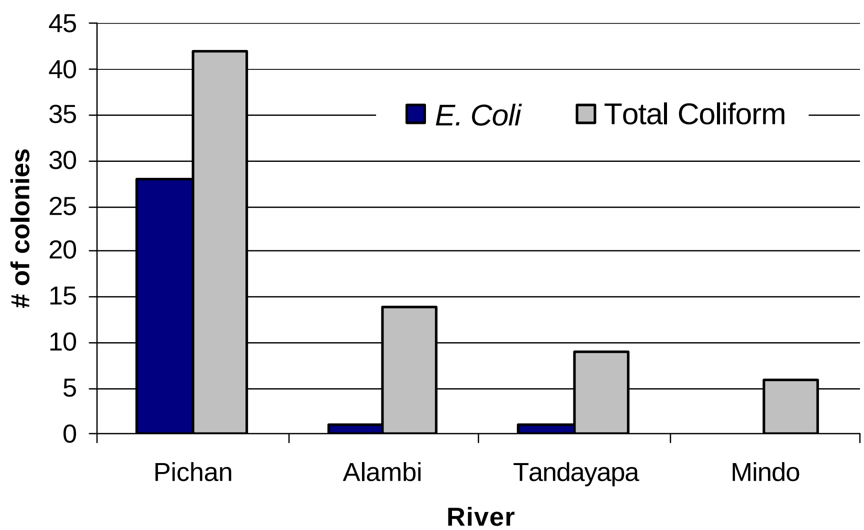


Figure 3.6. *E. Coli* and total coliform bacteria at 4 Ecuadorian rivers.

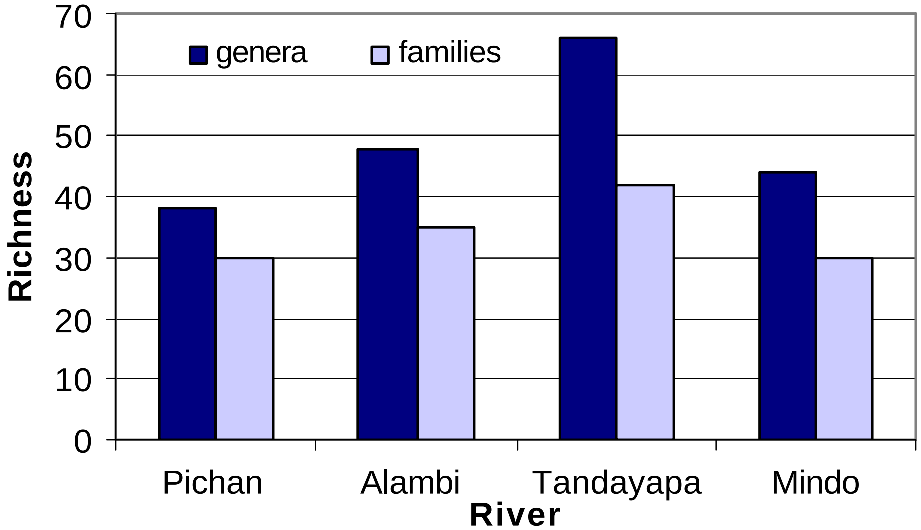


Figure 3.7. Generic and familial level richness of aquatic macorinvertebrates from 4 Ecuadorian rivers.

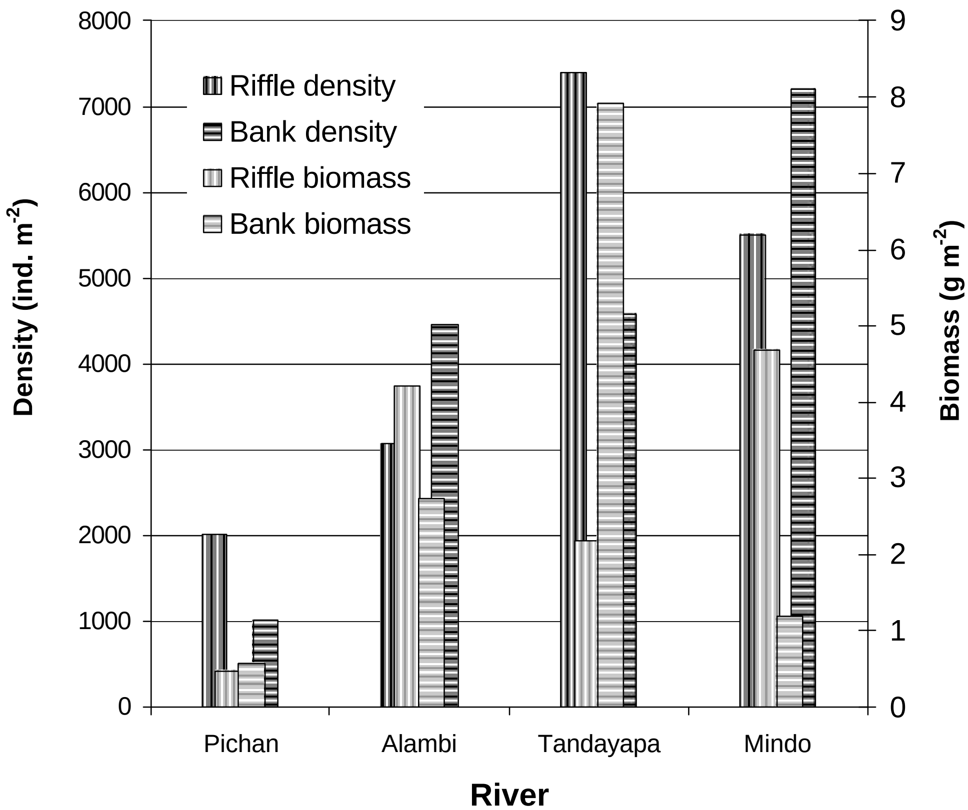


Figure 3.9. Average density (ind. m^{-2}) and average biomass (g m^{-2}) of aquatic macroinvertebrates in riffle and bank habitat types from 4 Ecuadorian rivers.

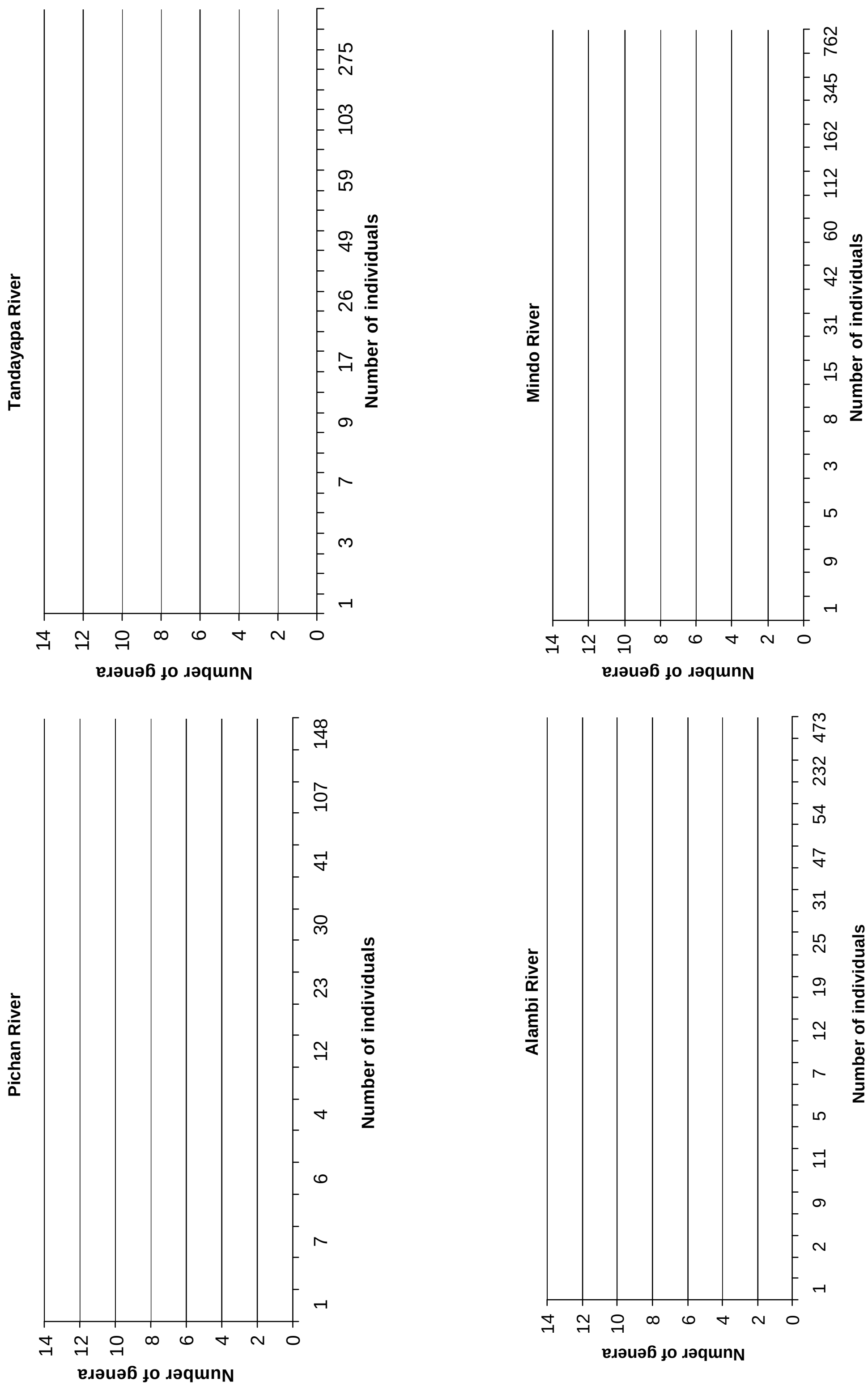


Figure 3.8. Rank abundance of number of individuals of aquatic macroinvertebrates per genera from 4 Ecuadorian rivers

