

EFFECT OF RIPARIAN VEGETATION COVER AND SEASON ON AQUATIC MACROINVERTEBRATE ASSEMBLAGES IN THE ECUADORIAN ANDES

SILVANA ANDREA GALLEGOS SÁNCHEZ

NORWEGIAN UNIVERSITY OF LIFE SCIENCES
DEPARTMENT OF ECOLOGY AND NATURAL RESOURCES MANAGEMENT
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**NORWEGIAN UNIVERSITY OF LIFE SCIENCES
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**EFFECT OF RIPARIAN VEGETATION COVER AND SEASON ON AQUATIC
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Silvana Andrea Gallegos Sánchez

Supervisor: Torbjørn Haugaasen

Co. Supervisor: John E. Brittain

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"If there is magic on this planet, it is contained in water." Loran Eisely

To my family, *Emma* and *Ya-Nua*

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ABSTRACT

The purpose of this study was to investigate the effects of season and changes in the riparian vegetation cover on diversity, structure, temporal variability, and trophic structure of aquatic macroinvertebrate assemblage in the Sambache River, Pasochoa Wildlife Refuge, Ecuador. Macroinvertebrate samples were collected using a Surber bottom sampler during the dry and rainy seasons from sections of the river dissecting three different riparian vegetation types with varying degrees of disturbance: 1) Humid montane forest, 2) Secondary forest near maturity and 3) Disturbed forest with shrubs and pastures. A select set of environmental variables were collected from the same sites. Results show that the Sambache River macroinvertebrate fauna is mainly composed of aquatic insect represented by three orders: Diptera, Ephemeroptera and Trichoptera. Important differences in abundance of several genera were found between the three riparian vegetation types and seasons. *Andesiops* and *Atopsyche* were more abundant in the dry season in sections of the river from humid montane forest sites. *Probezzia* increased its abundance during the rainy season in the three riparian vegetation types. Using a Canonical Correspondence Analysis to assess the effect of environmental variables on aquatic macroinvertebrate assemblages, I found that conductivity and amount of total dissolved solids were the most important parameters explaining macroinvertebrate assemblage structure. Regression analysis showed that genera richness and diversity were influenced by flow velocity, and that the most abundant genera in this study were controlled by a combination of different environmental variables. Trophic guilds were dominated by the collector-gatherers in all section of the river across the two seasons. Predators increased during the rainy season, possibly related to an increased abundance of food resources. This study provides further information on the distribution of macroinvertebrate taxa in the Ecuadorian Andes and their relationship with environmental factors. The study suggests that riparian vegetation may affect assemblage structure and that current land-use change in the region is affecting the composition of the aquatic fauna. I recommend that environmental variables and macroinvertebrates in the Sambache River should be monitored long term to establish better management strategies to protect the watershed and its ecosystem services.

Key words: Andes, aquatic macroinvertebrates assemblages, Pasochoa, Sambache, Ecuador, environmental variables.

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INTRODUCTION

Watersheds in the Andes have been heavily transformed through the conversion of forest for agricultural purposes, especially cattle farming (Buytaert et al. 2006; Harden 2006). This has led to a dramatic loss of natural riparian vegetation and such disturbances to the natural vegetation directly affect the physicochemical properties of rivers dissecting these areas. For example, deforestation may lead to increase sedimentation and runoff that usually is retained by the riparian vegetation (Allan 2004; Naiman & Decamps 1997) and therefore, changes in the particular organic matter, substrate composition and increase in the total amount of water transported annually (Garman & Moring 1991; Harr & McCorison 1979). This may have serious consequences for the resident aquatic macroinvertebrate assemblages. In fact, it has been shown that one of the most important factors defining aquatic macroinvertebrate composition is the extent of riparian vegetation near rivers and it is a primary source of energy. The leaves, branches and vegetation that fall into the river, it converts into organic matter and detritus food resources for the benthos (Dudgeon 1989; Lorion & Kennedy 2009). Riparian vegetation cover also affects water temperature a critical factor in the first stages of development for certain macroinvertebrate taxa (Allan & Castillo 2007). Other studies have shown that rivers with increased sedimentation have lower density of aquatic insects and some macroinvertebrates taxa have drift behavior (Larsen & Ormerod 2010). Some sensitive taxa such as Ephemeroptera, Trichoptera and Plecoptera are found more in areas with lush vegetation cover (Rios & Bailey 2006). And trophic guilds such as the scrapers increase in abundance at deforest sites, where algae is more readily available (Cummins & Klug 1979; Gurtz & Wallace 1984).

Since the macroinvertebrate assemblage composition is so closely associated with habitat conditions and water quality, they have been commonly used as bioindicators in rivers affected by agriculture, pastures and deforestation (Buss et al. 2002; Couceiro et al. 2007; Dance & Hynes 1980). Previous studies in the Neotropics have shown that the composition of the community changed and lower species richness is found in deforested and agricultural lands. The poor species richness of macroinvertebrates is associated with changes in the physical environment and habitat integrity (Bojsen & Jacobsen 2003; Mesa 2010; Miserendino 2001; Nessimian et al. 2008).

However, aquatic macroinvertebrates assemblages are also influenced by flow velocity and seasonality (Resh et al. 1988; Ríos-Touma et al. 2011a). This is especially the case in the tropics where seasonal rainfall is more pronounced than at higher latitudes and cause disturbance effects in the rivers (Jacobsen et al. 2008). In fact, Jacobsen and Encalada (1998) suggested that river flow in Andean streams were more important than other site characteristics in structuring the macroinvertebrate fauna, i.e suggesting that the macroinvertebrate communities are less affected by physicochemical changes in their habitat due to a transformation of the native riparian vegetation. However, macroinvertebrate community diversity and composition and their relationships with the environment is still poorly known in Andean rivers (Allan et al. 2006; Jacobsen 2008).

The purpose of this study was to investigate the effects of season and changes in the riparian vegetation on diversity, trophic structure, temporal variability, and assemblage structure of the macroinvertebrate fauna in the Sambache River in the Ecuadorian Andes. More specifically I wanted to: 1) Describe the composition of aquatic macroinvertebrate assemblages in the Sambache River; 2) Examine differences in richness and abundance of the aquatic benthos between river locations with different riparian vegetation and between seasons; 3) Investigate the influence of environmental factors on the aquatic macroinvertebrate assemblage composition and abundance. I discuss the results in relation to existing information and conclude by recommending strategies to better manage the Sambache watershed.

MATERIAL AND METHODS

Study Area

The current study was conducted in Pasocha Wildlife Refuge (Refugio de Vida Silvestre Pasocha [RVSP]), located in the southeast of the Pichincha Province in Ecuador ($0^{\circ}28'47''S$, $78^{\circ}41'4''W$). The 500 ha protected area encompasses the inside of the cone of the extinct Pasocha volcano and its foothills. The vegetation is a relic of an Andean forest mixed with secondary forest between 2800-4210 masl (Coloma-Santos 2007). The main vegetation types are Humid Montane Forest, Cloudy Montane Forest, Evergreen high Montane Forest and Paramo vegetation. Some important species of plants that one can find in this natural reserve are *Miconia* sp., *Cedrela montana*, *Alnus*

acuminata, *Oreopanax confusum*, *Polylepis reticulata* and *Ceroxylon alpinum* (Valencia & Jorgensen 1992; Valencia et al. 1999). Today, RVSP is surrounded by private pasture for cattle and agricultural fields and some of the Andean vegetation has been replaced by eucalyptus and pine trees, as in other areas of the Andes (Coloma-Santos 2007; Stern 1995). The study area endures two seasons; a rainy season occurring twice a year (Oct - Dec and Mar-May) and a dry season between June and September (INAMHI 2012).

Fieldwork was carried out in the Sambache River, a fourth order river that is born in the Pasochoa Mountains (ca. 4000 masl) inside the protected area (Fig. 1). The river runs through a deep gully until it connects with the San Pedro River in the lowlands (2600 masl). The river streambed is composed mainly of cobble, pebbles and some boulders. In the dry season the flow in the riffles is low and the depth does not reach 0.5 m. Native bamboo (*Chusquea scandens*) predominates in areas where secondary forest is the main riparian vegetation on both sides of the river. In riverine areas without human activity, one can find plants species such as *Miconia* spp., *Axinia macrophylla*, *Rynchosphaera* sp., *Mycianthes* sp., with a mixture of mosses, herbs and epiphytes like some bromeliads and orchids (Valencia & Jorgensen 1992).

The dynamic of this river has been modified by a mixture of natural and anthropogenic means. Two years ago during the rainy season a series of landslides occurred from the base of the crater causing rocks fall downstream, producing pools and natural dams along the river (Simbaña 2012). The boundaries of the protected area have not been defined yet, since the area became only part of the Ecuadorian State three years ago. Downstream (ca. 2800 masl) the river used to be the limit between the wildlife refuge and the farms. However, despite a large proportion of the river being protected by law, the surrounding farms have altered the riverbed to capture the water for cattle farming purposes and human water consumption. They have built artificial embankments, which have significantly diminished the natural flow of the stream. In addition, some riverbanks zones have been changed in to semi-open areas with grasses and pads for the cattle that drink water directly from the river (per. obs).

