(Stage class 3). This finding has two potential explanations. Seedlings in areas of high adult canopy cover may have lower survival rates from Stage class 2 to Stage class 3. Alternatively, seedlings in Stage class 2 may have slower growth rates under high adult canopy cover.

The soil beneath adult *P. macroloba* is more acidic than the surrounding soil, presumably because these trees have root symbionts that fix soil nitrogen, which is subsequently nitrified (Parker 1994). Soils with a lower pH have a lower retention of cations and other nutrients (Parker 1994). Thus, low soil pH has potentially negative consequences for *P. macroloba* seedling growth and survival.

In addition, *P. macroloba* leaves decompose at slower rates than the leaves of many other tropical forest canopy trees (Parker 1994). Therefore, *P. macroloba* seedlings beneath the canopy of conspecifics may have lower available nutrients, contributing to lower growth rates and reduced survival. High local conspecific seedling density may also negatively influence seedling growth and survival. Seedlings at higher seedling densities may be more susceptible to herbivory and pathogens, factors that potentially stress seedlings, limit growth, and increase mortality rates (Deem 1998, Dallison 1999). Based on our findings, we cannot separate the effects of adult density and seedling density on seedling survival; adult canopy cover and seedling density are spatially correlated. Through manipulation of seedling density or larger sample sizes, future studies could potentially separate these factors.

Lower survival and growth rates of conspecific seedlings under a canopy dominated by *P. macroloba* may help to explain the limitation of dominance of this species in the La Selva forest. In areas of low adult canopy cover, higher survival of seedlings may increase the recruitment of *P. macroloba* to the canopy. In contrast, where *P. macroloba* already dominates, adult replacement rates may be lower. Over time, these dynamics may help stabilize the population of adult *P. macroloba* and prevent complete canopy dominance by this species.

We suggest that these questions are of sufficient interest to warrant more extensive studies to confirm the patterns we found. Long-term demographic studies using marked individuals would distinguish between the effects of growth and survival on stage structure. Such studies could also elucidate the mechanisms responsible, e.g. by quantifying herbivore damage in areas of high and low conspecific density.

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A comparison of fish communities between two Costa Rican streams with geothermal and runoff inputs

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Abstract: Water chemistry and nutrient levels influence aquatic communities by affecting primary production, consumption, and predation. Streams with geothermal water inputs are highly heterogeneous but have high levels of soluble reactive phosphorus (SRP). SRP is highly correlated with other major ion concentrations and is a key determinant of primary productivity. We hypothesized that a stream (Sura) with geothermal groundwater input and a non-geothermal runoff stream (Sabalo) would have different fish community assemblages. We expected that higher SRP in the Sura stream would lead to higher fish abundance, richness and diversity. Contrary to our predictions, we found higher abundance in the Sabalo stream and similar levels of richness and diversity between the streams. Our results indicate that geothermal water inputs may have other impacts on stream communities in addition to increasing SRP available for primary productivity.

Key Words: community structure, nutrients, soluble reactive phosphorous, stream chemistry

Introduction

Water chemistry plays a key role in the biology of stream ecosystems. Ion and nutrient levels in water influence communities from the bottom-up by affecting primary production, consumption and predation (Begon et al. 1990). Streams with geothermal water inputs are particularly interesting because of their unique water chemistry. Streams at La Selva draining a volcanic landscape on the Caribbean slope of Costa Rica show great heterogeneity in their water chemistry, both within and among streams (Pringle et al. 1990, Pringle et al. 1991). This chemical variability is due to spatial variation in geothermal groundwater inputs (Genereux and Pringle 1997). Geothermal waters at La Selva have high concentrations of soluble reactive phosphorous (SRP), which is highly correlated with concentrations of other major ions such as Na^+ and Cl^- (Pringle et al. 1990). SRP is a major determinant of primary productivity, which influences overall system productivity and community structure of algae, invertebrates and fish.

We hypothesized that geothermal groundwater input would influence fish community assemblages. We expected that higher SRP in the geothermally–influenced Sura stream would lead to increased primary production, allowing for higher fish abundance, richness and diversity in comparison to the Sabalo stream, which is not geothermally-influenced.