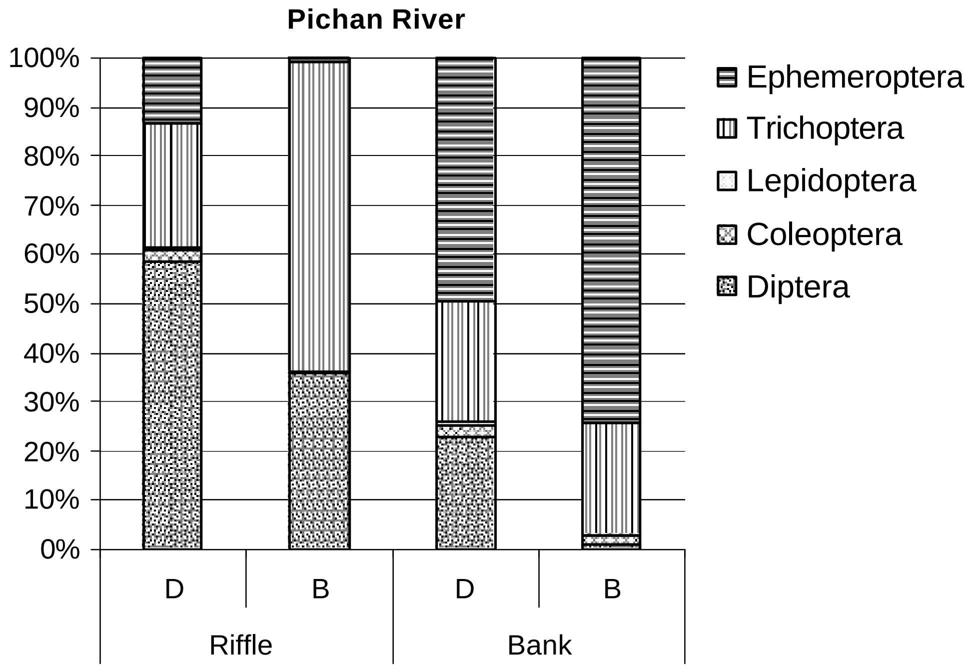


Figure 3.10. Percent composition of density (D = ind. m^{-2}) and biomass (B = g m^{-2}) of aquatic macroinvertebrate orders from the Pichan river's riffle and bank habitat types.

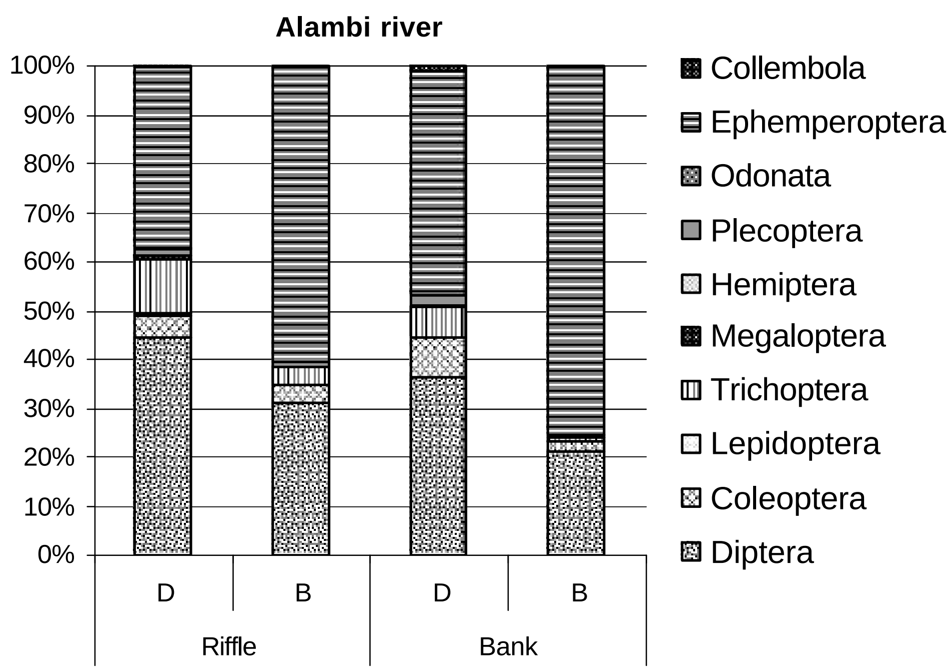


Figure 3.11. Percent composition of density (D = ind. m^{-2}) and biomass (B = g m^{-2}) of aquatic macroinvertebrate orders from the Alambi river's riffle and bank habitat types.

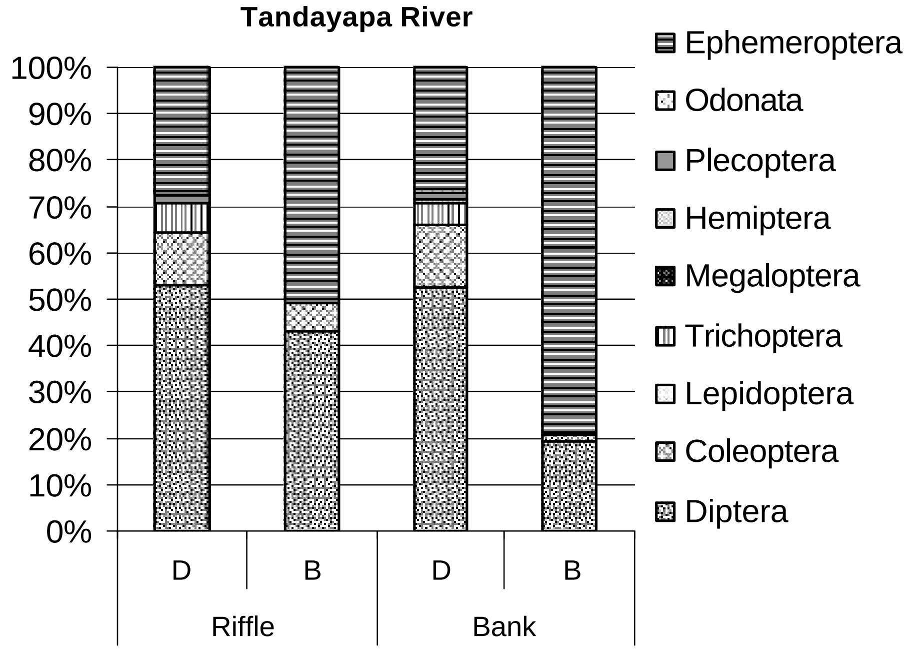


Figure 3.12. Percent composition of density (D = ind. m^{-2}) and biomass (B = g m^{-2}) of aquatic macroinvertebrate orders from the Tandayapa river's riffle and bank habitat types.

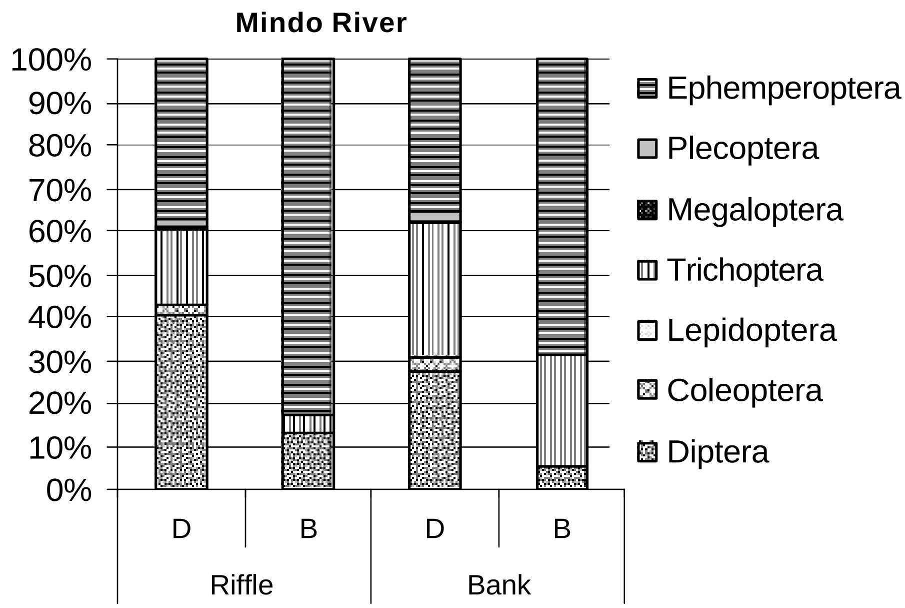


Figure 3.13. Percent composition of density (D = ind. m^{-2}) and biomass (B = g m^{-2}) of aquatic macroinvertebrate orders from the Mindo river's riffle and bank habitat types.