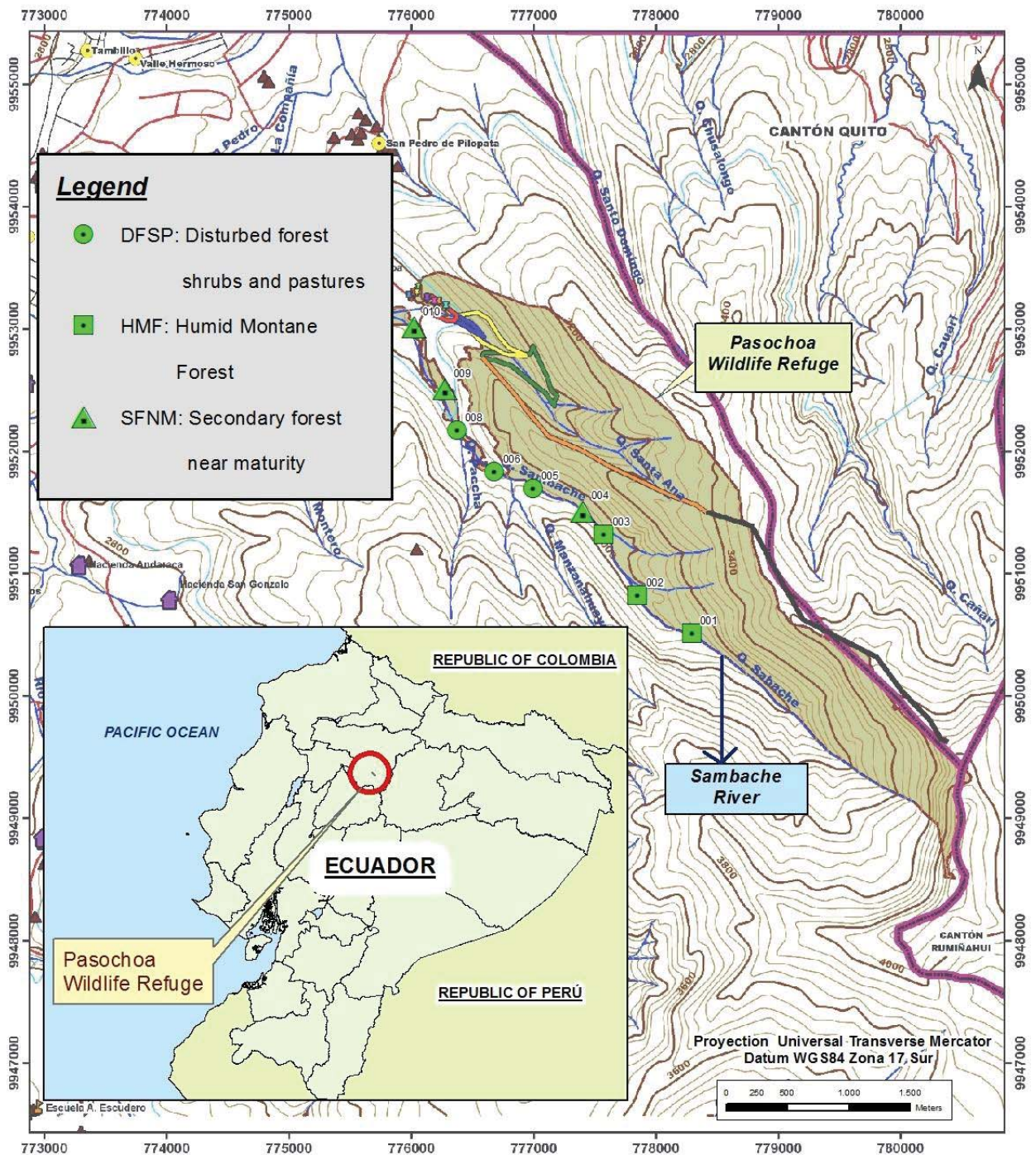
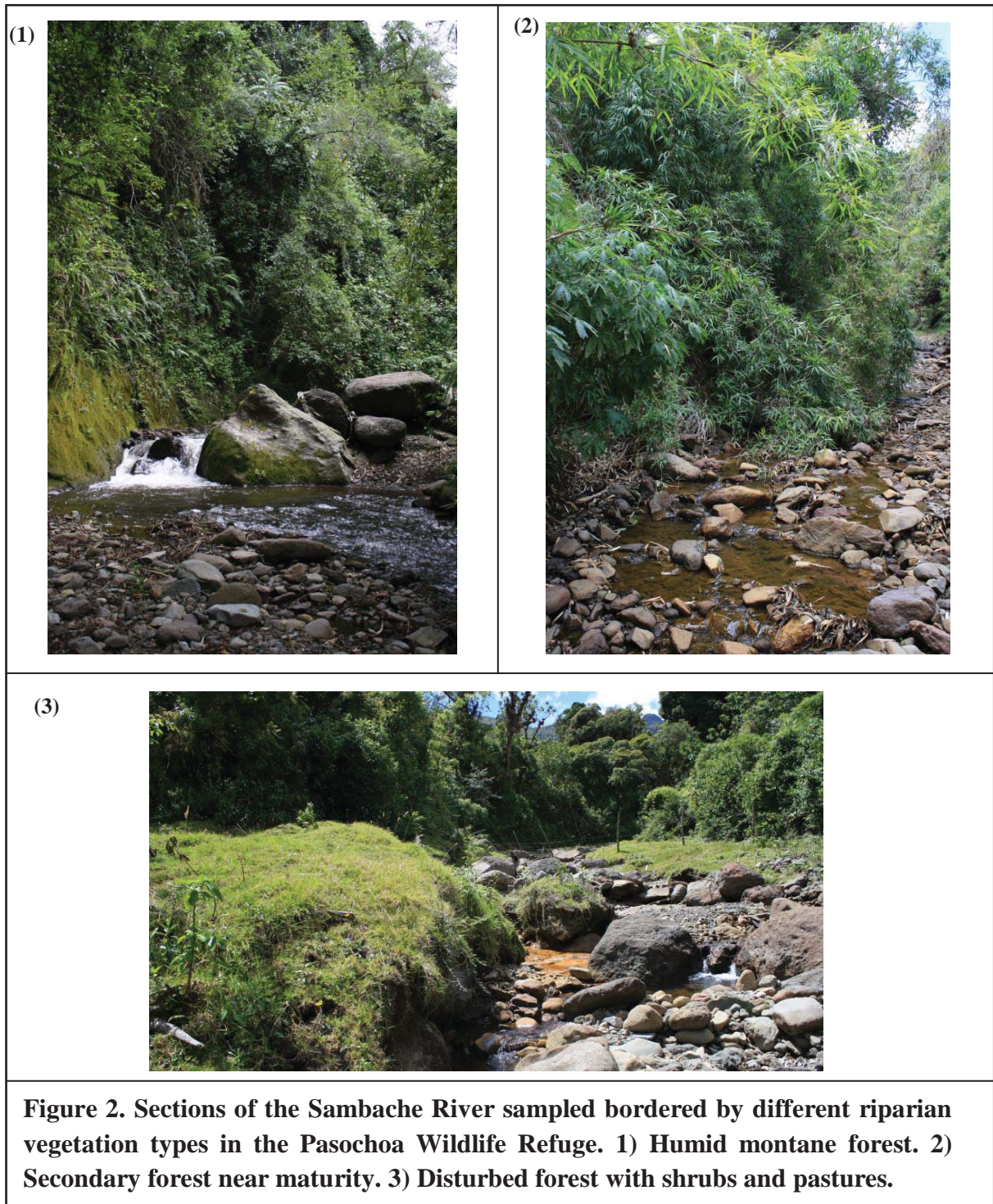


Figure 1. Map of the study area with the Paschocha Wildlife Refuge highlighted in brown. Sites sampled (green figures) along the Sambache River in three different riparian vegetation types.

Field work was carried out during dry season (August) and wet season (November). Nine sampling sites were established within the Sambache river system. To assess potential changes in the macroinvertebrate fauna in responses to changes in the riparian

vegetation, sampling sites were established, within a section of the river bordered by three different types of riparian vegetation: humid montane forest (HMF) (three sites from 3052 to 2766 masl), secondary forest near maturity (SFNM) (three sites at: 2948, 2811 and 2766 masl) and disturbed forest with shrubs and pastures (DFSP) (three sites from 2915 to 2832 masl) (Fig. 2)



Environmental variables

A number of environmental variables, including habitat and catchment characteristics, were measured at each sampling site. The environmental variables were sampled following methods used by Barbour et al. (1999) and Glidden and Burns (1967).

Water temperature (wT), pH, conductivity, total dissolved solids (TDS) and air temperature (aT) were measured in situ at each sample site with a HANNA Portable pH/EC/TDS/Temp tester.

Water samples were taken at each sample site. Four-liter plastic bottles were used to collect water, which was subsequently analyzed at the Faculty of Chemistry Sciences OSP (Oferta de Servicios y Productos) Laboratories in Quito, Ecuador. To satisfactorily preserve water characteristics, samples were transported from the field to the laboratory inside a cooler, on the same day of the sampling. Four important chemicals parameters often related with surrounding land uses were evaluated: nitrates (NO_3), nitrites (NO_2^-), phosphates (PO_4) and biological oxygen demand (BO_5D).

River depth was measured with a wooden rod and width measured with a flexometer. Flow velocity was taken using a floating plastic ball, which was timed over of one meter. This was carried out three times per site to obtain average water velocity at the surface (Glidden & Burns 1967).

The riparian vegetation cover was categorized in four groups: Trees totally covering the river (100%), trees partially covering the river (80%), shrubs partially covering the river (50%), pastures mixed with shrubs covering the riversides (30%).

Benthic macroinvertebrate sampling and identification

Macroinvertebrate sampling. Sampling was done following methods by Resh et al. (1996) and Roldán (1988). The benthic macroinvertebrate fauna was sampled using a Surber bottom sampler net (52x52 mesh; 280 microns). At each of the nine sampling sites, 3 sub-samples (one from the middle of the river and one from each riverside) were collected. Sampling was performed by, disturbing the river substrate for one minute with the foot in the area inside the sampler frame that was put against the current (Roldán 1988). As the substrate (rocks or sand) was removed, the invertebrates were

trapped into the net. Each sample was deposited in a Ziploc bag with 70% alcohol in order to conserve the macroinvertebrate structures.

Laboratory identifications. Identification of the collected specimens was carried out at the Central University of Ecuador and in the Entomology Department at the Gustavo Orcés Museum in Quito using a Stereo microscope (0.8x ~3.5x Zoom ratio: 4.4:1). All individuals were determined to the lowest taxonomic level possible and most of the individuals in the current study are identified to the level of genus. As there is no extensive literature or taxonomic keys for the aquatic macroinvertebrate fauna in Ecuador, keys from South America were used (Dominguez & Fernandez 2009; Roldán 1988). The macroinvertebrates were assigned to feeding guilds following Merritt and Cummins (1996) and Tomanova et al. (2006).

Statistical Analysis

Abundance and estimation of richness were analyzed according to Chao (1984), Gotelli and Colwell (2001) and Magurran (2004). Assemblage diversity was determined using the exponential Shannon diversity index ($\exp H'$) in accordance with Jost et al. (2010) which suggest to convert the value of Shannon (H') to its exponential ($\exp H'$) to see the effective number of species in the sampling. Pielou evenness index was estimated to know the degree of equality or uniformity of the abundance in the community (Pielou 1966). EstimatesS Win 9 (Colwell 2013) and SPADE (Chao & Shen, 2003) were used to perform the calculations.

Rarefaction curves were used to explain how taxonomic richness is expected to increase for in each sample site within the same riparian vegetation cover with the increasing number of individuals collected. The estimation was made using the Chao 1 richness estimator (Colwell et al. 2012). BioDiversityPro version 2 was used to construct the curve base on 2999 randomizations (McAleece et al. 1997).

General Lineal Models were performed to test for differences in mean abundance, richness, \exp Shannon diversity, evenness (random factors) between the three riparian vegetation covers and seasons (fixed factors) using crossed ANOVAs. Subsequently, I performed a Tuckey's post-hoc tests to identify the sources of potential differences. This test was also performed with the macroinvertebrate taxa that accounted for more than 4% of the total abundance.

