The Effects of Decreased Flow Rate in Streams due to the Extraction of Water for Human Consumption

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ABSTRACT

Humankind's water needs put more pressure on the natural environment everyday. The effects of decreased flow rate on streams due to the extraction of water for human consumption was studied in Tropical Lower Montane Wet Forests in Monteverde, Costa Rica. Twenty streams and two diverted springs were examined to see how flow rates correlate with macroinvertebrate communities. Reduction of flow rate was found to significantly positively correlate with diversity, abundance, and richness. These decreases on streams worldwide could lead to the loss of diversity because of diminished habitats of species with high endemism.

RESUMEN

Las necesidades de los humanos por agua ponen más presión en el medio ambiente cada día. Los efectos de una disminución en el flujo de extractión de agua para consumo humano fue estudiado en Bosque Tropical Montano Húmedo Bajo en Monteverde, Costa Rica. Veinte quebradas y dos manantiales fueron examinados para ver como la proporción en el flujo del agua se correlaciona con los macroinvertebrados. Cuando bajó la proporción del flujo de agua se notó que también dismiyó la diversidad, abundancia y riqueza de los macroinvertebrados. La reducción de flujo de agua a nivel mundial podrian disminuir la diversidad por causa de la perdida de habitat de especies que tienen alto endemismo.

INTRODUCTION

The demand for water is a growing, worldwide problem that is putting increasing pressure on the natural environment. The minimum amount of water that a person needs is twenty liters a day, about the same amount a first-world person uses with every flush of the toilet (Myers 1997). The amount of water used increases with higher standards of living, until a well-off person in an urban community may consume two hundred liters a day (Myers 1997). Socioeconomic development in Costa Rica coupled with a high population growth rate is putting increasing pressure on Costa Rica's freshwater resources (Gamez 1988). Simply being a tropical country with high rainfall no longer insures adequate water supply. Peninsular Malaysia, having among highest rainfall amounts on earth, now has to ration its water for part of the year. Declines in the quantity and quality of water supplies due to reforestation have also set back public health programs in many humid tropical countries (Myers 1997). Costa Rica is extremely susceptible to similar problems. Its deforestation rate is one of the highest in the Americas, and little forest is predicted to remain outside of the protected areas by the end of the decade (Terborgh 1992).

Deforestation and increasing water use inevitably puts pressure on the biodiversity of the tropics. Deforestation causes habitat fragmentation which is known to lead to the extinction of species (Terborgh 1992). Like fragmentation, decreased water flow in streams may also cause a loss of habitat. The loss of habitat for the larval stages of insects that depend on streams takes even greater importance because of the area's high endemism rates. The Panamanian region, the area between Guatemala and Colombia, contains an unusual abundance of endemic species of insects, particularly in Panama and Costa Rica (Kimsey 1992).

When water is extracted from a stream for human use there is a decreased volume of water in the stream and, thus, a decreased flow rate. Water velocity and the associated physical forces may collectively represent the most important environmental factors affecting the organisms of running waters (Allan 1995). Decreased flow rate may alter the habitat enough to directly change the composition of the organisms that live there. If stream macroinvertebrates decrease in number or go extinct, organisms that interact with them will also be affected, altering the ecosytem's balance. Diverting stream water may also have other indirect effects, such as drying the ground that would otherwise be bathed in spring water flowing down-slope to streams and rivers. This in turn should affect plant species composition and hence other species.

The piping of water directly from streams or springs is a common practice in Costa Rica and many other countries. The Centro de Educación Creativa in Monteverde, Costa Rica, has a private forest that has two springs that are currently being tapped. My study focuses on the school's interest in assessing the biological impact of the diverted water. I observed how the change of water flow affects the macroinvertebrates of the streams. If the macroinvertebrates have decreased in diversity, abundance and/or richness, extinctions could eventually follow.

MATERIALS AND METHODS

The study sites were in the cloud forests of Monteverde, Costa Rica. The streams were all found on the upper Pacific slope above 1500 meters within Tropical Lower Montane Wet Forest. Research was conducted during the end of the dry season in a dry El Niño year. At 20 sites, flow rates and samples of macroinvertebrates were taken from the streams.

At each sample site, the flow rate in liters/second was measured using stream width, average stream depth, and average current velocity. Stream width was measured from the water's edge to water's edge, perpendicular to the flow of the stream. For stream depth, measurements were taken at 1/4, 1/2 and 3/4 of the distance across the same transect used for width. The three values were totaled and divided by four to give the average depth. Current velocity was obtained by laying the ruler along the stream's edge and timing how long it took a buoyant float (for example a twig) to pass 40 centimeters. This was repeated five times to find an average velocity. Flow rate (m^3/s) was computed from the product of width x average depth x velocity, and then converted to L/sec (Resh et al. 1996).