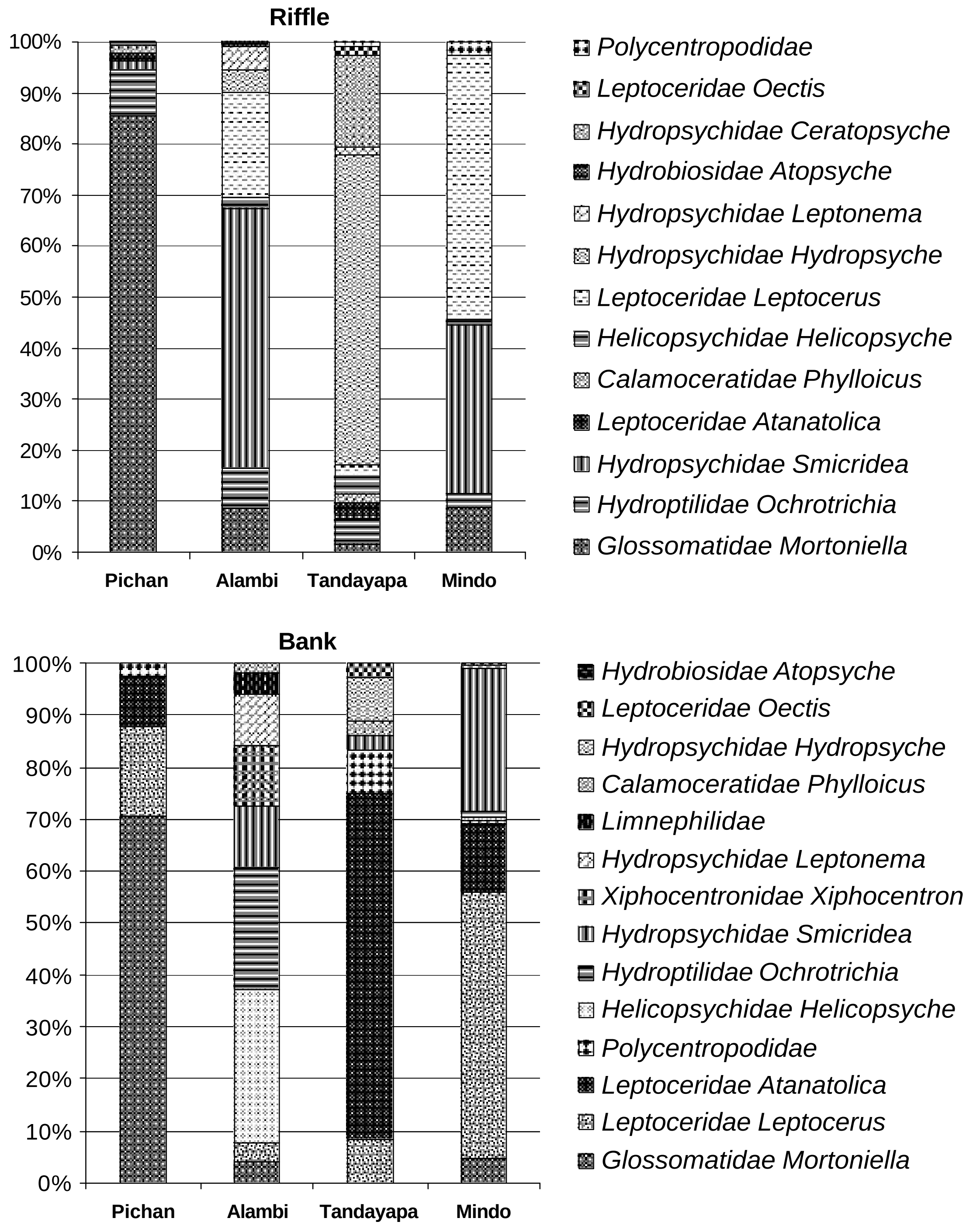


Figure 3.14. Percent composition of abundance of Trichoptera in both riffle (top) and bank (bottom) habitats for 4 Ecuadorian rivers.

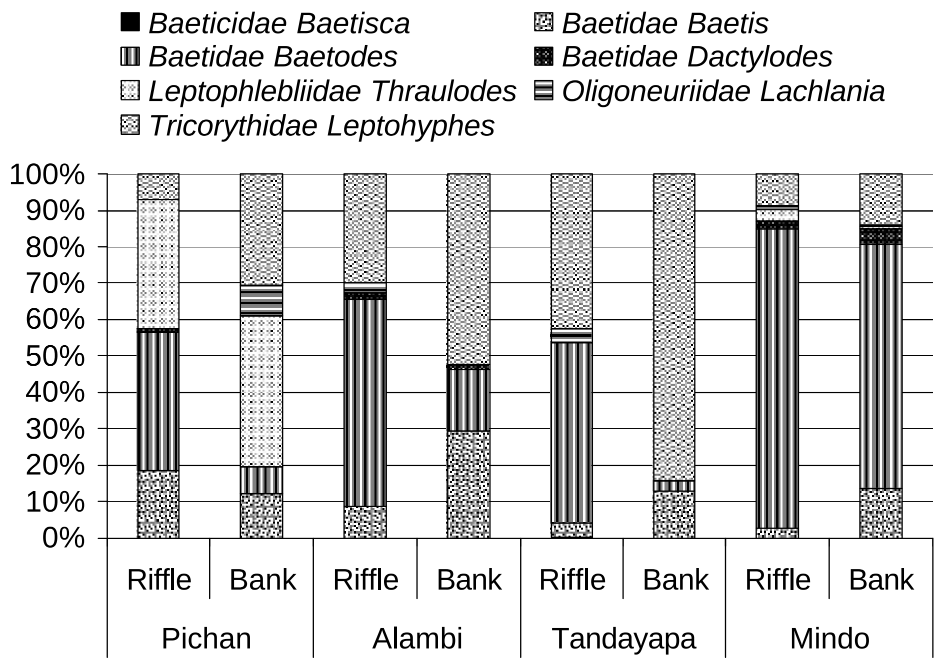


Figure 3.15. Percent composition of abundance of Ephemeroptera at both riffle and bank habitat types for 4 Ecuadorian rivers.

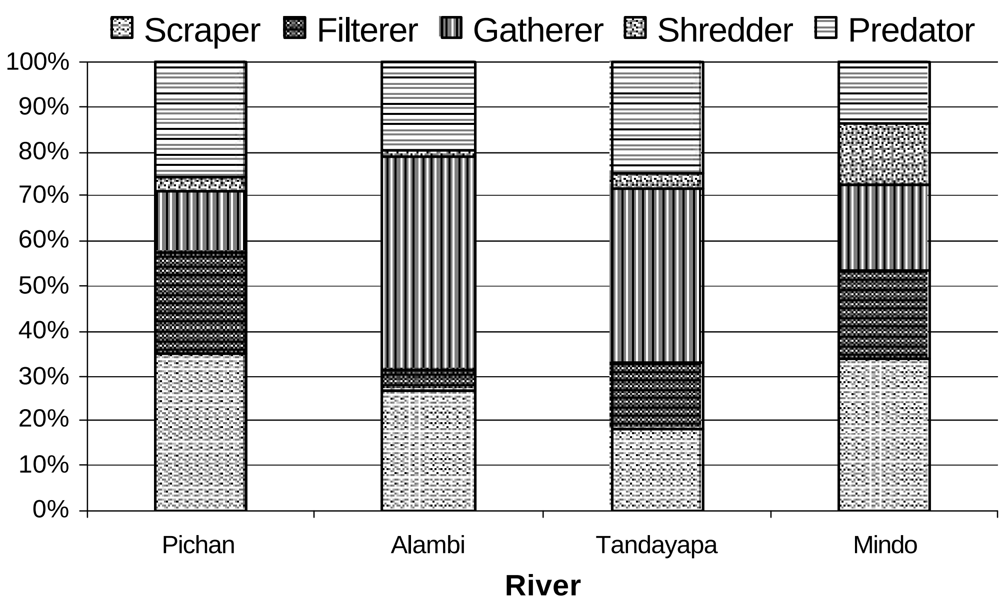


Figure 3.16. Percent composition of abundance of functional feeding groups of aquatic macroinvertebrates from 4 Ecuadorian rivers.

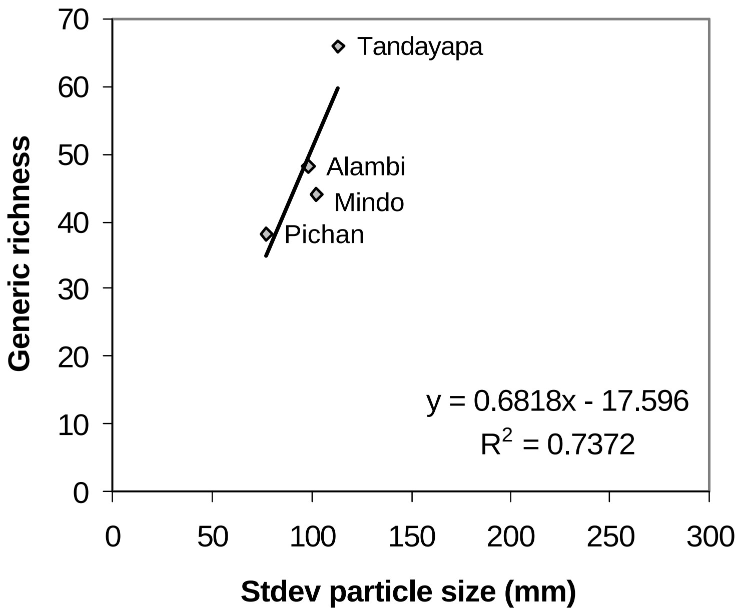


Figure 3.17. Scatter plot of generic richness of aquatic macroinvertebrates plotted against the standard deviation of particle size (mm) of substrate from 4 Ecuadorian rivers

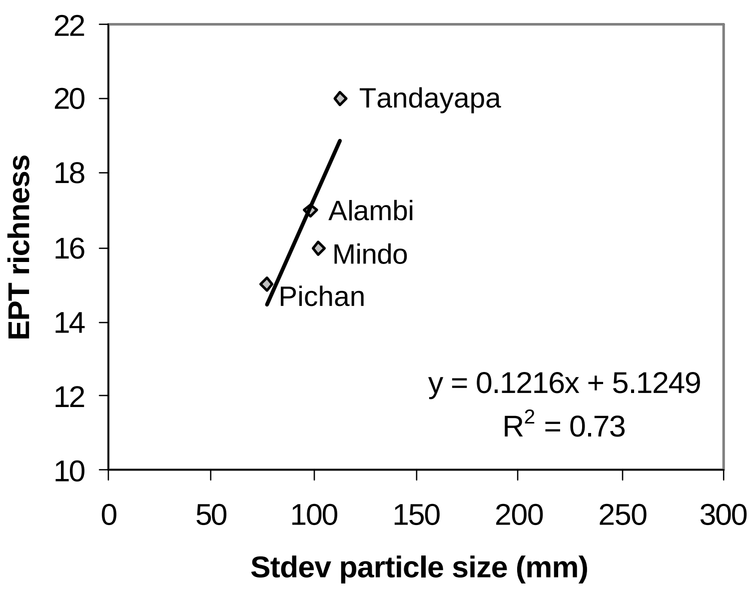


Figure 3.18. Scatter plot of EPT richness of aquatic macroinvertebrates and the standard deviation of particle size (mm) of substrate from 4 Ecuadorian rivers.