Methods

We assessed fish communities in the Sura and Sabalo streams at La Selva, Sarapiqui province, Costa Rica. Based on a chemical mixing model using concentrations of Na^+ and Cl^-, Genereux and Pringle (1997) found that approximately 35% of water in the Sura stream at La Selva is of geothermal origin. The nearby Sabalo stream is assumed to have very little geothermal water input (M. Hidalgo, pers. comm.). This difference in water chemistry is corroborated by conductivity, which is approximately 300 μS in the Sura and 40 μS in the Sabalo (M. Hidalgo, pers. comm.). We sampled the streams between the hours of 08:00 and 16:00 on 15 and 17 February 2003 by seining pools for fish in four areas, each approximately 50 m^2 in size. Each seine was replicated on the two days. We identified each fish to species according to Bussing (1998).

We calculated fish abundance, species richness, and Shannon-Wiener diversity at each site using the means of the two replicates at each site.

Results

Fish abundance was higher in the Sabalo than in the Sura (Fig. 1; t = 2.69, df = 14, P = 0.02). We did not find significant differences in richness or diversity between the two streams (richness t = 0.95, df = 6, P = 0.38; diversity t = 0.32, df = 6, P = 0.76). However, a plot of the number of species caught per seine vs. the number of individuals caught per seine (Fig. 2) suggests that species richness and diversity may in fact be higher in the Sura stream. In total, we found 11 species of fish (Fig. 3). Nine species were found in the Sabalo, and five were found in the Sura. *Astynax aeneus* (Characidae), *Poecilia gilli* (Poeciliidae), and *Alfara cultratus* (Poeciliidae) were the most common species. Different families appeared to occupy different vertical positions in the streams. We observed Poeciliidae occupying the surface waters, Characidae in the middle, and Cichlidae at the bottom.

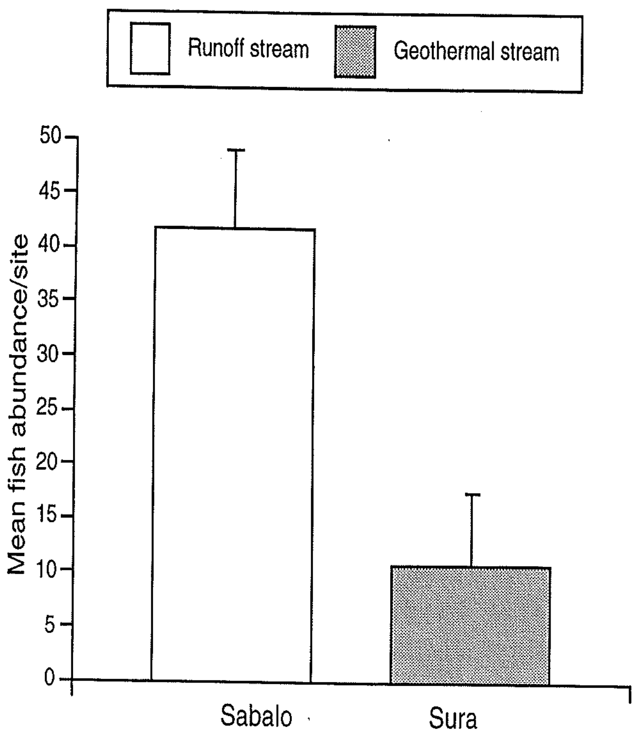

FIG. 1. Abundance of fish caught by seining in runoff (Sabalo) and geothermal (Sura) streams at La Selva, Sarapiqui, Costa Rica. Data represent means (± SE) of seine captures at 4 sites on each stream, n = 2.