A constrained ordination analysis, Canonical Correspondence Analysis (CCA) was performed using CANOCO 4.5 software (Ter Braak & Šmilauer 2002). This analysis uses 499 Monte Carlo Permutations ($P < 0.05$) that allowed testing the variability of the environment, making repetitive of regression analysis and correlations with the composition of the community. For this analysis I used the macroinvertebrate abundance and all environmental data previously transformed to Log10, except pH. All environmental variables were combined and tested for collinearity and those with a high inflation factor were removed (>20) (Lepš & Šmilauer 2003). Finally, the environmental variables used were conductivity, TDS, vegetation cover, water and environmental temperature, nitrites and flow velocity.

Stepwise multiple regression analysis was done to analyze which environmental variables were the best predictor of the assemblage composition in terms of richness and diversity. I also carried out this analysis for the most abundant taxa ($>4\%$) found in the community.

IBM SPSS Statistics, version 20, was the software used to analyze the data.

RESULTS

Environmental characteristics of the Sambache River

Appendix 1 summarizes the results of each environmental variable measured in the Sambache River. Only water temperature and vegetation cover differed significantly between the three sections of the river dissecting different riparian vegetation types (Appendix 1). Investigating the effect of season, flow velocity in the Sambache River doubled during the rainy season compared to the dry season and this difference was significant. The interactions riparian vegetation type/season presented no significantly results with the parameters studied.

Macroinvertebrate abundance, richness and diversity

A total number of 7197 individuals were collected in the Sambache River during the dry season (3351) and rainy season (3847), belonging to 57 genera from 37 families and 13

orders (Appendix 2, Fig. 4). Of the specimens collected 98.1% of the specimens were insects. The most abundant orders were Diptera (4872 individuals), Ephemeroptera (1514 individuals) and Trichoptera (415 individuals). These three Orders accounted for 94.5% of all the individuals captured. The Chironomidae was the most abundant family, representing 44.2% ($n=3179$) of the specimens collected. The second and the third most abundant family was Baetidae and Ceratopogonidae accounting for 20.9% ($n=1502$) and 18.6% ($n=1340$) of individuals, respectively. At genus level the midge subfamily of Chironominae, the mayfly genus *Andesiops* and the Diptera genus *Probezzia* were the most abundant genera with 3036 (42.2%), 1212 (16.8%) and 1206 (16.7%) specimens collected, respectively. Coleoptera comprised the highest number of genera ($n=18$), despite the few individuals collected from this group ($n=232$) and Diptera comprised sixteen genera (Fig. 3).

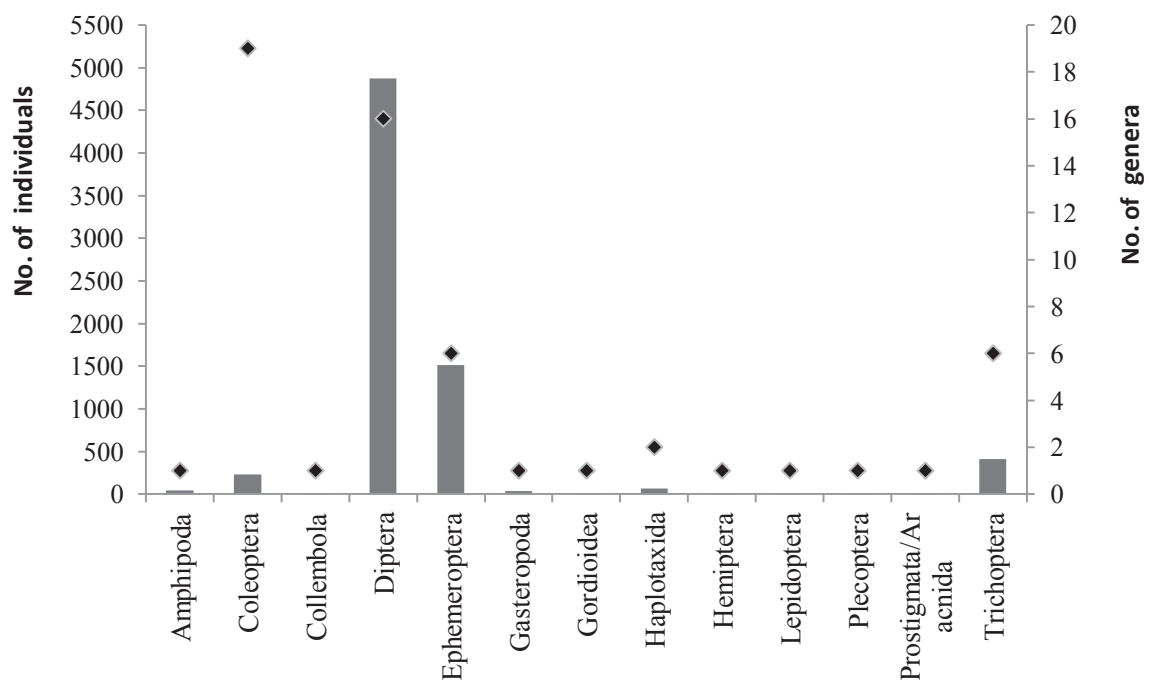


Figure 3. Taxonomic composition of macroinvertebrate assemblages in the Sambache River, Pasocha Wildlife Refuge, Ecuador. The gray bars represent the number of individuals collected from each order (left axis) and the black diamond's indicate the number of genera recorded within each order (right axis).

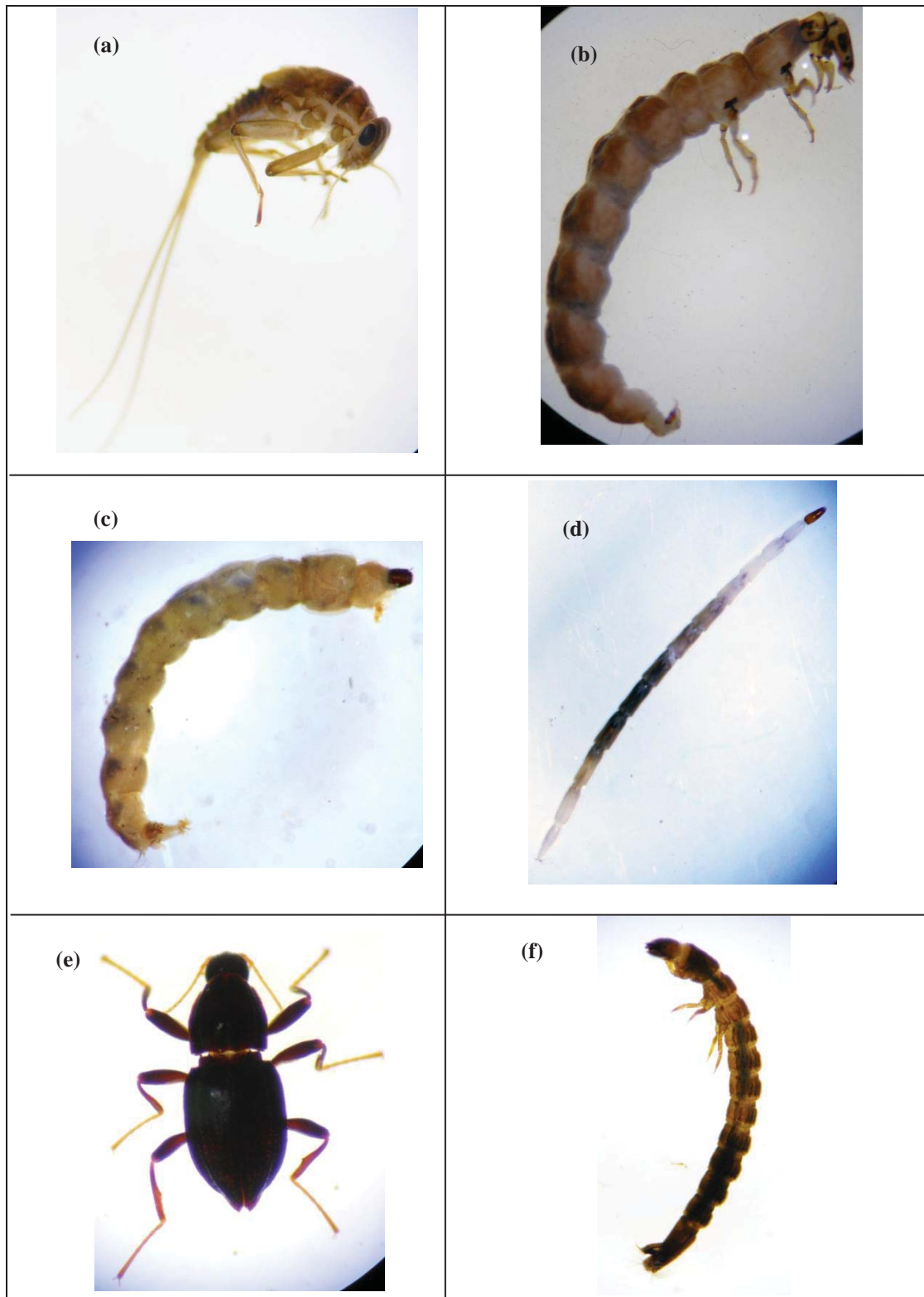


Figure 4. Some of the aquatic macroinvertebrates taxa collected in Sambache River, Pasochoa Wildlife Refuge, Ecuador. (a) Mayfly *Andesiops*, Ephemeroptera. (b) Caddisfly *Atopsyche*, Trichoptera. (c) Midge fly, Chironomidae. (d) Biting midge fly, *Probezzia*, Ceratopogonidae. (e) and (f) riffle beetles, *Austrolimnius* (adult) and *Heterelmis* (larvae), Coleoptera.

Spatial-temporal patterns in macroinvertebrate assemblage structure and composition

The slope of the rarefaction curves typically declined as sample size increased for all sections of the river dissecting different types of riparian vegetation (Fig. 5), but the curves did not approach an asymptote. It is clear, however, that few genera are added to the macroinvertebrate fauna in the section of the river dissecting humid montane forest (HMF) beyond 2500 individuals (Fig. 3). Nevertheless, taxa richness did not differ significantly between river sections and seasons (Table 1).