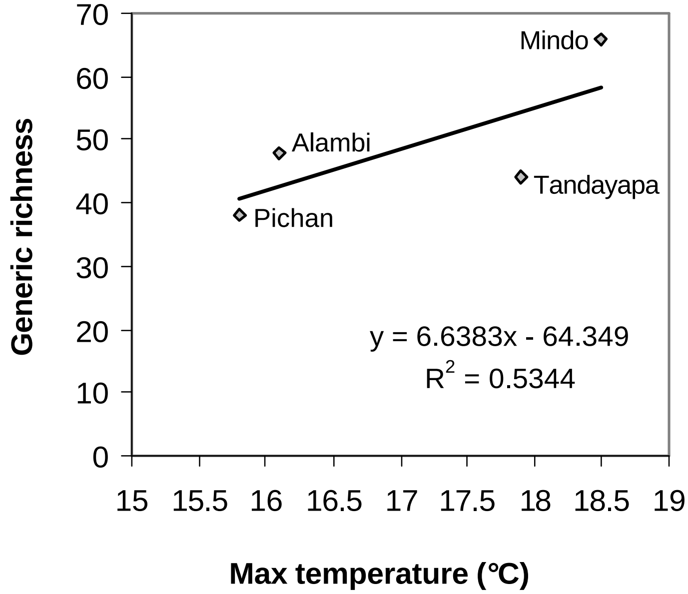


Figure 3.19. Scatter plot of generic richness of aquatic macroinvertebrates and max stream temperature (ºC) from 4 Ecuadorian rivers.

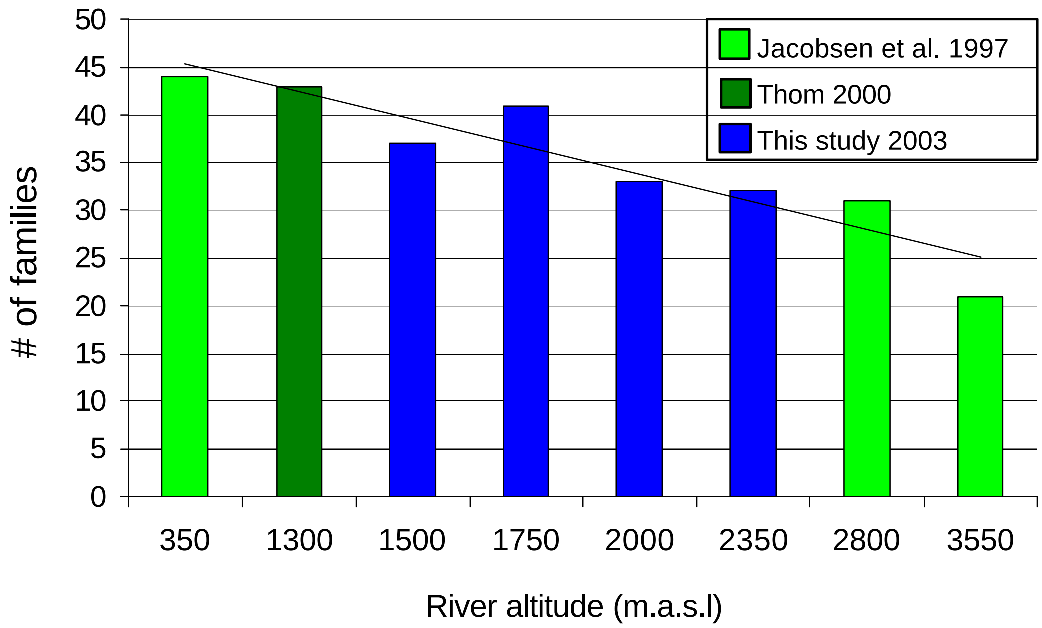


Figure 3.20. Family richness of aquatic macroinvertebrates along an altitudinal gradient from studies in northwestern Ecuador illustrates a negative correlation between family richness and altitude.

Table 3.1. Physico-chemical data for the Pichan, Alambi, Tandayapa and Mindo Rivers.

	Pichan	**Alambi**	**Tandayapa**	**Mindo**
Elevation (m.a.s.l.)	2400	2000	1726	1618
Substrate	gravel-cobble	cobble-boulder	cobble-boulder	cobble-boulder
Width (m)	3.6	5.1	5.8	20.0
Depth (m)	0.13	0.22	0.19	-
Velocity (m $^{-s}$)	1.1	1.2	1.3	-
Temperature Min (°C)	11.5	11.3	14.0	13.9
Temperature Max (°C)	15.8	16.1	18.5	17.9
Temperature Mean (°C)	13.7	13.6	15.2	15.1
SpCond (µ S/cm)	0.194	0.173	0.082	0.166
pH	8.75	8.01	8.24	8.52

Table 3.2. Summary table of richness, biomass and density of aquatic macroinvertebrates from 4 Ecuadorian rivers.

	Pichan	Alambi	Tandayapa	Mindo
Generic richness	38.00	48.00	66.00	44.00
Family richness	30.00	35.00	42.00	30.00
Average density (ind. m^{-2})	3022.00	7533.00	11977.00	12733.00
Average biomass (g m^{-2})	0.52	3.62	4.45	3.29

Table 3.3. Summary table of diversity, evenness, and similarity indices for aquatic macroinvertebrate taxa from 4 Ecuadorian rivers.

	Pichan	Alambi	Tandayapa	Mindo
Margalef	6.59	7.20	9.30	6.10
Shannon-Weiner (H')	2.55	2.51	2.51	2.35
Eveness	0.69	0.64	0.60	0.62
Simpson	8.38	6.87	6.05	6.64
Jaccard	0.41	0.52	reference	0.47
Sorenson	0.58	0.68	reference	0.64

Table 3.4. Biotic metrics for 4 Ecuadorian rivers: EPT=number of Ephemeroptera, Trichoptera and Plecoptera taxa; FBI=Family Biotic Index (modified from Hilsenhoff 1987 and Lenat 1993); % Shredders to total functional feeding groups; % Chironomidae to total Diptera; % Simuliidae to total Diptera; % Hydropsychidae to total Trichoptera; % Diptera to total taxa; and % EPT (adapted from Barbour et al. 1992).

	Pichan	**Alambi**	**Tandayapa**	**Mindo**
EPT	15.00	17.00	20.00	16.00
FBI	3.90	4.55	4.82	4.40
% Shredders to total FFGs	0.03	0.02	0.03	0.13
% Chironomidae to total Diptera	0.43	0.72	0.66	0.62
% Simuliidae to total Diptera	0.45	0.14	0.20	0.34
% Hydropsychidae to total Trichoptera	0.01	0.65	0.14	0.30
% Diptera	0.47	0.41	0.52	0.34
% EPT	0.45	0.52	0.32	0.62

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

This baseline study of river health in the pilot area of the Choco – Andes Conservation Corridor in northwestern Ecuador was conducted with little logistical support in rugged terrain, under a short time period, and under the policy and regulations of OCP, Ltd. Given these conditions, it was difficult to conduct an experimental design with the quantity of replicates needed for rigorous analysis.

Nonetheless, general trends in the data are evident and suggest anthropogenic disturbances in the landscape (sewage effluent and trout farms) and physical attributes (substrate heterogeneity and food quality) may influence the structure and composition of aquatic macroinvertebrates. The Tandayapa river was considered *a priori* as the reference condition for the study because of the primary forest above the sampling station. Indeed, the Tandayapa river had the largest heterogeneity of size of substrate particles, the most EPT taxa, and the highest generic and family richness, average density (of the third ordered rivers) and average biomass of aquatic macroinvertebrates as compared to the other three rivers.

Recommendations for basic and applied research in the pilot area of the Choco – Andes Conservation Corridor are listed below.

1. *Biotic metrics*. It is still unclear as to which biotic metric best reflects stream integrity for mid – altitudinal, tropical streams. Creating a index of stream

integrity for this region would be extremely helpful for future monitoring and may possibly be done in collaboration with local universities and NGOs.

2. *Trout farms.* A study designed to understand the influence of effluent of food wastes as both dissolved nutrients and suspended solids from trout farms on the structure and composition of aquatic macroinvertebrates. This study could be conducted on the Alambi and Tandayapa rivers with sampling stations above and below the trout farm effluent.
3. *Black flies.* In concert with the above study, it may be important to understand whether the nutrient enrichment from the trout farms influences population levels of black flies. This study would have important implications for human health.
4. *A River Assessment and Monitoring Program*. It is critical that a contingency plan is in place in case of an oil spill from the OCP crude – oil pipeline within the pilot area of the Choco – Andes Conservation Corridor. This plan should collaborate with the local landowners (particularly the trout farm owners), local NGOs and the local Universities. The river assessment protocol provided here (Appendix B) is meant to facilitate this process.