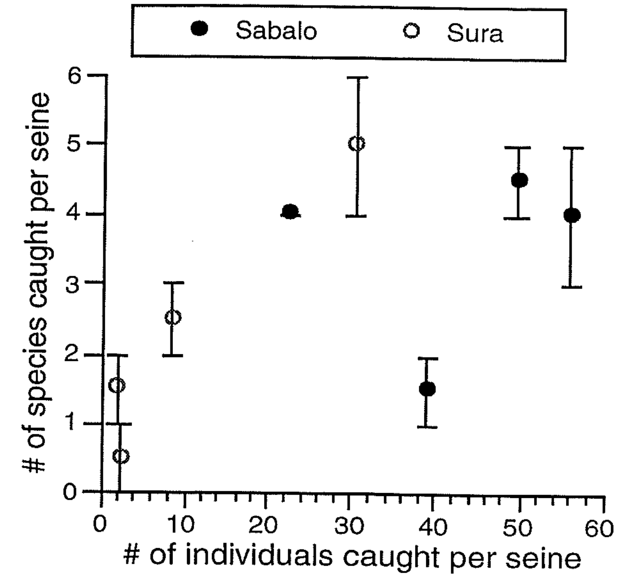

FIG. 2. Species richness per seine vs. number of fish caught per seine at 4 sites in runoff (Sabalo) and geothermal (Sura) streams at La Selva, Sarapiqui, Costa Rica. Data represent means of two replicates (± SE).

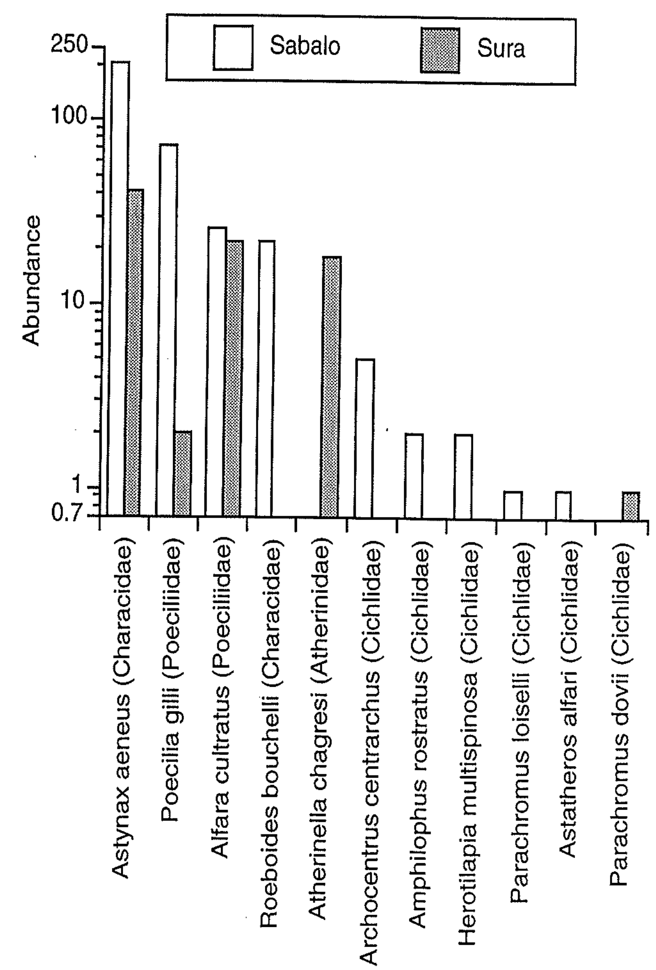

FIG. 3. Rank abundance of fish species in streams with geothermal (Sura) and runoff (Sabalo) inputs at La Selva, Sarapiqui, Costa Rica. Fish were seined at 4 sites within pools on each stream, n = 2.

Discussion

Contrary to our predictions, fish were more abundant in the Sabalo than in the geothermally-influenced Sura, and there were no differences in richness and abundance. However, more sampling may reveal higher richness and diversity in the Sura stream. The efficacy of seining in the Sura was limited by its steep, muddy banks. We recommend using electroshocking to assess the fish communities in each stream in the future.

Nonetheless, if richness and abundance are similar in the Sabalo and the Sura, other factors may be acting in addition to higher SRP in the Sura. For example, the low pH of geothermal waters could have a direct, negative impact on the fish community. In addition, physical differences between the two streams may obscure the relationship between geothermal water chemistry and fish communities. The elevation gradient is higher in the Sura, resulting in swifter-moving water and fewer pools for fish to inhabit. Furthermore, differences between the streams in levels of primary production may not be as pronounced as we assumed. Because the Sabalo is bordered by pasture, light and nutrient runoff may be elevated, which might increase primary production in this stream. Further studies investigating lower trophic levels may more clearly assess the effects of geothermal stream chemistry on primary productivity. This would help provide a better understanding of the bottom-up processes that shape invertebrate and vertebrate communities in geothermal streams.

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