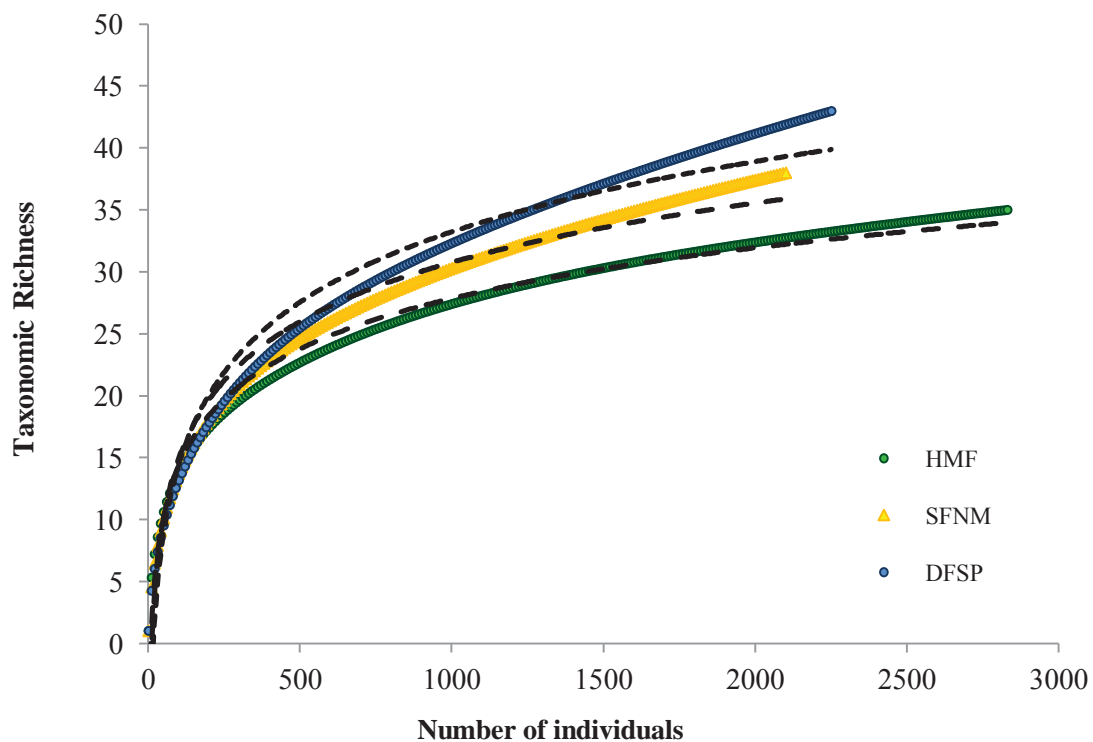


Figure 5. Individual-based rarefaction curves for sections of the Sambache river dissecting humid montane forest (HMF), secondary forest near maturity (SFNM) and disturbed forest with shrubs and pastures (DFSP), with logarithmic (95% C.I) trend lines (dashed lines).

Mean abundance between sections of the river differed significantly, but not between seasons. The riparian vegetation type/season interaction was significant (Table 1). The Tukey's post-hoc test indicated a difference between SFNM and DFSP during the rainy season ($P=0.048$). No significant differences were found for exp Shannon diversity or Evenness (Table 1).

Table 1. Mean (\pm SD) abundance, exp Shannon diversity (exp H'), taxa richness and evenness in humid montane forest (HMF), secondary forest near maturity (SFNM) and disturbed forest with shrubs and pastures (DFSP) for each season, results from GLM crossed ANOVAs.

		HMF	SFNM	DFSP	Riparian vegetation		Season		Interactions	
					F	P	F	P	F	P
Abundance	Dry	522.3 \pm 157.4	322.3 \pm 179.7	272.3 \pm 173.9	5.114	0.03	0.777	0.395	3.675	0.03
	Rainy	423.7 \pm 50.3	614.0 \pm 97.6	244.7 \pm 79.2						
exp H'	Dry	4.7 \pm 0.2	4.3 \pm 1.6	3.8 \pm 0.7	0.81	0.49	3.746	0.077	1.192	0.37
	Rainy	6.3 \pm 2.7	7.0 \pm 3.4	4.8 \pm 0.7						
Richness	Dry	19.2 \pm 2.9	15.1 \pm 4.3	20.0 \pm 3.4	0.19	0.83	3.270	0.096	0.845	0.54
	Rainy	22.9 \pm 4.3	25.7 \pm 3.4	26.2 \pm 9.8						
Evenness J'	Dry	0.3 \pm 0.007	0.3 \pm 0.06	0.2 \pm 0.07	1.548	0.25	2.466	0.142	1.525	0.25
	Rainy	0.4 \pm 0.02	0.3 \pm 0.1	0.3 \pm 0.1						

The abundance of Ephemeroptera and Trichoptera portrayed a significant difference between vegetation types, among seasons and their interactions (Table 2). A Tukey's post-hoc test showed that the mean Ephemeroptera abundance in HMF during the dry season was significantly different to SFNM ($P=<0.001$) and DFSP ($P=<0.001$), in addition, to being significantly different from the abundance recorded in the three types of riparian vegetation types HMF ($P=0.001$) SFNM ($P=<0.001$), DFSP ($P=<0.001$) during the rainy season.

Trichoptera portrayed a similar pattern, with Tukey's post-hoc test indicating that the abundance of this order in HMF was significantly different to SFNM ($P=0.038$) and DFSP ($P=0.034$) during the dry season, in addition to being significantly different from the rainy season samples in all three types of vegetation (HMF: $P=0.028$, SFNM: $P=0.023$, and DFSP: $P=0.032$).

The abundance of important genera such as *Atopsyche*, *Andesiops* and *Probezzia* were significantly influenced by seasons, but only, the two former differed significantly between the riparian vegetation types. In addition, the riparian vegetation type/season interaction was significant for three genera (Table 2). A Tukey's post-hoc test indicated that *Probezzia* was more abundant during the rainy season in the DFSP than the DFSP during the dry season ($P=0.049$), and was less abundant in the HMF during the dry season than the DFSP during the rainy season ($P=0.041$) Meanwhile, *Andesiops* presented a highly significant difference in mean abundance in the HMF collected

during the dry season comparing with the other riparian vegetation types (SFNM: $P < 0.001$; DFSP: $P < 0.001$) and also with the samples taken during the rainy season (HMF: $P = 0.001$, SFNM: $P < 0.001$, and DFSP: $P < 0.001$)

Table 2. Mean \pm SD of abundance of the most important orders and genera based on the results of interactions and mean effects between seasons and riparian vegetation types using GLM crossed ANOVAS ($P < 0.05$). Humid montane forest (HMF), secondary forest near maturity (SFNM) and disturbed forest with shrubs and pastures (DFSP).

		HMF	SFNM	DFSP	Riparian vegetation		Season		Interactions	
					F	P	F	P	F	P
Coleoptera	Dry	9.0 \pm 1.7	5.7 \pm 3.8	17.0 \pm 16.5	0.598	0.57	1.059	0.324	0.655	0.66
	Rainy	15.7 \pm 10.6	14.7 \pm 0.6	15.3 \pm 12.4						
Diptera	Dry	112.7 \pm 34.7	257.7 \pm 187.9	211.0 \pm 91.1	0.596	0.57	4.271	0.061	1.275	0.34
	Rainy	318.3 \pm 45	311.0 \pm 188.5	413.3 \pm 259.1						
Ephemeroptera	Dry	334.0 \pm 109.1	27.3 \pm 36.9	31.3 \pm 12.6	21.581	0.00	13.477	0.003	15.753	0.00
	Rainy	71.0 \pm 60.6	23.0 \pm 11.3	18.0 \pm 17.4						
Tricoptera	Dry	53.0 \pm 9.6	18.3 \pm 11.1	17.7 \pm 14.6	4.311	0.04	5.428	0.038	4.476	0.02
	Rainy	16.7 \pm 12.1	15.3 \pm 7.2	17.3 \pm 17.1						
Chironominae	Dry	77.0 \pm 20.1	202.3 \pm 145.8	197.3 \pm 86.9	1.848	0.2	0.728	0.127	0.815	0.56
	Rainy	114.0 \pm 29.4	183.0 \pm 161	238.3 \pm 159.1						
<i>Andesiops</i>	Dry	293.0 \pm 106.7	26.0 \pm 35.5	12.0 \pm 13.9	18.820	0.00	12.157	0.004	13.757	0.00
	Rainy	55.0 \pm 58.1	16.7 \pm 14.7	1.3 \pm 1.5						
<i>Probezzia</i>	Dry	22.0 \pm 17.6	14.7 \pm 18.6	8.0 \pm 5.6	0.217	0.81	26.968	0.00	5.547	0.01
	Rainy	128.7 \pm 47.1	103.7 \pm 28	125.0 \pm 84.8						
<i>Atopsyche</i>	Dry	53.0 \pm 9.6	18.3 \pm 11.1	16.3 \pm 15.4	4.453	0.04	5.437	0.038	4.504	0.02
	Rainy	16.3 \pm 11.6	14.7 \pm 7.6	16.3 \pm 15.9						

The genus *Atopsyche* presented the same pattern as *Andesiops*. More individuals were found in the HMF during the dry season than the other vegetation types (SFNM: $P = 0.041$; DFSP: $P = 0.03$), and the three types of riparian vegetation collected in the rainy season (HMF: $P = 0.030$, SFNM: $P = 0.022$, and DFSP: $P = 0.030$)

Trophic guild structure in the Sambache River

Seven trophic guilds were recorded from the Sambache River macroinvertebrate fauna. The dominant group was collector-gatherers (C/G) with 4962 (68.9%) individuals,

followed by predators (P) with 1863 (25.9%) specimens (Fig. 6). Collector-filterers (C/F), scrapers (Sc), shredders (Sh), shredder-detritivores (Sh/D) and shredder-herbivores (Sh/H) are less abundant, summing 373 (5.2%) individuals (Fig. 6).

The predator guild showed significant differences in abundance between seasons and the riparian vegetation/season interaction (Table 3). Tukey's post hoc test showed that the predator guild was more abundant during the rainy season in the HMF than the SFNM ($P=0.045$) and DFSP ($P=0.030$) collected in the dry season. The scraper guild abundance was influenced by the riparian vegetation/season interaction and the number of shredder-herbivores was significant influenced by seasons and the riparian vegetation/season interaction (Table 3). However, the Tukey's post hoc test did not explain where the significant differences existed between the vegetation types or seasons.