Funding options for the recommended research projects include the sources listed below:

1. *The Ecuador EcoFund.* The EcoFund was established by the OCP, Ltd. consortium to be administered by a group of Non – Governmental Ecuadorian Organizations for the development of environmental programs, training,

scientific research and other conservation projects in Ecuador. The 20 year fund is designed to invest more than US $20 million into environmental related programs in Ecuador.

2. *The Maquipucuna Foundation's Choco – Andes Conservation Corridor pilot project.* It is likely that the pilot project for the Choco – Andes Conservation Corridor will continue to be funded under by the Global Environmental Facility. The value of these research avenues are recognized and therefore may be funded at some level.

APPENDIX A

LIST OF AQUATIC MACROINVERTEBRATES

List of average density (ind. m^{-2}) of macroinvertebrates from 3 riffle samples and 2 bank samples for four rivers in northwestern Ecuador (LS=life stage [L=larva, A=adult]; FFG=functional feeding group [P=Predator, G=Gatherer, S=Shredder, Scp=Scraper, F=Filterer, GScp= Gatherer/Scraper; GP=Gatherer/Predator, GS=Gatherer/Shredder, PScp=Predator/Scraper]; R=Riffle and B=Bank).

Family	Genus	LS	FFG	Pichan		Alambi		Tandayapa		Mindo	
				R	B	R	B	R	B	R	B
Non-insects											
Turbellaria											
Planariidae	*Dugesia*	L	P	48.1	72.2	–	–	–	–	–	–
Annelida											
Oligochaeta		L	G	14.8	5.6	–	–	–	–	–	–
Araconoidea											
Acari		L	P	3.7	5.6	40.7	16.7	44.4	22.2	–	–
Amphipoda											
Gammaridae		L	S	3.7	–	–	5.6	7.4	22.2	–	–
Insects											
Collembola											
Entomobryidae	*Lepidocyrtus*	L	G		5.6	14.8	55.6	3.7		–	–
Ephemeroptera											
Baeticidae	*Baetisca*	L	GScp	–	–	–	–	7.4	–	–	–
Baetidae	*Baetis*	L	GScp	48.1	55.6	96.3	600.0	77.8	155.6	55.6	350.0
Baetidae	*Baetodes*	L	Scp	100.0	33.3	633.3	338.9	996.3	33.3	1685.2	1705.6
Baetidae	*Dactylodes*	L	GScp	3.7	–	22.2	27.8	–	–	44.4	105.6
Leptophlebliidae	*Thraulodes*	L	GScp	92.6	188.9	–	–	–	–	63.0	22.2
Oligoneuriidae	*Lachlania*	L	F	–	38.9	29.6	–	74.1	–	22.2	5.6
Tricorythidae	*Leptohyphes*	L	G	18.5	138.9	333.3	1061.1	859.3	1005.6	177.8	355.6
Odonata											
Libellulidae	*unknown*	L	P	–	–	–	–	3.7	–	–	–
Gomphidae	*Progomphus*	L	P	–	–	7.4	5.6	3.7	38.9	3.7	–
Zygoptera,		L	P	–	–	–	–	–	5.6	–	–
Plecoptera											
Perlidae	*Anacronueria*	L	P	–	–	40.7	77.8	96.3	–	114.8	161.1
Perlidae	*Andinoperla*	L	P	–	–	–	–	11.1	–	–	–
Perlidae	*Neoperla*	L	P	–	–	–	–	14.8	44.4	–	–
Hemiptera											
Corixidae		L	P	–	–	–	–	–	38.9	–	–
Naucoridae	*Limnocoris*	L	P	–	–	–	–	–	–	–	5.6
Veliidae	*Microvelia*	L	P	–	5.6	3.7	22.2	–	–	–	–
Megaloptera											
Corydalidae	*Chauliodes*	L	P	–	–	3.7	–	–	16.7	–	–
Corydalidae	*Corydalis*	L	P	–	–	14.8	–	22.2	–	3.7	33.3
Trichoptera											
Calamoceratidae	*Phylloicus*	L	S	7.4	–	–	5.6	7.4	5.6	–	–
Glossomatidae	*Mortoniella*	L	Scp	414.8	161.1	29.6	11.1	7.4	–	85.2	105.6
Helicopsychidae	*Helicopsyche*	L	Scp	3.7	–	7.4	83.3	14.8	–	11.1	16.7
Hydrobiosidae	*Atopsyche*	L	P	–	–	3.7	–	–	–	–	5.6
Hydropsychidae	*Ceratopsyche*	L	F	–	–	–	–	81.5	–	–	–
Hydropsychidae	*Hydropsyche*	L	F	–	–	14.8	–	274.1	16.7	–	16.7
Hydropsychidae	*Leptonema*	L	F	–	–	14.8	27.8	7.4	–	–	–
Hydropsychidae	*Smicridea*	L	F	7.4	–	174.1	33.3	3.7	5.6	322.2	622.2
Hydroptilidae	*Ochrotrichia*	L	PScp	44.4	–	25.9	66.7	22.2	–	25.9	27.8
Leptoceridae	*Atanatolica*	L	GS	7.4	22.2	–	–	11.1	133.3	–	294.4
Leptoceridae	*Leptocerus*	L	S	–	38.9	70.4	11.1	11.1	16.7	503.7	1161.1
Leptoceridae	*Nectopsyche*	L	GS	–	–	–	–	–	–	–	–
Leptoceridae	*Oectis*	L	GS	–	–	–	–	7.4	5.6	–	–
Limnephilidae		L	GS	–	–	–	11.1	–	–	–	–
Polycentropodidae		L	F	–	5.6	–	–	3.7	16.7	25.9	11.1
Xiphocentronidae	*Xiphocentron*	L	F	–	–	–	33.3	–	–	–	–

Lepidoptera											
Pyralidae	*Petraphila*	L	S	11.1	5.6	3.7	–	3.7	11.1	7.4	11.1
Coleoptera											
Dryopidae	*Helichus*	A	GScp	–	–	3.7	–	3.7	16.7	–	–
Elmidae	*cylloepus*	A	GScp	–	–	–	–	–	–	–	11.1
Elmidae	*Heterelmis*	A	GScp	–	–	66.7	55.6	111.1	–	74.1	72.2
Elmidae	*Macrelmis*	A	GScp	18.5	–	–	–	–	138.9	–	22.2
Elmidae	*Phanocerus*	A	GScp	–	–	–	–	–	–	7.4	–
Elmidae	*Ordobrevia*	A	GScp	–	–	–	–	–	5.6	–	–
Hydrochidae	*unknown*	A	GScp	–	–	–	11.1	22.2	0.0	–	5.6
Hydrophilidae	*Enochrus*	A	GScp	–	–	–	–	–	83.3	–	–
Amphizoidae	*Amphizoa*	L	P	–	–	–	–	–	33.3	–	–
Dyticidae	*Laccophiles*	L	P	–	–	–	–	–	5.6	–	–
Elmidae	*Cleptelmis*	L	GScp	–	–	–	–	–	50.0	–	–
Elmidae	*Disersus*	L	GScp	–	–	–	–	–	5.6	–	–
Elmidae	*Heterelmis*	L	GScp	11.1	16.7	–	–	–	138.9	–	–
Elmidae	*Macrelmis*	L	GScp	–	–	11.1	22.2	7.4	33.3	7.4	–
Elmidae	*Microcylleopus*	L	GScp	–	5.6	18.5	233.3	388.9	50.0	18.5	55.6
Elmidae	*Optioservus*	L	GScp	–	–	11.1	5.6	3.7	–	14.8	27.8
Elmidae	*Phanocerus*	L	GScp	–	–	7.4	11.1	63.0	–	3.7	11.1
Elmidae	*Rhizelmis*	L	GScp	–	–	–	–	18.5	–	–	–
Elmidae	*Staphylinidae*	L	GScp	–	–	3.7	–	–	–	–	–
Gyrinidae	*Dineutus*	L	P	3.7	–	–	–	–	–	–	–
Psephenidae	*Psphenops*	L	Scp	–	–	–	16.7	–	5.6	11.1	16.7
Ptilodactylidae	*Anchytarus*	L	S	11.1	–	11.1	–	200.0	27.8	–	11.1
Scirtidae	*Prionocyphon*	L	GS	3.7	–	–	–	–	5.6	–	–
Diptera											
Athericidae	*Atherix*	L	P	–	–	–	–	25.9	–	–	–
Blepharoceridae	*Limonicola*	L	Scp	74.1	–	133.3	16.7	114.8	–	18.5	16.7
Blepharoceridae	*Limonicola*	L	Scp	–	–	–	–	25.9	–	–	–
Blepharoceridae	*Limonicola*	L	Scp	–	–	–	–	33.3	–	–	–
Blepharoceridae	*Limonicola*	L	Scp	–	–	–	–	33.3	–	–	–
Ceratopoginidae	*Atrichopogon*	L	GP	7.4	–	–	–	–	–	–	–
Ceratopoginidae	*Bezzia*	L	P	22.2	5.6	25.9	22.2	218.5	172.2	3.7	–
Chironomidae	*Ablabesmyia*	L	GP	463.0	127.8	970.4	1172.2	2240.7	2127.8	1122.2	1611.1
Dixidae	*Dixa*	L	P	–	–	–	–	–	5.6	–	–
Dolichopodidae	*Rhaphium*	L	P	–	–	–	–	3.7	27.8	–	–
Empididae	*Chelifera*	L	GP	–	–	3.7	–	44.4	–	–	5.6
Empididae	*Hemerodromia*	L	GP	3.7	–	–	–	–	–	–	–
Empididae	*Oreogeton*	L	P	–	–	–	44.4	3.7	–	–	–
Empididae	*Rhamphomyia*	L	P	–	–	–	50.0	–	–	–	–
Ephydridae	*Ephydra*	L	GScp	3.7	–	–	11.1	–	5.6	–	–
Psychodidae	*Maruina*	L	GScp	22.2	11.1	7.4	11.1	48.1	–	22.2	16.7
Psychodidae	*Pericoma*	L	G	0.0	5.6	–	–	3.7	–	–	–
Muscidae	*Limnophora*	L	P	7.4	–	33.3	–	–	22.2	14.8	5.6
Muscidae	*Lipse*	L	P	–	–	–	–	3.7	–	–	–
Simuliidae	*Prosimulium*	L	F	140.7	16.7	77.8	183.3	381.5	–	448.1	227.8
Simuliidae	*Simulium*	L	F	377.8	27.8	18.5	38.9	688.9	11.1	448.1	44.4
Simuliidae	*Simulium*	L	F	14.8	16.7	81.5	50.0	7.4	–	103.7	22.2
Tabanidae	*Chrysops*	L	P	–	–	3.7	–	–	–	7.4	–
Tabanidae	*Tabinus*	L	P	–	–	–	–	11.1	5.6	–	–
Tipulidae	*Helurisa*	L	P	–	–	–	–	–	–	25.9	–
Tipulidae	*Hexatoma*	L	P	–	–	–	–	–	–	–	5.6
Tipulidae	*Limnophila*	L	P	–	–	–	11.1	–	–	–	–
Tipulidae	*Tipula*	L	SG	–	–	–	–	14.8	11.1	7.4	–
Total average density (ind. m $^{-2}$) for riffle and bank habitat types				**2014.8**	**1016.7**	**3074.1**	**4461.1**	**7400.0**	**4583.3**	**5511.1**	**7205.6**
				Pichan		**Alambi**		**Tandayapa**		**Mindo**	

