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Research Article

Fish Species Richness in Lowland Streams with a Geothermal Input Phenomenon, Sarapiquí de Heredia, Costa Rica

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Lowland streams of the Caribbean Costa Rican slope are naturally enriched by minerals and solutes such as phosphorus, a phenomenon known as geothermal input. The resulting stream phosphorus gradient affects the food web by altering primary production, leading to complex biotic and abiotic interactions. The objective of this study was to describe fish species richness patterns in relation to a naturally occurring phosphorus gradient in three lowland streams. We hypothesized that phosphorus input in La Selva Biological Station streams is correlated with species richness. 354 individuals were identified at 4 sites: Surá, El Salto, Sábalo and Jaguar, using a cast net, a total of 150 throws were made, distributed in 10 samplings, at each site. An estimation of species richness along with alpha and beta diversity indices were calculated in order to describe fish community structure. Species richness was estimated to be higher at Jaguar but presents a lower phosphorus enrichment. Jaguar and Sábalo, differed the most while Salto and Surá were the most similar as indicated by species turnover among streams. There is a non significant relationship between phosphorus levels and diversity; however, this interesting trend encourages further studies on species richness patterns and natural nutrient enrichment of streams.

1. Introduction

Geothermal input is a hydrological phenomenon that has occurred in the Caribbean slope of Costa Rica for about 1.2 million years, in which volcanic activity in the valley causes natural contamination in the lowlands [1, 2]. Geothermal input results in diluted, sodium-chloride-bicarbonate waters and a nutrient gradient along and among streams [1]. Solute concentration in some protected lowland streams is comparable to human-polluted streams [1, 3].

Phosphorus, nitrate, and ammonia concentrations in stream waters have been monitored by a long-term project at La Selva Biological Station since 1988. This laboratory has shown that soluble reactive phosphorus (SRP) in streams can attain concentrations of about 400 μg/L. Researchers have sought a better understanding of nutrient dynamics effects on the stream food web in recent years [3–6]. Particular attention has been given to the effects of geothermal input on primary producers, decomposers, and macroinvertebrates such as shrimps. Because of their role as primary consumers, macrovertebrates are important indicators of changes in the structure of the overall food web.

Anthropogenic activities affect stream nutrient cycling and food web structure as well. Key studies in the tropics have shown that pollution, deforestation, and overexploitation are the main types of negative impacts on biodiversity, in particular primary consumers such as freshwater fish [7–11]. Special attention is given to the difference in the number of species captured and in the feeding habits of the fish between deforested and protected lowland streams [8].

In this study we focus on freshwater fish species richness and abundance to gain a better understanding of the impact of natural variation in abiotic conditions on fish communities. Our hypothesis is that natural nutrient enrichment will be coupled with a difference in freshwater fish diversity, quantified species richness measures, or heterogeneity measures. We expect that phosphorus concentrations will play a major role in shaping fish community structure in the streams. This project aims to increase understanding of abiotic factors that affect fish communities in streams for further studies and management plans.

2. Materials and Methods

2.1. Study Site. La Selva Biological Station (1,536 ha), classified as Tropical Wet Forest [12], is drained by 13 streams that are tributaries of the Puerto Viejo and Sarapiquí rivers of the Caribbean lowlands of Costa Rica [13]. Surá, El Salto, and Sábalo-Esquina are the larger station streams (5–15 m wide) [13]. Our study sites were located in these three main streams. A fourth site (Jaguar) is located upstream along the Surá and was chosen to allow us to compare variation both within and among streams. The Sábalo site presented a substrate composed, mainly by rocks, gravel, and silt; this site represents a border between La Selva protected forest and deforested pastures. Salto and Surá presented a substrate composed mainly by silt, logs, and leaf litter. The Jaguar site at upstream Surá presented a substrate with larger rocks and contained pools with silt substrate with many logs and leaf litters. Surá, Salto, and Jaguar exhibited vegetation cover on both sides composed mainly by mosses, ferns, grass, woody plants (shrubs and trees), and palms.