Table 3. Mean (\pm SD) abundance of macroinvertebrate trophic guilds found in the Sambache River. Results show differences between riparian vegetation types, seasons and their interaction ($P<0.05$) using GLM one-way crossed ANOVA model. Humid montane forest (HMF), secondary forest near maturity (SFNM) and disturbed forest with shrubs and pastures (DFSP)

Trophic guild*		Vegetation			Seasons		Interaction			
		HMF	SFNM	DFSP	F	P	F	P		
C/F	Dry	1.0 \pm 1.7	0.7 \pm 0.6	1.0 \pm 1.0	0.731	0.51	1.438	0.25	0.94	0.49
	Rainy	0.00	4.7 \pm 5.7	3.7 \pm 5.5						
C/G	Dry	421 \pm 130.9	268.0 \pm 216.8	248.0 \pm 105.5	0.352	0.071	1.005	0.34	0.7	0.64
	Rainy	215.7 \pm 90.6	227.0 \pm 161.7	274.3 \pm 186.9						
P	Dry	83.7 \pm 11.6	37.3 \pm 31.1	26.7 \pm 18.6	1.792	0.21	16.995	0.001	4.18	0.02
	Rainy	193.3 \pm 68.9	127.3 \pm 38.4	152.7 \pm 105.1						
Sc	Dry	0.7 \pm 1.2	6.7 \pm 10.5	0.3 \pm 0.6	3.342	0.07	3.335	0.09	3.56	0.03
	Rainy	0.3 \pm 0.6	13.3 \pm 11.9	0.00						
Sh	Dry	14.3 \pm 17.4	4.7 \pm 5.0	6 \pm 6.6	1.271	0.32	4.240	0.06	2.2	0.12
	Rainy	14.0 \pm 9.0	12.7 \pm 7.0	0.00						
Sh/D	Dry	0.00	0.2 \pm 0.4	0.2 \pm 0.4	0.5	0.62	0.00	1.000	0.8	0.57
	Rainy	0.00	0.3 \pm 0.6	0.00						
Sh/H	Dry	1.7 \pm 1.5	0.7 \pm 1.2	0.7 \pm 0.6	1.500	0.26	5.786	0.03	3.39	0.04
	Rainy	0.3 \pm 0.6	4.7 \pm 3.2	4.0 \pm 2.0						

* collector-gatherers (C/G); predators (P); collector-filterers (C/F); scrapers (Sc); shredders (Sh), shredder-detritivores (Sh/D); shredder-herbivores (Sh/H)

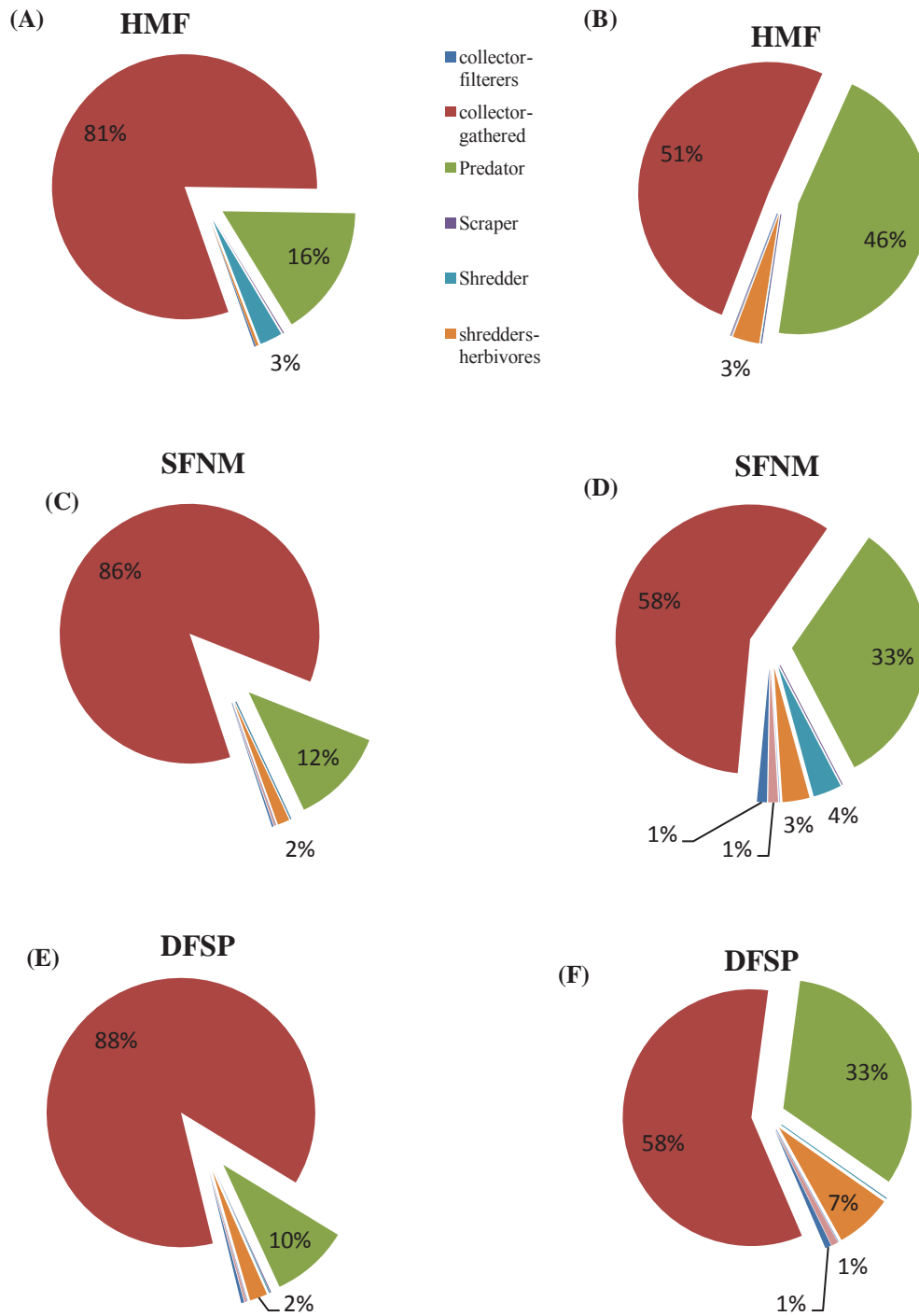


Figure 6. Percentage of trophic guilds identified in Sambache River during the dry season (left column) and the wet season (right column) in a humid montane forest (A and B), secondary forest near maturity (C and D), and disturbed forest shrubs and pastures (E and F).

Effects of environment on macroinvertebrate assemblage structure

The first two CCA axes accounted for 27.3% of the variance in taxa abundance and the accumulative variation explained by these axes of the taxa-environmental relationship was 51.9% (Fig. 7A and B). Monte Carlo Permutation test demonstrated that conductivity and TDS were the most important predictors of benthic macroinvertebrate assemblage structure in the Sambache River (Table 4).

Conductivity was positively correlated with the first axis (Table 5) and the macroinvertebrate taxa strongly associated with this physical parameter were *Chrysops*, *Camelobaetidius*, *Cossidae*, *Mortiniella* and *Lymnaea* in addition to unidentified genera of Gordioidea and Lumbriculidae (Fig. 7B). These taxa were more abundant in two samples from Humid Montane Forest and one sample from Secondary forest Near Maturity during the rainy season and these are thus located in the lower right quadrat (Fig. 7A).

Table 4. Conditional effects result from the CCA analysis. The interactions between environmental variables with the assemblage composition (F) used Monte Carlo Permutation ($P < 0.05$). λA are the eigenvalues.

Variable	λA	P	F
Conductivity	0.21	0.002	2.54
TDS	0.19	0.002	2.33
Vegetation cover	0.1	0.112	1.36
NO ₃	0.1	0.158	1.34
Water Temperature	0.08	0.272	1.18
Flow velocity	0.08	0.33	1.12
Air Temperature	0.06	0.742	0.78

TDS was strong correlated with the second axis (Table 5) and was a negatively correlated with several samples taken during the rainy season (Fig. 7A). Those samples were the ones recorded with least total dissolved solids during this study (Appendix 1). Genera such as *Atanatolica*, *Protoptila Alluaudomyia*, *Hexatoma*, *Tabanus*, and some Coleopteran genera clustered in the upper left quadrat were associated with the samples taken in the rainy season (Fig. 7B).

Samples taken during the dry season, or those with lowest water temperature and flow velocity, are mainly clustered in the lower left quadrat (Fig. 7A). No positive correlation between higher water temperatures and macroinvertebrate taxa were found in this study.

However, mayfly genera such as *Andesiops*, *Leptohyphes*, *Baetodes*, *Traulodes*, some caddisfly genera (*Atopsyche*, *Phylloicus*) and several Coleopteran genera preferred colder waters and they were negatively correlated with this parameter (Fig. 7B).

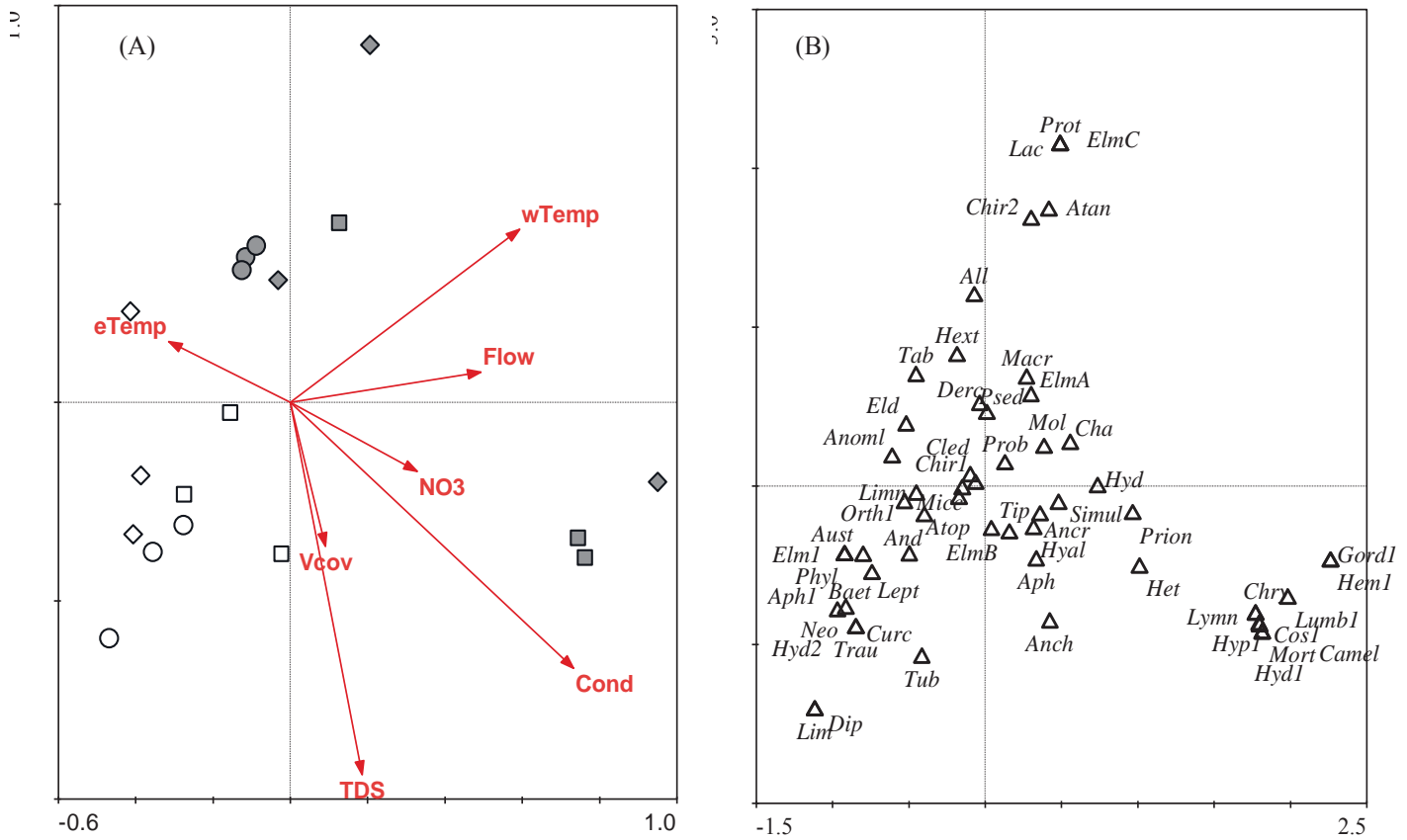


Figure 5: Canonical correspondence analysis (CCA) ordination plots for: A) sites and environmental variables; and B) taxa (complete names are shown in Appendix 2). Solid symbols denote dry season samples and open symbols dry season samples. Circles=Humid Montane Forest (HMF), Squares=Secondary Forest near Maturity (SFNM), Rhomboids=Disturbed Forest shrubs and pastures (DFSP).