APPENDIX B

PROTOCOLS FOR THE ASSESSMENT AND MONITORING OF HIGH GRADIENT STREAMS IN THE PICHINCHA PROVINCE, ECUADOR.

Introduction

The protocols presented here are designed to investigate river health within the cloud forest region of the Pichincha Province in northwestern Ecuador. The objective of this document is to provide a standardized methodology that is logistically (time and energy) efficient and replicable. The goal is to establish a monitoring effort and a framework within which future data may be analyzed over time to gain a deeper understanding of natural and human induced disturbances and the impacts of these on river health. Included here are the protocols for monitoring physical / chemical parameters and biological parameters including populations of benthic macroinvertebrates (retained by mesh size > 200-500 micrometer mesh) and coliform bacteria.

Site Selection

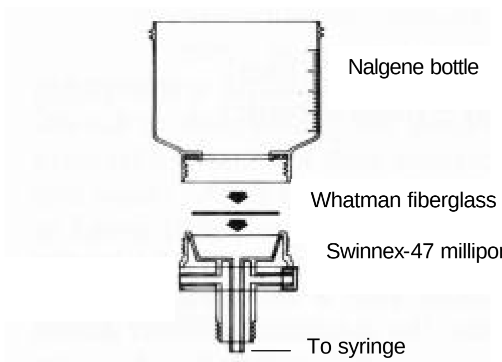
Appropriate sample sites within a watershed need to be selected. A study can be designed so as to have an impacted reach of a stream to compare with an unimpacted or “reference” reach. Reaches within the same stream are chosen when the interest at hand is to monitor a point source of pollution. However, an alternative to this design is to sample sites in two different streams. If this is the case, it is important that the two streams are as similar as possible so they can be compared. Important characteristics to consider include: 1) gradient or slope of reach; 2) substrate (e.g. cobble dominated reach will have different macroinvertebrates than a sand-dominated substrate); 3) stream order; 4) permanent or intermittent. Be sure to take coordinates of the reach sampled with a GPS and to record these in Lat/Long in your field notebook.

Physical Parameters

Equipment / Materials. YSI data logger and sonde, D batteries for the data logger, Whatman fiberglass filters, Swinnex-47 millipore filter, 250ml Nalgene plastic vials, Syringe (as vacuum), Aluminum foil envelopes for fiberglass filter, Propeller-type meter (or Fluorescein dye or float for measuring velocity), stop watch, Zigzag method data sheets, Meter stick, ruler (cm), densiometer, altimeter (DO), forceps, field notebook, clip board, pencil.

Procedures. Collect the following physical parameters: temperature (max, min ºC), total suspended solids (TSS, mg l^{-1}), Sketch of study reach, river profile (representative of channel form), velocity (m/s), and pebble count (description of bed materials). Temperature data will be measured along with the chemical parameters using the YSI data logger and sonde (see below).

TSS. Measure TSS by filtering a 500 ml sample of well-mixed stream water through a Swinnex-47 millipore filter in which a pre-weighed Whatman fiberglass filter will be placed. Vacuum filtration can be simulated using a syringe attached to the bottom of the Swinnex filter. The residue retained in this filter should be dried in an oven at 103 to 105° C. The filter is cooled to room temperature and then weighed again.

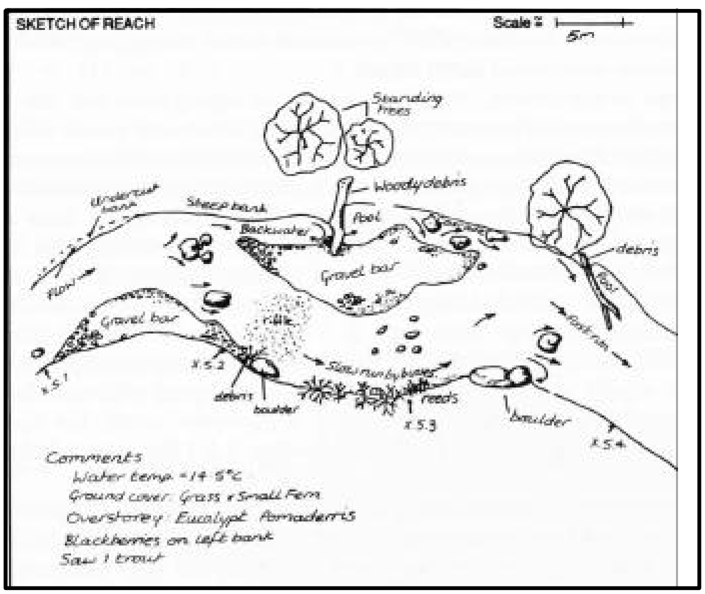


Analysis. The increase in weight to the filter represents the suspended solids or concentration (C_s) which is expressed in terms of sediment mass per measured volume of water-sediment mix (mass in grams and volume is in liters):

$$C_s\ (\text{mg/l}) = \frac{(\text{Mass of filter + sediment}) - (\text{mass of filter})}{\text{Volume of water-sediment mix}} \times 10^3$$

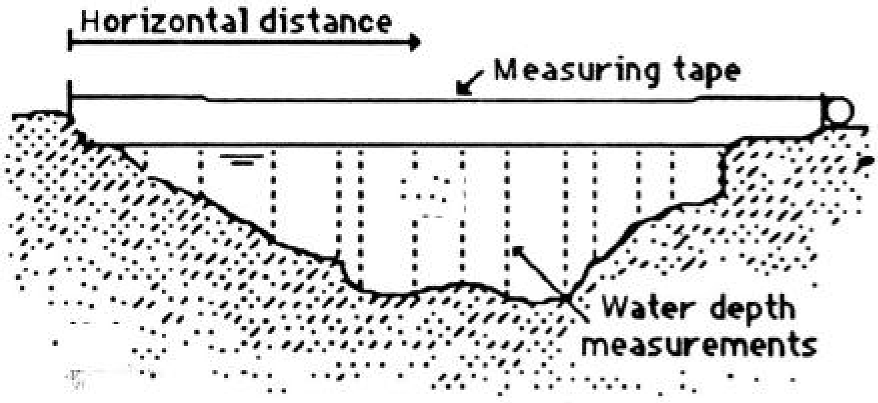
When sampling streams for suspended sediment it is important to obtain a sample which reflects the stream's sediment load and therefore, samples should be taken that represent an average for the section because the sediment concentration will vary with depth and across the section. In high gradient streams, this may be easier than in lower elevation streams. It is recommended to collect numerous samples (particularly during high flows) for example every 20 minutes to get a range of the variability around the mean. Average TSS concentrations of 25 mg/L has been suggested as an indicator of unimpaired stream water quality (Holmbeck-Pelham and Rasmussen 1997) however, some states us 50 mg/L.

Sketch of study reach. Sketch the reach in which you are conducting the study including details such as landuse types and percentages, canopy cover (use a densitometer if available), recent rain, livestock damage, impact sources, stream width and depth, slope and wildlife as suggested in this illustration below:



Analysis. Describe landuse on both sides of stream and percentage of landuse types (see physical data sheet and reach sketch).

River profile. Within the chosen reach of study, select three to five sites for measuring cross-sections (fewer will be needed in uniform reaches). The cross-sectional profile will be obtained by using a measuring tape and meter stick. Stretch the measuring tape across the stream from bank to bank and measure the distance from the bed to the water surface using the meter stick every .50 m along the tape.