2.2. Fish Sampling. There are around 43 species of fish at La Selva, of which approximately 10 fish species can be found in our study streams [8, 14]. High densities of large fish become difficult to found in low-order streams such as those under study here [8]. Fish were captured from June 18th to July 16th, 2010 using a throw net of about 1.5 m diameter at 16 sites. The total area sampled with the throw net comprised 26 m^2. At each site, 150 throws were made along an approximated 100-meter transect along the river during 10 samplings. Captured fish were identified and measured and a photo record was made before returning them to the appropriate site. If identification in the field was not possible, fish specimens were preserved and added to LARNAVISI Laboratory fish collection at the Universidad Nacional de Costa Rica. Upon each sampling location, the composition of riparian vegetation, river substrate, type of water level, current (using a buoy), water clarity (using a Secchi Disk), and temperature were recorded. STREAMS Laboratory provided average information about chemical variables involving streams ecosystem, measured in 2008. Phosphorus (μg P/L), nitrate (μg NO_3^-/L), and ammonia (μg NO_4^+/L) levels data are available in Table 1.

2.3. Diversity Measures and Statistical Analysis. Sampling effort was described by constructing accumulation curves in which the number of samplings would be linked to a cumulative number of species. Alpha diversity was determined using Simpson (D') and Shannon-Wiener (H') indexes; evenness was also determined (J' and E_D). These indices measure diversity emphasizing one in species richness (Simpson D') and the other in evenness (Shannon-Wiener). Since exhaustive sampling of stream fish communities was not possible, the EstimateS program [15, 16] was used to generate a Chao 1 estimate of the absolute number of species in each sample. Beta diversity, or species turnover among the four sites, was quantified using the Sørensen similarity index. To determine if there is a correlation between stream nutrient concentrations and diversity (as H' or as Simpson D') a non parametric Spearman's rank correlation was performed using JMP 7.0 [17]. To explain variation in similarity index values, we calculated resemblance using Primer 6 and determined the significance using a Mantel test.

Table 1: Average solute concentrations for August 2008 in 4 sites located in low-order streams at La Selva Biological Station, Heredia Costa Rica. Data were provided by STREAMS Project Laboratory, La Selva Biological Station, Heredia, Costa Rica.

Site	μg P/L	μg NO_3^-/L	μg NH_4^+/L
Sábalo	8.97	228.63	26.64
Salto	54.51	218.93	19.63
Surá	79.56	229.48	20.63
Jaguar	4.96	274.03	32.42

3. Results

A total of 354 individuals from 14 different species were captured in the four sites Sábalo, Surá, Salto, and Jaguar (Table 2). Species accumulation curves reached a plateau, indicating that sampling effort was adequate. Shannon-Wiener diversity (H') was the highest in Sábalo (Table 2). This site had the highest diversity using Simpson D' index too (Table 3). Estimated species richness was the highest at Jaguar, but there were no significant differences in estimated species richness among sites (Figure 2; Table 3).

Fish communities in Surá and Salto were highly similar (Sørensen similarity index, 0.82; Tables 3 and 4). The least similar fish communities were the Sábalo and the Jaguar (Sørensen similarity index, 0.47; Table 4). Sábalo is significantly different from Salto, Surá, and Jaguar, and there is no difference in each of the last three sites mentioned (Table 5). There is a weak relationship between phosphorus levels and diversity (as Shannon H' or as Simpson D') (Spearman's rank correlation $\rho = 0.4$, $P = 0.6$, and $n = 4$). Using a Spearman rank correlation with a BIOENV method, there is a strong correlation between nitrate and ammonia and beta diversity values ($r^2 = 0.83$ and $n = 6$), and also phosphorus and nitrate presented a strong correlation ($r^2 = 0.71$ and $n = 6$) with beta diversity values for the four sites. There is a trend for a species turnover with increasing nutrient concentration or vice versa. A mantel test determined that these correlations were not significant ($r = 0.81$, $P = .6$ and $n = 6$).

4. Discussion

Physical and chemical barriers result in differences in fish communities [8]. What makes the difference in species richness? Is it food resources or abiotic conditions? This study attempted to determine how differences in stream chemistry modify fish community structure. The Simpson's index quantifies the probability that any two individuals

Table 2: Species abundance at 4 sites in low-order streams at La Selva Biological Station, Heredia, Costa Rica.

Species	Abundance			
	Sábalo	Salto	Surá	Jaguar
Alfaro cultratus	5	3	2	3
Archocentrus nigrofasciatus	2	0	2	0
Asthateros alfari	2	1	1	0
Astyanax aeneus	37	28	43	19
Atherinella hubbsi	0	0	1	0
Bramocharax bransfordii	6	0	0	0
Brycon guatemalensis	17	29	26	25
Bryconamericus scleroparius	6	0	0	22
Cryptoheros septemfasciatus	0	3	2	2
Hypsophrys nicaraguensis	3	0	0	0
Neetroplus nematopus	15	10	25	0
Poecilia gilli	4	0	0	2
Priapichthys annectens	0	1	0	0
Tomocichla tuba	3	3	2	0
Total number of individuals (N)	100	77	104	73
Total number of species (S)	11	8	9	6
Estimated species richness (mean)	9.8	13.4	14.8	15.5
Lower 95% C.I.	9.4	12.5	14	15.1
Upper 95% C.I.	14.3	23.6	22.2	23.3

Table 3: Diversity index (Shannon-Wiener index H', Equitability, applied to J', and Simpson Index D') sites in low-order streams at La Selva Biological Station, Heredia, Costa Rica.