Samples of macroinvertebrates were collected by disturbing bottom sediments (e.g., gravel, mud, leaves) and placing a net downstream to catch organisms. A siphon was also used to gather macroinvertebrates so that at every sample site, one m^2 was examined. At the site or later that day, organisms were picked out of the debris using a tweezers and placed in containers with 70% ethanol to preserve them. After the samples were sorted they were assigned a species designation based on morphology. At least one individual of every morphological species was preserved for comparison.

Besides the data that were collected from the streams, the average flow rate being taken for human consumption from two different springs was measured. The springs that were measured are in the forest belonging to the Centro de Educación Creativa in Monteverde, Costa Rica. This forest is in the same life zone as all of the observed streams, many of them being within a kilometer of the springs. At the time of the study the streams that would have been fed by the springs had dried up. Thirteen of my 20 stream sites were on streams that are downstream from these dried up tributaries. The water from the first spring is piped to the school, where there is a holding tank without a stop valve. The piping from the second spring goes into a container that also has water from other springs adding to it. The piping leaving this container goes to an unknown destination. Flow rate measurements were taken by timing how long it took the piping from the spring to fill a liter container. Ten measurements were taken on three different days to get an average flow rate.

RESULTS

A total of 1112 individuals were found from 20 collection sites. Fifty-one (morpho-species) were identified. Table 1 presents the 11 orders of macroinvertebrates that were represented in the 20 samples. Copepods were found at every site and were 59% of the total individuals found.

Table 1. Macroinvertebrate orders, and the corresponding number of species and individuals found in samples from 20 stream sites.

Order	# of Species	# of Individuals
Copepoda	1	654
Trichoptera	5	150
Ephemeroptera	7	148
Coleoptera	16	60
Hemiptera	7	51
Diptera	8	31
Odonata	2	11
Hymenoptera	2	2
Bivalvia	1	2
Araneae	1	1
Homoptera	1	1
Total	**51**	**1112**

Simple regressions were calculated for flow rate vs. three different parameters: diversity, abundance, and richness. The correlation of flow with diversity, H', rate can be seen below in Figure 1A . There is a very strong trend of increasing diversity with increasing flow rate ($R = 0.79$, $F = 29.64$, $p = 0.0001$). In Figure 1B the relationship between flow rate and abundance (i.e., the number of individuals) reveals a strong positive correlation ($R = 0.57$, $F = 8.62$, $p = 0.0088$). Likewise, in Figure 1C there is a strong correlation of increasing flow rate with increasing richness, number of species ($R = 0.83$, $F = 38.42$, $p = 0.001$).

