five hummingbird-pollinated plants were non self-supporting. Although we did not address this question explicitly in our experimental design, our data suggests that selection may favor non self-supporting growth for plants with hummingbird-pollinated flowers, allowing for more energy allocation to flowers. This requires further study in a wider variety of communities.

Literature Cited

Bawa, K. S. and Hadley, M., eds. 1990. Reproductive ecology of tropical forest plants. The Parthenon Publishing Group: New Jersey.

Effects of trout farming on invertebrates in a tropical montane stream

R. M. Brayce, B. J. Garcia, A. E. Hanke, M. A. Novello, and A. E. Santoro

Abstract. We examined the effects of effluent from the trout farm at Cuerici Biological Station, Cerro de la Muerte, Costa Rica, on aquatic invertebrate diversity, abundance, and composition. Stream temperature was slightly higher downstream, while suspended particulate matter did not differ above and below the effluent output. There was no difference in diversity, abundance or composition of stream invertebrates between sample sites located at 10 m and 40 m above and below the input of effluent when rock scrapes and leaf pack sampling methods were combined. However, a greater diversity occurred in leaf samples 40 m upstream than 40 m downstream of the pipe, suggesting that effects of the effluent may be distance-dependent.

Keywords: *aquaculture, diversity, effluent*

Introduction

The trout farm at Cuerici Biological Station at Cerro de la Muerte, which rears approximately 15,000 fish per year, involves diverting a portion of water from one stream and running it through five, large, fish-containing pools. Fish food composed of wheat, fish, and vitamins is added to the pools several times a day. The effluent from the trout farm powers a hydroelectric generator before being released into a second stream, the Quebrada Los Leones.

We examined the impact of trout farm effluent on Quebrada Los Leones. We hypothesized that the diversity, abundance, and composition of invertebrates would be greater below than above the effluent introduction, since this water may contain high concentrations of nutrients and fish excrement. We also predicted that stream temperature would be higher below the site of water introduction as the effluent comes from pools exposed to relatively full sunlight. Finally, because of the high turbidity of the water in the trout pools, we predicted the amount of suspended particulate matter in the effluent and downstream of the outflow would be higher than the water input to the farm and water upstream of the effluent.

Methods

We sampled along Los Leones, east of the Cuerici Biological Station at Cerro de la Muerte, Costa Rica on 29 and 30 January, 1999. The effluent from the trout farm flowed out of a pipe directly into Q. Los Leones. Within Q. Los Leones we selected sampling sites 10 m and 40 m upstream and downstream from the pipe (a total of four sites).

To evaluate basic abiotic characteristics of water in this system, we collected water samples from six sites: the input stream above the trout farm, at the pipe outflow, and the four sites along Q. Los Leones. We then performed a "true-color test" to determine the relative amount of suspended particulate matter at each site. Each sample was poured into a clear glass on a sheet of white paper and left untouched for 2 h to allow any sediment to settle. Samples were then ranked qualitatively on a gradient from least to most sediment. Water temperature was measured three times between 1400 – 1430 hrs at all four sites along Q. Los Leones, using a Sensortek Bat 12 temperature probe.

Two methods were used to sample invertebrates above and below the effluent. First, at the four sampling sites, we selected a submerged rock approximately 20 x 10 x 15 cm from the nearest three riffles. Before removing each rock, we placed a kick net immediately downstream from the rock to catch any invertebrates washed off the rock during removal. We then scraped all invertebrates off each rock and stored them in alcohol.

The second sampling method involved collecting three submerged leaf litter samples from the stream ("leaf packs") at all four sites. Leaf packs were of approximately equal volume (0.5 l), and were stored in Ziplock_ bags until sorted. All invertebrates were identified to order and family when possible using keys in Pennak (1978). Composition was calculated as the proportion of individuals in each taxonomic group at each site. Diversity (H) was calculated using the Shannon Diversity Index as described by Begon et al. (1990).

Results

The true-color test ranked sites as follows (least to most sediment): pipe; input water to the trout farm; 10 m downstream; 10 m upstream; 40 m upstream; 40 m downstream. Also, temperatures were higher at sites below the pipe (12.3 ± 0.02) than above the pipe (12.0 ± 0.03; Kruskal-Wallis: X^2=8.8, df=1, P=0.003).

We found a total of 1466 invertebrates, keyed to 10 orders and 17 families (Appendix A). With data from rock and leaf samples combined, invertebrate diversity was not significantly different between combined sites upstream from the pipe and those downstream (Fig. 1; Kruskal-Wallis: X^2=1.08, df=1, P=0.30).

When diversity in rock and leaf samples were analyzed individually, the diversity was also not significantly different between combined sites upstream and downstream. However, the leaf sample 40 m upstream had a significantly greater mean invertebrate diversity (n=3, Shannon Diversity Index, H=1.54 ± 0.12) than that 40 m downstream (n=3, Shannon Diversity Index, H=1.36 ± 0.04; Kruskal-Wallis: X^2=3.86, df=1, P=0.05). Leaf samples 40 m upstream had both higher richness (n=3, 8.3 ± 0.67; Wilcoxon: X^2=0.83, df=1, P=0.36) and evenness (n=3, J=0.73 ± 0.05; Wilcoxon: X^2=1.19, df=1, P=0.28) than leaf samples 40 m downstream (n=3; richness: 7.7 ± 0.33; evenness: J=0.67 ± 0.03).