Site	H'	J'	Simpson $D'_{(1/D)}$	E_D
Sábalo	1.83	0.71	4.69	0.02
Salto	1.37	0.54	3.32	0.04
Surá	1.38	0.54	3.36	0.03
Jaguar	1.30	0.50	3.43	0.05

drawn at random from a finite community will belong to the same species; Simpson D' was lower in Sábalo than in Salto, indicating greater diversity in the Sábalo. Calculation of the Shannon-Wiener index confirmed that there was more diversity at Sábalo than at any other site. Species richness was estimated to range from 0 to 38 species; since the 95% confidence intervals on the Chao 1 estimate overlap, there are not real differences in species richness among sites. There was more similarity between fish communities in Surá and Salto, less similarity was found between communities in Sábalo and Jaguar. Solute concentrations did not satisfactorily explain variation in fish community composition because of the little number of sites. By sampling at each site until obtaining proper accumulative curves, to increase the number of sites was not affordable. However, a combination of nitrate and ammonia or a combination of phosphorus and nitrate was nonsignificantly correlated with beta diversity, presenting a trend that encourages further study.

Table 4: Beta diversity Sørensen similarity index applied to 4 sites located in low-order streams at La Selva Biological Station, Heredia, Costa Rica.

Site	Sábalo	Salto	Surá	Jaguar
Sábalo	1	0.63	0.7	0.47
Salto	0.63	1	0.82	0.57
Surá	0.7	0.82	1	0.53
Jaguar	0.47	0.57	0.53	1

Table 5: Significance test applied to 4 sites located in low-order streams at La Selva Biological Station, Heredia, Costa Rica. *represents sites with values that are significant.

Site	Sábalo	Salto	Surá	Jaguar
Sábalo	1	0.02*	0.02*	0.03*
Salto	0.02	1	0.00	0.00
Surá	0.02	0.00	1	0.00
Jaguar	0.03	0.00	0.00	1

Natural changes on streams can produce drastic variation in abiotic conditions such as light, turbidity, stream substrate, and dissolved nutrients in water as well as human-caused changes. In turn, biotic interactions are affected by those changes in the overall food web and community structure. Some fish may do better receiving more sunlight (e.g., Sábalo) because light availability increases periphyton and benthic invertebrate production. Other fish depending on fruits do better in more covered streams (e.g., Surá, Jaguar, and Salto) [8]. Aquatic invertebrates (e.g., chironomids) have shown to be affected significantly by phosphorus, displaying changes in abundance and biomass [3, 6]. Based on this fact, we would expect shifts in abundance and biomass in insectivore fish (e.g, *Alfaro cultratus*). The fact that insectivore fish might benefit from high phosphorus levels is inconsistent with the observation that there are more insectivore fish in Sábalo, a low-phosphorus stream. However, the Sábalo stream acts as a border and is frequented by cattle. Cattle use of streams may cause an increase in sediments, nutrients, and other biotic elements in streams. We observed presence of ectoparasites, a possible sign of alteration, in fish captured in Sábalo stream.

To try to obtain more information from biodiversity indices, in particular alpha diversity index poses both a conceptual problem and a statistical problem [18]. Measures that combine species composition and abundance, such as Shannon-Wiener index, have already been pointed out to have no meaning by themselves, because an index value of a set of data is a reduction of information that makes interpretation difficult [18]. Beta diversity index, such as Sørensen similarity index, and species richness information allowed to make proper comparisons of sites that evidently showed differences in species richness and abundance.

An interesting avenue for further study would be an investigation of adaptation of local fish communities to initially challenging conditions, such as those presented by geothermal input of dissolved nutrients. We expected differences in species richness and abundance in sites where nutrient levels were higher. However, fish community responses might differ in human-modified environments as opposed to geothermally contaminated environments, which have experienced high nutrient input over a very long time scale. Challenging habitats could influence species richness patterns and lead to interesting biodiversity patterns in a long time scale.

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