Analysis. The data collected from the several cross-sectional profiles will represent the channel form which can be monitored over time for erosion. Computer programs exist, such as XSECT in AQUAPAK, that will plot cross-sectional profiles using present water depths as the vertical heights. The program will calculate area, wetted perimeter, hydraulic radius and a hydraulic depth for each section and as an average for the reach.

Velocity. The recommended method for measuring stream velocity for high gradient streams is the propeller-type meter because they are less likely to become entangled with debris than others. If the propeller-type meter is not available, use a Fluorescein colored dye which will be poured into the water and its movement timed. If dye is unavailable, one can use the float method to measure velocity by observing the time required for floating an object a known distance downstream. Half-filled bottles or oranges may be used however, it is ideal to have a float that moves with the same velocity as the water at the stream surface. Select a suitable (relatively straight) reach with a selected distance marked at the bank at each end. Select the distance that is long enough to have at least a 20 second travel time. Place the float at the midpoint of the stream width and conduct several runs to obtain an average.

Analysis. The surface velocity is calculated as:

$$V \quad \frac{L}{T}$$

Where *L* is measured reach length in meters, *t* is travel time in seconds and V is expressed as m/s. A correction coefficient (*k*) is used to account for the higher surface velocity as compared to the mean velocity and ranges from 0.80 for rough beds to .90 for smooth beds. However, 0.85 is commonly used but for mountain streams 0.67 has been used. It is recommended to use 0.76, an average of the two.

Pebble count. Conduct a pebble count (Harrelson et al. 1994; Bevenger and King 1995) using the zigzag method to estimate particle size distribution of the streambed. For each reach, a zig-zag pattern of transects across the channel is followed and particles are measured on a toe-to-heel spacing until 100 pebbles are collected. Step by step procedure follows:

1) For each reach choose a random location on the bank. Then identify an upstream target point on the opposite bank that can be use to guide you in a straight line while sampling.
2) Pace off 7 feet (3 to 4 steps depending on your pace) and reach over the toe with your hand without looking down and pickup the first pebble touched and measure it in millimeters. The particles are tallied by using the Wentworth size classes (see Pebble Count data sheet).

3) Assign the particle sample to the appropriate Wentworth size class by measuring the intermediate axis (neither the longest nor shortest of the three mutually perpendicular sides of each particle picked up). Measure embedded particles or those too large to be moved in place. This is most efficiently done with two people so that one person can measure and call out to a notetaker who will then tally the measurement by size class.
4) Replace the rock and sample another pebble after your next pace and continue working across and up the stream until you reach the bank.
5) Locate another target across the channel (where the survey began) and work across and up the stream.
6) This zig-zag technique will be repeated until 100 pebbles have been collected. The pebble count data form should be used to record the count.

Analysis. Plot the data on a graph as a cumulative size distribution curve by plotting the cumulative percent finer on the y-axis and particle size (expressed as the endpoint of each size range) on the x-axis. The frequency distribution represents the percent of the stream bed covered by particles of a certain size as each pebble represents a percentage of the bed substrate.

Chemical parameters:

Use the YSI sonde and data logger to collect pH, conductivity, dissolved oxygen and temperature data *in situ* at 15 minute intervals over a four day period. Read the YSI sonde and data logger manual for more information on use of this equipment and on the methodology for calibration of the different probes. If further chemical analysis in a laboratory is warranted (e.g. oil spill) and possible take water samples (125 ml) and freeze for chemical oxygen demand, total recoverable carbons and total petroleum hydrocarbons analysis in the laboratory.

Analysis. The YSI sonde and data logger come with a computer program for analysis of the chemical parameters (for PC computers only-will not work on Macintosh).

Biological Parameters

Equipment / Materials. D-ring aquatic dip net, no. 30 mesh (595 - µm openings), 0.3 meter width (approximately 1 foot), 500 μm sieve, wash bucket, 95 % ethanol and/or 10% formalin, Whirl Pack bags (or plastic bags and rubber bands), forceps, scintillation vials, forceps, white sorting pans, stopwatch, EasyGel coliform gels, field notebook, pencils, fist aid kit.

Procedures

Macroinvertebrates. Select a 100 meter in stream segment that has no major tributaries. All unique habitats (riffles – cobble substrate, riffles – boulder substrate, riffles – bedrock substrate, snags, soft sediment bottom, banks and root mats, leaf packs, submerge macrophytes, etc.) should be sampled to address habitat availability and proportion of habitat within the reach. A suggested number of samples for each habitat is 3 as a minimum and 5 as a target. Once the types of macroinvertebrate habitat have been designated, estimate the proportion or percentage of the habitat within the reach so that a weighted average can be calculated. For example, in a hypothetical reach suppose 30% habitat is cobble, 10% bedrock and 60% is boulder. The stream weighted average for each of these habitats would be calculated by multiplying by 0.3 for cobble, 0.1 for bedrock and 0.6 for boulder habitats.

1) Collect the macroinvertebrate samples with a standard 30 centimeter D-frame kick net (500 μm mesh) facing upstream by disturbing a 30 x 30 cm (0.090 m^2) area of substrate for 30 seconds.
2) Remove larger rocks and wash by hand in bucker or pan to remove all macroinvertebrates.
3) After a sample is collected, rinse the end of the net into a plastic bucket or pan and carefully remove all large organic and inorganic material after each large particle has been closely washed and inspected for organisms. This will insure that the researchers have removed all organisms that may be clinging to the inside sampler and to the larger particles and are added to the sample.
4) Pour the contents of the bucket through a 500 μm mesh sieve to remove the water.
5) Take the sample from the sieve and place in a plastic bag (preferably in Whirl Pak bags but simple plastic bags and rubber bands will be sufficient) that has been prepped with:

a. a 10% solution of formalin for a fixative preservative (specimens should remain in the fixative for a minimum of 2-4 days). Be sure to have at least twice as much formalin volume as specimen volume in each sample. It is best to use formalin for fixing the organisms and later transferring the samples to a 70% ethanol solution for preservation however, ethanol may be used in place of formalin if the researcher so desires.

b. a card stock label that has the location (name of stream), the reach (downstream or upstream and reference or impacted) the site (# from the most downstream to upstream within each reach), and date written in pencil.

6) In the lab, sort the samples by using different size sieves to separate out larger particles.

Subsampling Procedure (Barbour and Gerristen 1996). The purpose of following the sub-sampling procedure is to reduce bias so that a random representative subsample of macroinvertebrates from the sample. The subsample is a minimum of 100 individual organisms although a larger subsample can be taken if necessary (researchers choice depending on preference, budget, and sample characteristics) however be sure to use the same subsample at all sites for comparative analysis.

1) In the lab, rinse the sample of macroinvertebrates and debris with water using 500 μm mesh sieve.
2) Using a spoon or a butter knife, divide the sample into approximately four equal sections on the surface of the sieve-screen. The sample is now divided into ¼ subsamples.
3) Remove one of the ¼ subsamples and begin to sort this sample under a microscope.
4) Remove the macroinvertebrates with forceps and roughly sort them to order level and place each taxon into glass scintillation vials with a label and 70% ethanol.
5) Be sure to count and record the number of individuals within each taxon. It is important that at least one hundred individuals are sorted

for the sample. If there are tens of individuals in the ¼ subsample then add an additional ¼ subsample from the sieve as needed. If there are thousands of individuals, then you will need to further subsample by taking the ¼ sample and re-wash in the sieve and divide into ¼ subsamples. Remember that the subsamples are now 1/16 of the original sample. Be sure to preserve all of the remaining subsamples with labels.

Analysis (Hauer and Resh 1996). Identify macroinvertebrates to family level. Use local keys for taxonomic identification if available along with Merritt and Cummins 1984. Enumerate the selected taxa from each sample collected and:

1) Calculate mean density and standard deviation for each selected taxon by habitat.
2) These data for the macroinvertebrate assemblages (e.g. abundance, taxa richness) can be used to calculate population descriptors. Calculate the Shannon-Wiener index and the Simpson's index. Both are relative measures of species richness and equitability.
3) The Shannon-Wiener index (H') is calculated as: H'=-? *pi* log *pi*. Where *pi* is the proportion of the total number of individuals in the *i*th species.
4) Simpson's index (?) is the probability that any two individuals picked at random will be of the same species and is calculated as: ?= ? p^2 *i* and is a measure of how individuals in a sample are concentrated into a few species.
5) Calculate biomass by measuring individuals to the nearest size class

in mm (easily done by taping graph paper to bottom of Petri dish and counting the number of squares or millimeters) and multiply by described weights for each taxon.

6) EPT Index (Plafkin et al. 1989) is a count of the number of taxa in each order of Ephemeroptera, Plecoptera, and Trichoptera and is a relative measure of the presence and diversity of pollution-sensitive macroinvertebrate taxa. EPT diversity increases with water quality however note that with organic enrichment, this index may be artificially inflated and that the Order Plecoptera is not as diverse in South America as it is in North America.
7) Trophic metrics will provide more information about the community than taxonomic metrics because dominant feeding groups can indicate a disruption in the community that is responding to a food source. Calculate percent of filterers (Plafkin et al. 1989) and percent shredders.

Bacteria. Measure coliform bacteria were using the EASYGEL technique. Take water samples and keep cold/refrigerated until they can be added to the EASYGEL solution and incubated at elevated room temperatures between 24 to 48 hours. All pink and purple colonies will be counted to calculate total coliform and total purple dots to calculate *E. Coli* or fecal coliform per mL of water. Be sure to follow the specific guidelines provided by EasyGel. An incubator can be assembled in the field with a cardboard box, a light bulb and an electrical outlet.

Analysis. In the state of Georgia, 200 colonies per 100 ml of sample water is standard from May thru October and 1000 colonies per 100 mL from November thru

April.