Table 5. Pearson correlation coefficient between the first two axes of the CCA ordination with the environmental variables (n=18)

Environmental variables	CCA	
	Axis 1	Axis 2
Vegetation cover	0.0887	-0.3424
Flow velocity	0.4793	0.0721
environmental temperature	-0.306	0.1443
Conductivity	0.7124	-0.632
NO ₃	0.319	-0.1642
water Temperature	0.5763	0.4113
TDS	0.1805	-0.8857

Macroinvertebrate assemblage correlations with environmental variables

Flow velocity was the only variable retained in the model explaining variability in taxa richness and exp Shannon diversity (Table 6). In terms of genera (Table 6), the best model from a stepwise multiple regression analysis showed that the best predictors for *Andesiops* abundance were air and water temperature. For Chironominae the best model retained was vegetation cover, water temperature, conductivity and phosphates. *Probezzia* abundance was influenced by TDS, conductivity and width of the river which were all retained in the best regression model. Finally, the best predictor of *Atopsyche* abundance was air temperature.

Table 6. Results from the stepwise multiple regression analysis performed from the combining richness and exp Shannon diversity and the most abundant macroinvertebrates taxa with environmental variables.

	Variables retained	r²	F	d.f	P	Regression coefficient
Richness	Flow Velocity	0.365	9.2	1,16	0.008	0.604
exp H'	Flow Velocity	0.733	43.89	1,16	<0.001	0.856
Chironominae	vegetation cover, water temperature, conductivity and phosphates	0.734	8.96	1,16	0.001	-0.493, 0.453, -0.365, 0.335
<i>Andesiops</i>	Air, water Temperature	0.455	6.27	2,15	0.01	-0.624, 0.423
<i>Probezzia</i>	TDS, conductivity and width	0.88	34.26	3,14	<0.001	-1.395, 0.948, -0.306
<i>Atopsyche</i>	air temperature	0.227	4.69	1,16	0.046	0.476

In terms of trophic guilds, multiple regression analysis with the stepwise procedure showed that abundance scrapers was best explained by the combination of conductivity, flow velocity and dissolve solids (Table 7). Flow velocity explained the variability in the abundance of shredders. Nitrates explained the abundance of shredders-detritivores. And the abundance of shredders-herbivores was best explained by conductivity. None of the other trophic guild presented any significant relationship between their abundance and the environmental factors and is not presented.

Table 7. Results from the stepwise multiple regression ($P < 0.05$) analysis performed from combining trophic guilds and environmental variables.

Trophic guild*	Variable retained	r²	F	d.f	P	Regression coefficient
Sc	conductivity, flow velocity, TDS	0.817	20.8	3,14	<0.001	1.392, -0.570, -0.534
Sh	Flow velocity	0.447	12.937	1,16	0.002	0.669
Sh/D	NO ₃	0.283	6.322	1,16	0.023	0.532
Sh/H	conductivity	0.656	30.57	1,16	<0.001	0.635

* scrapers (Sc); shredders (Sh), shredder-detritivores (Sh/D); shredder-herbivores (Sh/H)

DISCUSSION

Environmental characteristics of the Sambache River

Only vegetation cover and water temperature differed significantly between sections of the Sambache River dissecting different riparian vegetation types. Not surprisingly, vegetation cover was highest where the river dissected humid montane forest. Elevated water temperature has been associated with deforestation and is clearly linked to vegetation cover (Allan 2004; Allan & Castillo 2007; Mesa 2010). Forest shade reduces the amount of sunlight reaching the water surface and reduces water temperature, especially in small streams where cover vegetation plays an important role in defining the water characteristics and the associated biota (Allan & Castillo 2007). Higher water temperatures observed in the current study where the river dissected degraded scrub were therefore to be expected.

Nevertheless, my results contrast significantly to those from other studies. For example, several studies report significantly increased amounts of nitrogen and phosphates transported by streams from catchments dominated by agriculture and urban development (Allan 2004; Allan & Castillo 2007; Johnson et al. 1997; Osborne & Wiley 1988; Johnson et al. 1997). In addition, Gowns and Davis (1994) and Kasangaki et al. (2008) observed greater conductivity in streams from deforested areas. I was therefore surprised to find no significant differences in the chemical parameters of river water between the pasture areas along the Sambache river and the more pristine montane forest sites. However, potential differences may have been masked by the fact that my sampling locations were continuous along a single river rather than different

rivers draining catchments with varying degrees of disturbance. This may have influenced the degree of variability of these parameters from headwaters to the lowland waters and decreased the potential detectability of any changes.

An increase in water flow velocity associated with the rainy season was expected due to the increased water discharge from increased precipitation (Lewis 2008; Resh et al. 1988). The increase in discharge can modify the ecological structure of a river and can be considered a disturbance (Resh et al. 1988; Ríos-Touma et al. 2011a) that affects other environmental variables such as conductivity and the amount of total dissolved solids related with inputs from surrounding fields (Allan & Castillo 2007; Dodds 2002). However, I did not find any significant changes among these environmental characteristics between the different sample sites and seasons. This could be attributed to the fact that the rainy season is stronger from January to April than in November when the samples were collected (INAMHI 2010)

Abundance, Richness and Diversity

No previous study has investigated the aquatic macroinvertebrate assemblages in the Sambache River at the Paschocha Wildlife Refuge. However, the macroinvertebrate assemblage structure in Sambache is mainly composed of insects, which is consistent with other studies from other Andean streams (Burneo & Gunkel 2003; Jacobsen & Encalada 1998; Jacobsen 2004). In fact, the dominance of Diptera, Ephemeroptera and Trichoptera is also very similar to observations from other river systems in South America (Miserendino 2001; Miserendino & Pizzolon 2004; Ríos-Touma et al. 2011a). A major difference from other studies was the low abundance of Coleoptera (Jacobsen & Encalada 1998; Ríos-Touma et al. 2011a) but this group nevertheless accounted for a great number of genera.

Riparian vegetation has been shown to play an important role in the structure and composition of aquatic macroinvertebrate assemblages (Dudgeon 1989; Dudgeon 1994; Gregory et al. 1991). In the current study, macroinvertebrate abundance was higher in the river sections dissecting humid montane forest compared to the ones that had some degree of disturbance (secondary forest near maturity and disturbed forest with shrubs and pastures). These results are in accordance with studies by Mesa (2010) and Ríos-Touma et al. (2011a) who reported significant differences in abundance of

macroinvertebrates between land-uses (pastures and forest) during the dry season in Andean streams.

Diversity, richness and evenness of macroinvertebrates assemblages were not influenced by the riparian vegetation types along the Sambache River. This contrasts with other studies in the tropical Andes which show that riparian vegetation or land-use significantly decreases diversity and richness (Benstead et al. 2003; Mesa 2010). This may again reflect that the sampling locations were continuous along a single river and sampling effort also influences these measures in aquatic macroinvertebrate (Cao et al. 2002; Melo et al. 2003).

However, the rarefaction curves clearly showed that humid montane forest had a higher abundance of individuals slightly lower richness than the secondary forest and the disturbed forest. This suggests a higher turn-over of taxa in the more disturbed habitats and there may also be an effect of altitude since the humid montane forest sites were the highest of the sites sampled (Jacobsen et al. 2003; Jacobsen 2008). This was not investigated in the current study.

Seasonality did not influence the abundance of macroinvertebrates. This is consistent with Jacobsen and Encalada (1998) who sampled other streams in the Ecuadorian Andes. Similarly, richness and diversity did not vary with season and it has been suggested that this is a common pattern for rivers in the highlands of the Neotropics (Jacobsen & Encalada 1998; Melo & Froehlich 2001).

The orders Ephemeroptera and Trichoptera were more abundant in sections of the river dissecting humid montane forest. These groups are known to be more common in rivers bordered by pristine forest rather than disturbed natural vegetation (Lorion & Kennedy 2009). In fact, they are often used as bioindicators of water quality (Álvarez-Cabria et al. 2010; Saether 1979). My results were reinforced at genus level where the mayfly *Andesiops* was considerably more abundant in humid montane forest sites compared to the more disturbed sites. This reflects other studies from the Andean region where this genus was found to be common in rivers with more vegetation cover and without disturbance (Domínguez et al. 2001; Pérez & Segnini 2007).

The Chironominae is associated with more disturbed aquatic ecosystems (Coimbra et al. 1996; Kleine & Trivinho-Strixino 2005). However, this sub-family portrayed no

significant difference in abundance between the three riparian vegetation types studied. Nevertheless, Chironominae larvae were considerably more abundant in sample sites from secondary forest near maturity and disturbed forest with shrubs and pastures than those from humid montane forest, particularly in the dry season. I therefore suggest that the Chironominae can still be used as a disturbance indicator in the Sambache River, because it clearly shows the opposite pattern to the *Andesiops* mayflies (Hodkinson & Jackson 2005; Mesa 2010). Overall, my results therefore suggest that the upper parts of the Sambache River are relatively pristine.