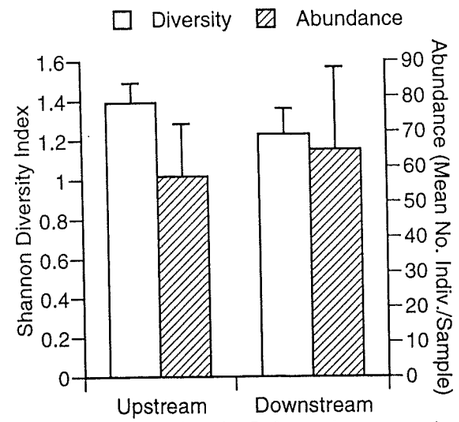

Fig. 1. Shannon Diversity Index and mean number of invertebrate individuals per sample collected using rock and leaf sampling methods for four sites, (10 m and 40 m upstream and downstream) from trout farm outflow (mean ± 1 SE). Neither diversity nor abundance was significantly different (Diversity, P=0.30; Abundance, P =0.91).

For both leaf and rock sampling methods, there was no significant difference among invertebrate abundance between sample sites above and below the pipe (Fig. 1; Kruskal-Wallis: X^2=0, df=1, P=1.00 and Kruskal-Wallis: X^2=1.5, df=1, P=0.22, respectively). Composition of invertebrates was similar among all sample sites (Fig. 2).

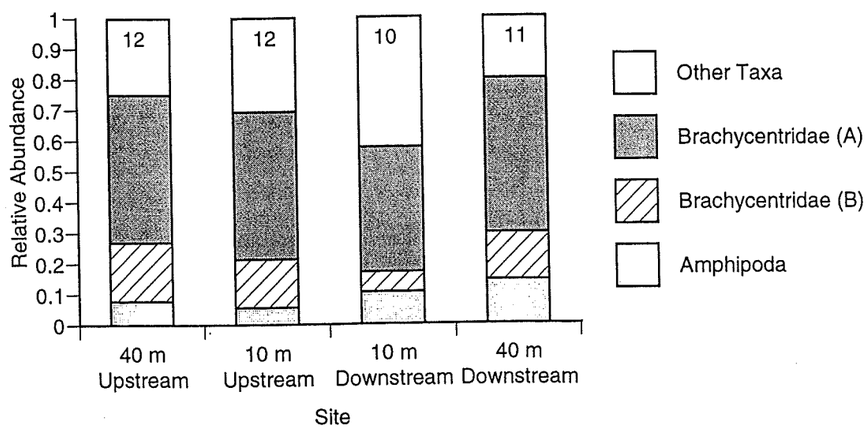

Fig. 2. Abundance of common invertebrate groups encountered in a stream at Cuerici Biological Station, Costa Rica. Sites do not differ in species composition. Numbers indicate taxonomic groups represented by the "other taxa" category. A and B are two different morphotypes of Brachycentridae (Trihcoptera). Distances are from site where trout hatchery outflow enters the stream.

Discussion

Discharge from the Cuerici trout farm had little measurable effect on the invertebrate diversity, abundance, or composition in the stream, Quebrada Los Leones. A significantly greater invertebrate diversity, however, was found in leaf packs at 40 m upstream compared to 40 m downstream from the pipe. This suggests that nutrients may not be immediately incorporated into the system, and therefore not affect invertebrate composition so close to the effluent outflow. However, this result could also be due to changes in invertebrate diversity with elevation or to a dilution effect caused by increased stream volume below the pipe. Both of these alternate explanations need further investigations.

As predicted, stream temperature was highest downstream from the pipe, possibly due to the input of water warmed in the dark-colored trout pools. Alternatively, this small temperature difference might be attributed to differences in elevation or in forest canopy cover, conditions that were not controlled for in our study.

Although dissolved nutrients not measured in the study, such as nitrogen and phosphorous, may affect stream quality, we found no evidence that the addition of outflow from the trout farm increased the amount of suspended particulates in the stream. Trout farm maintenance requires that sediment deposits are cleaned out from the pools on a regular basis, which may account for the low amount of suspended particulates released from the outflow pipe. This further reduces the possibility that the trout farm will have little substantial effect on the Quebrada Los Leones or its invertebrate population, at least within 40 m of effluent output.

Acknowledgements

We would like to thank Carlos Solano and Alberto Torres for their patient explanation of the history and details of the trout farm.

Literature Cited

Begon, M., J. L. Harper, & C. R. Townsend. 1990. Ecology: Individuals, Populations and Communities. Second Ed. Boston: Blackwell Scientific Publications. p. 618.

Pennak, Robert W. 1978. Fresh-water invertebrates of the United States. Second Ed. New York: John Wiley & Sons.

APPENDIX A: Taxonomic groups of invertebrates found in Quebrada Los Leones at 10 and 40 m upstream and downstream from trout farm effluent, Cerro de la Muerte, C.R. *Hirudinea is a class level designation.

Order	Family	Upstream 40 m	Upstream 10m	Downstream 10 m	Downstream 40 m
Amphipoda	Unknown	25	20	16	89
Coleoptera	Amphizoidae	1	2	1	0
	Dryopidae	0	2	0	1
	Carabidae	0	0	2	0
	Haliplidae	0	0	6	0
	Unknown	31	19	8	16
Diptera	Unknown	16	47	35	38
Ephemeroptera	Ephemeridae	1	0	0	0
	Heptageniidae	0	1	1	1
	Leptophlebiidae	1	0	0	0
	Tricorythidae	0	1	0	0
	Baetiidae	11	9	2	19
	Unknown	1	0	0	2
Isopoda	Asellota	3	0	0	1
Hirudinea*	Unknown	2	1	0	1
Mollusca	Unknown	10	10	1	14
Odonata	Unknown	0	0	1	0
Plecoptera	Perlidae	2	4	4	9
Trichoptera	Brachycentridae(A)	156	174	62	314
	Brachycentridae(B)	62	57	10	96
	Hydrodpsychidae	2	8	4	20
	Leptoceridae	1	1	0	0
	Rhyacophilidae	0	1	0	5
Total		**325**	**362**	**153**	**626**