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Una evaluacíon visual de los ríos

Nombre del (la)
Dueño/a____
Nombre del
Ayudante_______________________________Fecha____________________
Localidad del
Tramo____
Areá ecologico__________________Areá de
drainaje________________Pendiente_____
Sitío de referencía
____

Típo de uso de la tierra (%): Caña_______ Cultivación en lineas_______
Pasto_______ Selva_______ Casas_______ Reserva_______ Otra_______

Condiciónes del tiempo(hoy)__________________ Los ultimós 2-5
días_______________
Ancho del canal activo________________
Sustrato dominante: piedra _____ grava _____ arena ____ cieno______ lodo _____

Dibujo del sitío

Physical data sheet and reach sketch

Name of Owner (s) ____

Surveyors ____________________________Date __________________

Locality____

Ecological area________________Drainage area______________Slope_____

Reference site ____

Landuse type (%): Sugar cane_______ **Agriculture**_______ **Pasture**_______

Forest_______ **Houses**_______ **Protected**_______ **Other**_______

Weather conditions (today)_______________ last 2-5 days ______________

Active stream width _______________

Dominant substrate: rock _____ gravel _____ sand ____ silt______ clay _____

Sketch of reach

Pebble count data and key											
Reach Name: Page:				Date surveyed:				Surveyors:			
Particle Size (or type)	**Number from Zig-Zag survey (stop at 100)**										**Totals**
	1-10	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**	
< 2 mm											
2 - 4 mm											
4 - 8 mm											
8 - 11 mm											
11 - 16 mm											
16 - 22 mm											
22 - 32 mm											
32 - 48 mm											
48 - 64 mm											
64 - 90 mm											
90 - 128 mm											
128 - 256 mm											
> 256 mm											
bedrock											
small wood <15 cm dia.											
large wood >15 cm dia.											
other (?) ____________											

Particle Description	Particle Size
M - Silt/clay	muck
S - Sand	< 2 mm
P - Pea gravel	4 - 16 mm
G - Large gravel	16 - 64 mm
C - Cobble	64-256 mm (bigger than a softball)
B - Boulder	>356 mm (bigger than a basketball)
BR - Bedrock	

Other Material	Particle Size
L - Single Log	> 15 cm diameter
LJ - Log jam	
SW - Small wood	< 15 cm diameter
R - Roots	
RJ - Rock jam	64-256 mm (bigger than a softball)

Bacteriological Datasheet				
Collector				
Watershed				
Stream				
Date				
Time				
Reach				
Site				
Weather				
Water temperature (ºC)				
Incubation temperature (ºC)				
Incubation period (hours)				
Observations*				
Replicate #	**Sample Volume (mL)**	**# E. coli colonies/plate (dark blue - purple)**	**# General coliform colonies/plate (pink - dark red)**	**# blue - green colonies/plate**
1				
2				
3				
Blue-green colonies may include important genera in the Enterobacteriaceae family (Salmonella, Shigell or others).				
General coliform colonies may include such genera as Klebsiella, Citrobacter and Enterobacter				
If more than 200 colones per plate, record ad TNTC (too numerous to count).				
* Note any evidence of rainfall and runoff within the previous 48 hours				
* This number may be divided by the sample volumen and multiplied by 100 for comparison to EPA Standards				

Drinking water standards for wome water quality characteristics (Georgia)		
Dissolved Oxygen	5.0 mg/l average 4.0 mg/l minimum	GA water quality standards
Temperature	90ºF / 32.2ºC	GA water quality standards
pH	6.0 - 9.5	GA water quality standards
Fecal coliform	200 col/100 ml (May-Oct) 1000 col/100ml (Nov-April)	GA water quality standards
Phosphorus	no standard for GA	standards are waterbody specific
Total Nitrogen	4.0 mg/l	GA water quality standards
Nitrate	10 mg/l	Federal Drinking Water Standard
Metals:		Federal Drinking Water Standard
Arsenic	0.05	
Cadmium	0.01	
Chromium	0.05	
Copper	1	
Lead	0.05	
Mercury	0.002	
Silver	0.05	
TDS	500 mg/l	

Conversion tables for calibrating the DO probe on the YSI Data logger.

PRESSURE			ALTITUDE		CALIBRATION VALUE
Inches Hg	mm Hg	Millibars	Feet	Meters	Percent Saturation
30.23	768	1023	-276	-84	101
29.92	760	1013	0	0	100
29.61	752	1003	278	85	99
29.33	745	993	558	170	98
29.02	737	983	841	256	97
28.74	730	973	1126	343	96
28.43	722	963	1413	431	95
28.11	714	952	1703	519	94
27.83	707	942	1995	608	93
27.52	699	932	2290	698	92
27.24	692	922	2587	789	91
26.93	684	912	2887	880	90
26.61	676	902	3190	972	89
26.34	669	892	3496	1066	88
26.02	661	882	3804	1160	87
25.75	654	871	4115	1254	86
25.43	646	861	4430	1350	85
25.12	638	851	4747	1447	84
24.84	631	841	5067	1544	83
24.53	623	831	5391	1643	82
24.25	616	821	5717	1743	81
23.94	608	811	6047	1843	80
23.62	600	800	6381	1945	79
23.35	593	790	6717	2047	78
23.03	585	780	7058	2151	77
22.76	578	770	7401	2256	76
22.44	570	760	7749	2362	75
22.13	562	750	8100	2469	74
21.85	555	740	8455	2577	73
21.54	547	730	8815	2687	72
21.26	540	719	9178	2797	71
20.94	532	709	9545	2909	70
20.63	524	699	9917	3023	69
20.35	517	689	10293	3137	68
20.04	509	679	10673	3253	67
19.76	502	669	11058	3371	66

	kilo Pascals	mm Hg	millibars	inches H,0	PSI	inches Hg
1 atm	101.325	760.000	1013.25	406.795	14.6960	29.921
1 kiloPascal	1.00000	7.50062	10.0000	4.01475	0.145038	0.2953
1 mmHg	0.133322	1.00000	1.33322	0.535257	0.0193368	0.03937
1 millibar	0.100000	0.750062	1.00000	0.401475	0.0145038	0.02953
1 inch H,0	0.249081	1.86826	2.49081	1.00000	.0361	0.07355
1 PSI	6.89473	51.7148	68.9473	27.6807	1.00000	2.0360
1 inch Hg	3.38642	25.4002	33.8642	13.5956	0.49116	1.00000
1 hectoPascal	0.100000	0.75006	1.00000	0.401475	0.0145038	0.02953
1 cm H,0	0.09806	0.7355	9.8×10^{-7}	0.3937	0.014223	0.02896

Additional conversion tables:

Velocity

1 m/sec	= 3.6 km/hr	1 ft/sec	= 0.6818 mi/hr
	= 2.237 mi/hr		= 1.097 km/hr
1 km/hr	= 0.2278 m/sec	1 mi/hr	= 1.4767 ft/sec
	= 0.9113 ft/sec		= 0.4470 m/sec

Discharge

1 m^3/sec = 35.32 cfs

1 cfs = 0.0283 m^3/sec
= 28.32 liters/sec
= 2447 m^3/day

1 cfs for 1 day = 1.98 ac-ft

Hydrologic Information

g = 32.2 ft/sec^2 = 9.82 m/sec^2
1 in/hr of runoff from 1 acre = 1 cfs
1 ac-ft = 325,851 gal
At 70°F, properties of water include:
ρ, density, 1.94 slugs per ft^3
γ, specific wt = 62.3 lb/ft^3 = 1000 kg/m^3
μ, dynamic viscosity = 2.04×10^{-5} lb-sec/ft^2
ν, kinematic viscosity = 1.05×10^{-5} ft^2/sec

Temperature

°F	0	10	20	30	32	40	50
°C	−17.8	−12.2	−6.7	−1.1	0.0	4.4	10.0

°F	60	70	80	90	100
°C	15.6	21.1	26.7	32.2	37.8

°C	−10	0	10	20	30	40
°F	14.0	32.0	50.0	68.0	86.0	104.0

°C = 5/9(°F − 32)
°F = 9/5(°C) + 32
°K = °C + 273

Area

1 mm^2 = 0.01 cm^2 = 0.00155 in^2	1 in^2 = 6.452 cm^2
1 cm^2 = 100 mm^2 = 0.1550 in^2	1 ft^2 = 144 in^2 = 929.0 cm^2
1 m^2 = 10000 cm^2 = 1550 in^2 = 10.76 ft^2	1 yd^2 = 9 ft^2 = 8361 cm^2
1 ha = 10000 m^2 = 2.471 ac = 0.00386 mi^2	1 ac = 43560 ft^2 = 4840 yd^2 = 4047 m^2 = 0.4047 ha
1 km^2 = 247.1 ac = 0.3861 mi^2	1 mi^2 = 27878400 ft^2 = 640 ac = 259 ha = 2.590 km^2

Volume

1 cm^3 = 0.0610 in^3	1 in^3 = 16.39 cm^3
1 m^3 = 35.31 ft^3 = 264.2 U.S. gal	1 ft^3 = 1728 in^3 = 7.480 U.S. gal = 28317 cm^3 = 28.32 liters
1 ml = 0.0610 in^3	
1 liter = 61.02 in^3 = 0.2642 U.S. gal	

Weight

1 kg = 2.205 lb	1 lb = 0.4536 kg
1 g = 0.001 kg = 0.0353 oz = 0.0022 lb	1 grain = 0.0648 g 1 oz = 28.35 g
1 t = 1000 kg = 2205 lb	1 sht = 2000 lb = 907.2 kg