Seasonality plays an important role in the distribution of the benthic river fauna. The dry season is considered a period of stability in river ecosystems where flow and inputs tend to be stable (Allan & Castillo 2007; Lewis 2008). On the contrary, the rainy season sees an increase in discharge and flow velocity that can change the dynamics of the rivers and consequently the abundance of certain taxa (Bispo et al. 2006; Colwell 2013; Lewis 2008; Resh et al. 1988). In the current study, Ephemeroptera and its most abundant genus *Andesiops* portrayed a considerable decline in abundance during the rainy season. This agrees with other studies which report mayflies to be more abundant during the dry season (Burneo & Gunkel 2003; Epele et al. 2011), but contrarily to the study by Ríos-Touma et al. (2011a) who found an increase in number of mayflies during rainy season. The caddisfly *Atopsyche* appears to show the same pattern in the current study, perhaps a result of its predatory feeding habits, where an increase in abundance is linked to more prey to catch (such as nymphs of mayflies) during the dry season (Collier et al. 1995; Reynaga & Martín 2010). Contrastingly, *Probezzia* increased substantially during the rainy season in all three riparian vegetation types. This may be linked to the increase in abundance during the rainy season of the certain preferred prey taxa (some Nematodes) or dietary shift algae as suggest Aussel and Linley (1994).

Effect of environment on macroinvertebrate assemblage structure

The biotic structure and dynamic of river ecosystems is strong highly dependent on the variability of the environment (Allan 2004; Allan & Castillo 2007; Stanford & Ward 1983). Moreover several aquatic organisms are sensitive to perturbations in the environment and are affected by physicochemical factors (Saether 1979; Yoshimura 2012). In the current study, the CCA analysis indicated that TDS and conductivity were

the most important factors shaping the variability among the macroinvertebrate assemblages. The amount of dissolved solids are influenced by topography and may be correlated with river discharge, where the amounts of TDS are less when discharge or flow increases (Allan & Castillo 2007; Lewis 2008). This is supported by results presented in the current study (Appendix 1) and the CCA analysis clearly shows that TDS is negatively correlated with many samples taken in the rainy season (Fig 5A). In fact, the CCA analysis portrays a significant difference in assemblage composition between the dry and rainy seasons. In addition, assemblage composition appears to be much more congruent during the dry season. There are particularly three sites in the wet season that are different to the other sample sites. This appears to be closely linked to an increase in conductivity at these sites (Fig 5A), and the presence of taxa such as Lumbriculidae, Gordioidea and *Lymnaea*. These groups are known to be found in habitats with more sediments, often associated with pastures and disturbed forest (Miserendino & Pizzolon 2004; Nijboer et al. 2004) and correlated with conductivity rates (Fashuyi 1981). A study from Patagonian streams presented similar results, where conductivity was one of the main factors explaining the variability in community composition (Miserendino 2001; Miserendino & Pizzolon 2004).

In addition, the highest amount of dissolved solids was negatively correlated with one sample from the disturbed forest dominated with pastures and shrubs (Fig 5A). Taxa such as *Atanotica*, *Protophila*, *Laccobius*, an unidentified genus of Elmidae and Chironomidae (Fig. 5B) were confined into this place and there were found only during the rainy season. This suggests that these rare genera prefer disturbed habitats with less dissolved solids or were taxa that colonized this site after a disturbance as increased rainfall (Ríos-Touma et al. 2011b).

Although water temperature were not the main factor that influenced the abundance of the community composition, mayfly genera such as *Andesiops*, *Leptohyphes*, *Baetodes*, *Traulodes* and some caddisflies genera as *Atopsyche* and *Phylloicus* and several beetles seems to be adapted to colder waters taken during the dry season (Fig. 5A,B). This pattern is consistent with studies done in the high Andes where some Ephemeropteran taxa have been shown to be adapted to develop in fast-flowing and cold waters (Pérez & Segnini 2007) and were dominated with Trichopteran or Coleopteran genera (Ríos-Touma et al. 2011b; Sites et al. 2003).

In terms of richness and diversity in Sambache River were significant correlated with flow velocity. These results are similar as the study by Ríos-Touma et al. (2011b) where flow velocity was described as a disturbance effect affecting the macroinvertebrate richness.

Looking at the assemblage structure in more detail and taking in account the more abundant genera found in this study, *Andesiops* abundance was explained by the of the water temperature.. This genus is endemic of the highland Andean rivers, and inhabits cold water environments (Epele et al. 2011; Jacobsen & Encalada 1998; Pérez & Segnini 2007). Chironomid larvae seemed to be adaptable in most of the environments, especially in the ones that have some degree of disturbance (Adriaenssens et al. 2004; Odume & Muller 2011). In Sambache River the abundance of this taxon was explained by the combination of vegetation cover, water temperature, conductivity, and amounts of phosphates. Higher water temperature is probably linked to less vegetation cover and chironomid larvae were thus most abundant in the disturbed forest with shrubs and pastures. In fact, studies found that peaks in water temperature are important in the development of chironomid larvae (Hauer & Benke 1991). Despite the amount of phosphates being constant across the Sambache River samples, it appears to affect the abundance of this taxon. Several studies suggest that phosphorus is one of the important parameters related with the distribution of chironomid larvae, especially in the eutrophic aquatic systems (Fukuhara & Sakamoto 1987; Saether 1979). Conductivity was also a factor that explained the abundance of Chironominae and *Probezzia*. Additionally, TDS influenced the abundance of *Probezzia*. These physical factors are presumably linked but it is too soon to predict why the abundance of these taxa was influenced by these variables. However, some studies suggest that e.g. chironomids are tolerant to live in high levels of conductivity (Hauer & Benke 1991; Helson et al. 2006; Orendt 2000) and during the rainy season there was a small difference detected in this variable. Lastly, the abundance of *Atopsyche* was explained with air temperature, but the correlation was weak. It may suggest that some instars of these caddisfly larvae are adapted to specific environmental conditions such as air temperature, but this needs further investigation.

Trophic guilds

The dominant trophic guild in the Sambache River was the collector-gatherers which readily occupied most of the environments sampled during dry and rainy season. This is consistent with other studies from other South American streams, where this guild has been recorded as common (Jacobsen & Encalada 1998; Tomanova et al. 2006; Touma et al. 2009). It has been suggested that this generalist feeding group is dominant in Andean rivers due to highly variable food availability; the dominant organisms thus tend to be generalists to avoid resource competition (Mihuc 1997; Tomanova et al. 2006; Touma et al. 2009). Fine particulate organic matter is the principal food resource for this guild (Cummins & Klug 1979).

Predators were also relatively abundant in the Sambache River. Abundance did not vary between riparian vegetation types, supporting previous studies suggesting that the predator guild remain unaffected by changes in riparian vegetation cover (Dudgeon 1989). The increase in predator abundance seen during the rainy season could be explained by an increase in prey resources. For example macroinvertebrates in their first life stages; Chironominae larvae and some Ephemeroptera nymphs develop during this season (Allan & Castillo 2007) which are potential prey for some Trichopteran and Dipteran taxa (Collier et al. 1995; Reynaga & Martín 2010; Thut 1969).

Other guilds were not abundant at any site, although significant changes in abundance were found between riparian vegetation and season for some feeding guilds. For example, scrapers were more abundant in secondary near maturity sites during both seasons. Yoshimura (2012), found sites near clear-cuts to contain a higher percentage of scrapers, probably due to a higher availability of periphyton related to more turbulent waters (Cummins & Klug 1979). I did not measure periphyton availability, but the fact that they were most abundant in the secondary forest areas may suggest an association with slightly perturbed sites. Shredder-herbivores were more abundant in humid forest sites during the dry season and more abundant in the more disturbed sites during the rainy season. This could reflect increased leaf fall and leaf litter availability during the dry season in the humid forest (Touma et al. 2009) The more degraded sites may experience an increased influx of coarse particular organic matter from the riparian zones due to increased precipitation, which in turn could explain the increase in shredder-herbivores during the rainy season at these sites (Jacobsen et al. 2008).

Nevertheless, the small numbers make inferences difficult and speculative for these feeding groups. In any case, the low number of individuals recorded that were predominantly shredders is consistent with findings from other tropical streams in South America (Bojsen & Jacobsen 2003; Touma et al. 2009).

CONCLUSION

We still know very little about the taxonomy and ecology of macroinvertebrates in Andean rivers and streams, which limit the understanding of certain patterns that specific taxa present (Jacobsen 2008; Jacobsen et al. 2008). The current study contributes with information in terms of diversity, richness and distribution patterns of the Ecuadorian macroinvertebrate fauna. In addition, it provides some insights to macroinvertebrate relationships with environmental factors along a disturbance gradient in an area where agricultural expansion is happening inside a protected area. Nevertheless, I suggest that environmental variables and macroinvertebrates should be monitored long term to establish more robust results. In this way, we may also be able to better understand and predict ecological relationships between macroinvertebrate assemblages and environmental variables in the future. Still, my results suggest that certain taxa of aquatic macroinvertebrates are related to the undisturbed and forested sites. It is therefore clear that current agricultural expansion is affecting the composition of the aquatic fauna. This clearly demands a more controlled management of the Sambache River catchment and immediate measures to protect the river ecosystem and its resources. This must be a combined effort between the Pasochoa community and the correct governmental institutions. In Brazil and Colombia, national legislation requires that a landowner leaves a minimum of 30 m of natural vegetation between any river and developed land to protect the watershed and its ecosystem services. I suggest that a similar strategy in the Sambache River may help protect against agricultural runoff and other problems arising from agricultural development and better safeguard river quality. Protected area limits must also be better defined and controlled.

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APPENDIX 1. Mean \pm SD and range (in brackets) of environmental variables collected for the three different riparian vegetation types along the Sambache River, Pasocha Wildlife Refuge, Ecuador. Results from GLM crossed ANOVA $^*(P<0.05)$. Humid montane forest (HMF), secondary forest near maturity (SFNM) and disturbed forest shrubs and pastures (DFSP).