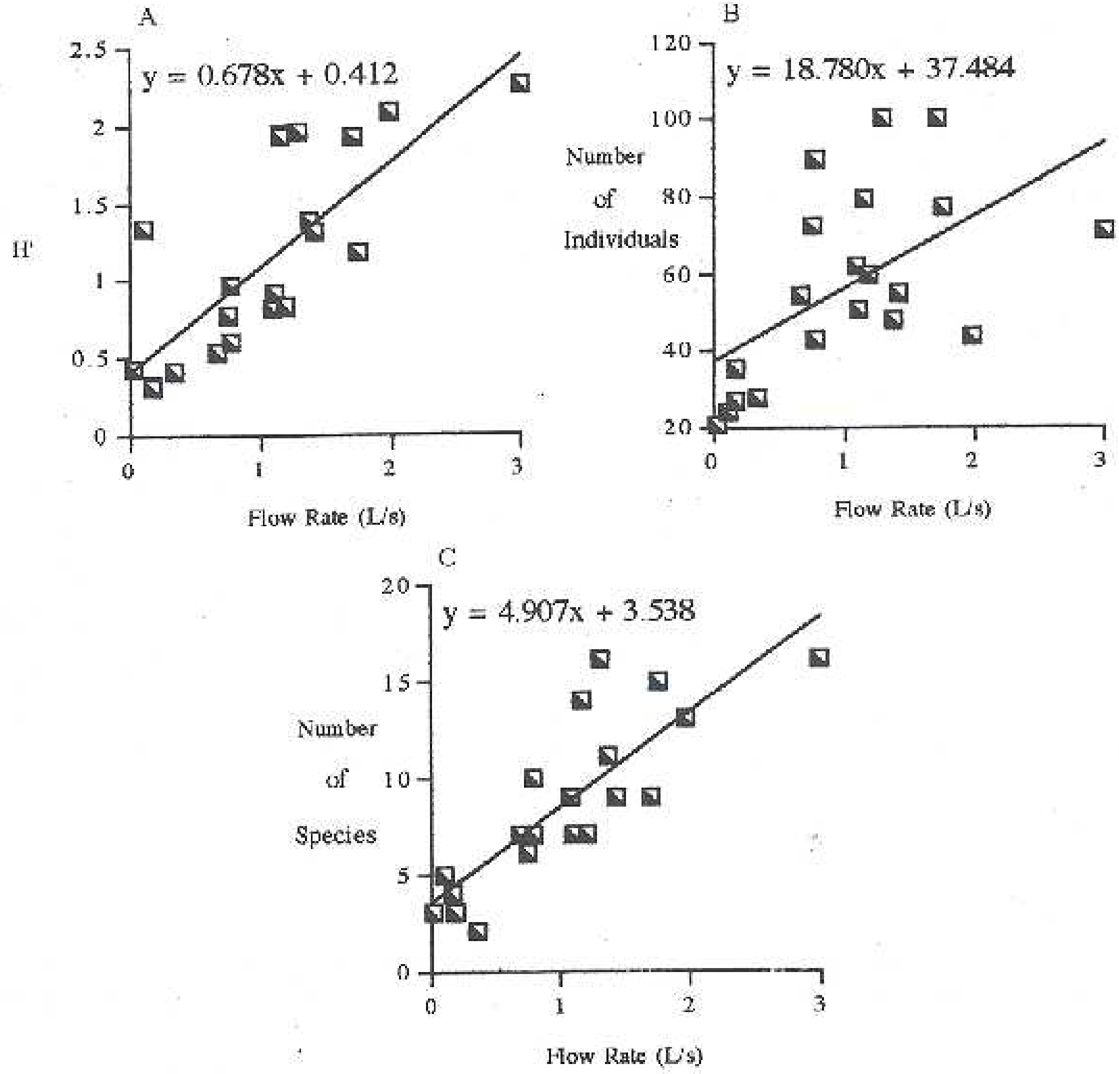

Figure 1. The effect of flow rate (L/s) on macroinvertebrate diversity, abundance, and richness in 20 stream sites. The simple regression graphs with fitted linear curves show a significant correlation between flow rate and (A) H', (B) abundance and (C) richness.

The average flow rate of the spring that leads to the school is 0.653 L/s, over 54,000 liters a day. The piping from the second spring that pours into a container that has additional water sources has an average of 0.187 L/s, and the total water leaving the container has average flow rate of 0.558 L/s.

DISCUSSION

As the flow rate of a stream declines, so does its diversity, abundance and richness of macroinvertebrates. These reductions could be connected with decreased water flow acting as a loss of habitat and decreasing the food resources available to the macroinvertebrates. Many factors, including hydraulic processes, food resources, and nutrient dynamics are known to intimately affect the structure and function of stream ecosystems (Hauer and Resh 1996). My study found that streams with lower water flow rates tend to support fewer macroinvertebrates. Therefore, water being diverted from streams for human consumption negatively affects the composition of the streams. When you reduce a stream by the lower of my two flow rates, 0.187 L/s, H' decreases by 0.127 (from the fitted linear curve $\Delta y/\Delta x = 0.678$; therefore $0.678 \times 0.187 = .127$) Using the equations from the other two parameters, I found that abundance is reduced by 3.51 individuals and richness decreases by 0.918 species. These losses are especially important since water is being diverted from many streams locally and around the world. The diversity of this area is extremely vulnerable to global extinction because of the high endemism and already decreased habitats. Even if the species do not go extinct instantly, the drop in average abundance makes a species extinction-prone. The loss of individuals reduces the available genetic makeup. A population with a reduced genetic makeup may be less able to adjust to avoid a proximate causes of extinction, creating a double-jeopardy because the species are already at a low abundance.

For streams with very low flow rates, a small change could result in complete desiccation, in which case, the predicted reductions in diversity, abundance and richness would underestimate the actual change. There would be a large depletion in the macroinvertebrates because of their dependence on flowing water. An example of severely diminished macroinvertebrate populations would be seen in the dried up streams that would have been fed by the two springs had they not been diverted. During the wet season, or even the dry season of a non-El Niño year, all of the streams in my study may have greater flow and, thus, support more macroinvertebrates. However, the reductions in diversity, abundance and richness due to diverted water will also be greater because the amount of diverted water will increase until the flow in the piping is at its maximum rate. Because these streams act as tributaries to other (secondary) streams, the decreased flow also affects the organisms in the secondary streams. Not only could macroinvertebrates be affected, the balance of the whole community could be disrupted. A reduced prey population may not be able to support as many predators. Reductions could then be seen in many other species because across trophic-level interactions can have cascading effects in a food-web (Blaustein et al. 1994, Dobson and Crawley 1996).

The findings of decreased diversity, abundance and richness from this study should act as a warning flag to communities around the world. Individual water use needs to be kept at a minimum. Improvements to existing and future water extraction systems (for example installing stop valves) could save organisms. Future studies should look for the most biologically friendly ways of supplying water. A balance between human needs and the protection of the environment for the future is a pressing issue that deserves more attention.

ACKNOWLEDGMENTS

I would like to thank Drs. Karen and Alan Masters for their valuable advice throughout my research. I also owe many thanks to Sabastian Irazuzta for his help in finding streams and identifying macroinvertebrates, to Brendan Lucey for guidance with my paper and the Estación Biológica de Monteverde and the Centro de Educación Creativa, especially Jean Godar, for permitting me to research on their land.

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