		HMF		SFNM		DFSP		Riparian Vegetation		Season		Interaction	
		F	p*	F	p*	F	p*	F	p*	F	p*	F	p*
Flow Velocity (m/s)	Dry	0.20 \pm 0.57 (0.17-0.27)	0.24 \pm 0.9 (0.15-0.33)	0.15 \pm 0.4 (0.10-0.18)	2.680	0.109	6.598	0.025	1.021	0.390			
	Rainy	0.41 \pm 0.29 (0.14-0.71)	0.63 \pm 0.32 (0.33-0.96)	0.23 \pm 0.12 (0.09-0.30)									
Depth (m)	Dry	0.19 \pm 0.2 (0.17-0.21)	0.12 \pm 0.3 (0.09-0.14)	0.15 \pm 0.71 (0.09-0.23)	0.721	0.506	0.855	0.373	1.128	0.356			
	Rainy	0.14 \pm 0.02 (0.12-0.16)	0.14 \pm 0.56 (0.08-0.18)	0.12 \pm 0.05 (0.07-0.15)									
Width (m)	Dry	2.09 \pm 0.29 (1.78-2.36)	2.31 \pm 0.69 (1.62-2.99)	2.06 \pm 0.74 (1.21-2.55)	0.314	0.737	1.480	0.247	0.466	0.639			
	Rainy	2.36 \pm 0.34 (1.97-2.62)	2.59 \pm 0.22 (2.38-2.82)	3.36 \pm 2.35 (0.72-5.24)									
Water (°C) Temperature	Dry	10.73 \pm 2.19 (9.0-13.2)	12.73 \pm 0.29 (12.4-12.9)	11.4 \pm 1.91 (10.3-13.6)	4.122	0.043	4.139	0.065	0.255	0.779			
	Rainy	11.47 \pm 0.85 (10.5-12.1)	14.27 \pm 1.16 (13.5-15.6)	13.3 \pm 1.41 (11.8-14.6)									
pH	Dry	8.45 \pm 0.27 (8.24-8.75)	8.07 \pm 0.40 (7.63-8.41)	7.89 \pm 0.45 (7.36-8.16)	1.642	0.234	0.113	0.743	1.480	0.266			
	Rainy	8.14 \pm 0.06 (8.07-8.19)	8.38 \pm 0.24 (8.1-8.56)	8.05 \pm 0.39 (7.63-8.39)									
Conductivity (μ S/cm ⁻¹)	Dry	227.7 \pm 15.04 (212-242)	223.7 \pm 43.57 (197.4-274)	160.87 \pm 26.55 (131.1-182.1)	1.442	0.275	1.518	0.241	1.475	0.267			
	Rainy	160.7 \pm 0.58	399.7 \pm 211.02	273.3 \pm 222.5									

Air (°C) Temperature	Dry	(160-161) 23.3±3.14 (20.5-26.7)	(156-523) 20.37±3.34 (18.1-24.2)	(135-530) 20.2±4.84 (16.6-25.7)	1.464	0.270	0.037	0.850	0.159	0.855
	Rainy	(22.8-23.3) 23.1±0.26 (18.8-26.8)	(18.8-26.8) 21.9±4.29 (18.2-21.3)	(18.2-21.3) 19.77±1.55 (18.2-21.3)						
TDS (ppm)	Dry	(211-242) 227.3±15.57	(119-273) 224±42.44	(131-183) 161±26.91	1.686	0.226	4.300	0.060	1.694	0.225
	Rainy	(80-82) 81±1.0	(78-263) 200.3±105.95	(67-265) 136.3±111.54						
NO ₂ (mg/L)	Dry	(0.003-0.009) 0.005±0.003	(0.002-0.003) 0.003±0.001	(0.004-0.007) 0.005±0.002	0.310	0.739	1.761	0.209	0.342	0.717
	Rainy	(0.005-0.007) 0.006±0.001	(0.005-0.008) 0.006±0.001	(0.001-0.014) 0.007±0.006						
NO ₃ (mg/L)	Dry	(0.2-0.4) 0.3±0.12	(0.2-1.1) 0.6±0.5	(0.4-0.4) 0.4±0.0	1.919	0.189	1.667	0.221	0.200	0.821
	Rainy	(0.4-0.8) 0.6±0.2	(0.5-1.0) 0.8±0.27	(0.1-0.8) 0.5±0.35						
BO ₅ D (mg/L)	Dry	(4.0-4.0) 4±0.0	(4.0--10.0) 6.0±3.5	(4.0-4.0) 4.0±0.0	0.792	0.475	0.009	0.927	0.792	0.475
	Rainy	(4-10) 7±3	(4.0-7.0) 5.7±1.53	(4.0-7.0) 6±1.7						
PO ₄ (mg/L)	Dry	(0.09-0.09) 0.09±0.0	(0.09-0.09) 0.09±0.0	(0.001-0.3) 0.13±0.0	0.213	0.811	3.421	0.089	0.810	0.468
	Rainy	(0.09-0.09) 0.09±0.0	(0.09-0.09) 0.09±0.0	(0.09-0.09) 0.09±0.0						
vegetation Cover %	Dry	(80-100) 86.7±11.5	(50-80) 70±17.3	(30-80) 46.7±28.87	6.067	0.015	0.000	1.000	0.000	1.000
	Rainy	(80-100) 86.7±11.5	(50-80) 70±17.3	(30-80) 46.7±28.88						

APPENDIX 2. Macroinvertebrate aquatic fauna collected in the dry and rainy season in three different riparian vegetation types along the Sambache River, Pasocha Wildlife Refuge, Ecuador. Humid montane forest (HMF), secondary forest near maturity (SFNM) and disturbed forest shrubs and pastures (DFSP).

Order	Family	Subfamily	Genus	CCA code	DRY					RAINY				
					HMF	SFNM	DFSP	HMF	SFNM	DFSP	Total	S	TF	
Amphipoda	Hyalellidae	Hyalellinae	<i>Hyalella</i>	<i>Hyal</i>	5	7	5	4	23	3	47	L	C/G	
				<i>Derc</i>	1	1	1	1	1	2	A	P		
Coleoptera	Carabidae	n.d*	<i>n.d</i>	<i>Curc</i>	1	1	1	1	1	1	1	A	Sh	
				<i>Dipropus?</i>	1	1	1	1	1	1	A	C/G		
	Elateridae	Elaterinae	<i>Austrolimnius</i>	<i>Aust</i>	3	1	8	1	1	12	A	C/G		
				<i>Heterelmis</i>	1	1	1	7	1	9	L	C/G		
	Elmidae	Elminae	<i>Macrelmis</i>	<i>Macr</i>	1	1	1	4	2	12	L	C/G		
				<i>Microcylloepus</i>	12	1	8	7	8	1	37	A-L	C/G	
	Hydrophilidae	Hydrophilinae	n.d	<i>Neoelmis</i>	<i>Neo</i>	5	1	6	1	1	12	A-L	C/G	
					<i>Pseudodisersus</i>	1	5	14	25	11	11	67	L	C/G
					<i>Elm1</i>	1	1	1	1	1	1	A	C/G	
					<i>ElmA</i>	8	8	7	11	18	44	L	C/G	
<i>ElmB</i>					3	6	4	2	1	16	L	C/G		
<i>ElmC</i>					1	1	1	1	1	1	L	C/G		
<i>Laccobius?</i>					1	1	1	1	1	1	A	Sh		
<i>Hyd1</i>					1	1	1	1	1	1	L	P		
<i>Hyd2</i>					1	1	1	1	1	1	L	P		
Ptilodactylidae					Scirtinae	Scirtinae	<i>Anchytarsus</i>	<i>Anch</i>	1	1	1	1	1	2
	<i>Eld</i>	1	2	1				1	1	4	L	Sh/H		
Collembola	Hypogastruridae	n.d	<i>Hypogastruridae1</i>	<i>Hyp1</i>	3	3	3	3	3	3	A	Sh/H		
				<i>Lim</i>	2	2	2	2	2	2	L	Sc		
Diptera	Blepharoceridae	Edwardsiniinae	<i>Limonicola</i>	<i>Lim</i>	2	2	2	2	2	2	L	Sc		

Ceratopigonidae	Ceratopogoninae	<i>Alluaudomyia</i>	<i>Allu</i>	105	29	134	L	P
Chironomidae	Chironominae	<i>Probezzia</i>	<i>Prob</i>	66	44	24	386	311
	Orthocladiinae	<i>n.d.</i>	<i>Chir1</i>	231	607	592	342	549
	n.d.	<i>n.d.</i>	<i>Orth1</i>		92	6	41	
Dolichopodidae	Hydrophorinae	<i>Aphrosylus</i>	<i>Aph</i>	3			1	1
	Hemerodromiinae	<i>Chelifera</i>	<i>Cha</i>	8	14	2	42	27
Limoniidae	Chioneinae	<i>Molophilus</i>	<i>Mol</i>	21	12	4	11	13
	Limoniinae	<i>Hexatoma</i>	<i>Hext</i>	3	2	3		1
Muscidae	Coenosiinae	<i>Limnophora</i>	<i>Limn</i>	21	12	4	11	13
	Simuliinae	<i>Simulium</i>	<i>Simul</i>	3	2	3		1
Simuliidae	Chrysopsinae	<i>Chrysops</i>	<i>Chry</i>					
	Tabaninae	<i>Tabanus</i>	<i>Tab</i>		1	1	1	1
Tipulidae	Tipulinae	<i>Prionocera</i>	<i>Prion</i>	4	2		1	8
	Baetinae	<i>Tipula</i>	<i>Tip</i>	879	78	36	165	50
Baetidae		<i>Andestiops</i>	<i>And</i>	59	2	2	5	3
		<i>Baetodes</i>	<i>Baet</i>	57	4	54	41	15
Leptohiphidae		<i>Camelobaetidius</i>	<i>Camel</i>					
		<i>Cleodes</i>	<i>Cled</i>	6	6	2	2	1
Leptophlebiidae	Leptohiphinae	<i>Leptohyphes</i>	<i>Lept</i>	1				
	Atalophlebiinae	<i>Traulodes</i>	<i>Trau</i>					
Lymnaeidae	Lymnaeinae	<i>Lymnaea</i>	<i>Lynn</i>	37				
	n.d.	<i>n.d.</i>	<i>Gord1</i>					
Lumbriculidae	Lumbriculinae	<i>n.d.</i>	<i>Lumb</i>					
	Tubificinae	<i>Tubifex</i>	<i>Tub</i>	34	13			3
Aphididae	n.d.	<i>n.d.</i>	<i>Aph1</i>		1			
	n.d.	<i>n.d.</i>	<i>Hem1</i>					
Cossidae	n.d.	<i>n.d.</i>	<i>Cos1</i>					
				1	1	1	1	1

Plecoptera	Perlidae	Anacronaurinae	Anacronauria	Ancr	2	1	2	1	6	N	P
Prostigmata/Aracnida											
	Hydrachnidae	n.d	<i>Hydrachna</i>	<i>Hyd</i>			1		2	A	P
	Calamoceratidae	Calamoceratinae	<i>Phylloicus</i>	<i>Phyl</i>	3				3	L	Sh
	Glossosomatidae	Protoptilinae	<i>Mortoniella</i>	<i>Mort</i>			1		1	L	C/G
			<i>Protoptila?</i>	<i>Prot</i>				1	1	L	C/G
	Hydrobiosidae	Hydrobiosinae	<i>Atopsyche</i>	<i>Atop</i>	159	49	44	49	405	L	P
	Leptoceridae	Triplectidinae	<i>Atanatotica</i>	<i>Atan</i>			1	2	3	L	C/G
	Limnephiloidea	Dicosmoecinae	<i>Anomalocosmoecus</i>	<i>Anoml</i>		1		1	2	L	Sc
Total					1567	934	1170	1406	7198		

*not determined

S=State
L=Larvae

TF=Trophic Guild

C/G=Collector-gathered

Sh/D=Shredder-detritivores

C/F=Collector-filterer

Sh/H=Shredder-herbivores

Sh=Shredder

P=Predator

Sc=Scraper