The Impact of Point Source Pollution from Santa Elena on a Local River

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Abstract

Rio Nuevo, a river that runs through the hub of Santa Elena, Costa Rica, receives large inputs of gray water and oil several times a week from the town. Stream invertebrates were collected and identified from three sites on the river: upstream from the road to Santa Elena, immediately after the road where the contaminants enter the stream, and 20 meters downstream from the road. Three other local streams were evaluated where they crossed roads as well; turbidity, velocity, stream width, and depth were recorded as well. Nested ANOVAs indicated that Rio Nuevo experienced a significant reduction in species diversity, richness, and abundance as compared to the other rivers' sites. Analysis of the few organisms present at the post-pollutant sites as bioindicators revealed that the sites were highly disturbed. The other rivers included in the study were also found to be anthropogenically altered, all exhibiting a depression in diversity just after the roads and some sites notably impacted by industrial or agricultural waste. It is hoped that this study will provide incentive for the town of Santa Elena to consider other methods of domestic waste disposal, as the health of Rio Nuevo has been seriously effected by current practices.

Introduction

Throughout human history, populations have disposed of their waste in local waterways. This has the effect of diluting the waste and carrying it away from the producer (Brewer 1979). In ancient times, these practices were not harmful due to low population densities and the absence of urbanization.

The global trends of exponential population growth and rapid industrialization have had a dramatic impact on the health of streams, lakes, and the oceans themselves (Soulé, 1986). Pesticide use has increased nearly exponentially in the last twenty years, air pollution falls as acid rain into aquatic systems, fertilizer runoff has greatly elevated the rate of eutrophication of lakes, and domestic sewage and other waste have increasingly found their way into local waterways. Perhaps the most widespread pollution is associated with domestic waste; typically black water, detergents, and garbage (Whittaker, 1975).

The Monteverde/Santa Elena region of Costa Rica is currently facing many of the problems associated with rapid population growth. A "hot-spot" for ecotourists, the town has recently begun attracting thousands of visitors a year. The impacts of this boom are clearly visible in the hub of Santa Elena: a steady stream of gray water, issuing from an estimated 75% of the homes and businesses, flows freely from the homes to the street, then down a hill to a stream. A mechanic shop changes the oil of an estimated 6 buses a week and the oil waste (approximately 1 liter per bus), left in the street, follows the gray water down the hill with the next rain. Both enter a nearby stream, Rio Nuevo, at the bottom of the hill where it crosses the road. Rio Nuevo then joins up with the Quebrada Sucia, and eventually with the Rio Guacimal, a very large river that drains into the Golfo de Nicoya.

Oil pollution has had a well-documented impact on the health of coral reefs, where it has resulted in severe reductions in sea birds and shore life (Soulé, 1986). Detergents that contain phosphates have been shown to upset the nutrient balance in water systems, resulting in rapid eutrophication of lakes. Those that do not contain phosphates are resistant to decomposition, causing foaming and toxicity in aquatic systems (Whittaker, 1975).

Robert H. Whittaker (1975) noted that severe environmental stress, such as pollution or a high rate of erosion, will result in greatly reduced species diversity in local communities. Pollution in aquatic environments results in decreased productivity, biomass, and community diversity. Although the nature of the detrimental inputs varies widely, as does their impact, there is a clear trend of species retrogression in affected water systems. For this reason, invertebrates serve as useful bioindicators of the health of streams. It was hypothesized that Rio Nuevo would display ~~greatly~~ reduced stream invertebrate diversity as a result of the pollution issuing from Santa Elena when compared to three other streams. It is hoped that this study will encourage both the residents of Santa Elena and the Water Quality Commission to consider alternate methods of waste disposal.

Materials and Methods

Study Sites

Three streams were selected in addition to Rio Nuevo for inclusion in this study. Quebrada Máquina, a river that originates north of the Belmar Hotel in Santa Elena was analyzed ~~by~~ La Cascada discotheque. Quebrada Sucia, which originates north of the Hotel Heliconia in Santa Elena, was studied ~~By~~ the site for the Santa Elena cultural museum. A larger river which originates in Monteverde, Rio Guacimal, was analyzed where it passes under a bridge by the Monteverde cheese factory. These were selected because they crossed a road near an area of high human development but did not have a point source input of pollution at the road and because they had similar microhabitats. Samples for each river were taken upstream from the road, after the road, and 20 meters downstream from the second sample to allow insight into the recovery rate of the invertebrate communities. Four samples were taken at each of the 12 sites.

Since species diversity has composition have been shown to vary widely with the microhabitat of the river (Guillozet, 1993), samples were taken in areas with rocky stream beds. The location of the second sample varied within a five meter range of the road for this reason, in order to allow consistent sampling of this microhabitat. It is thought that variance in the type of stream bed sampled would confound the data more than this slight variance in distance.

Sampling Technique

An aquatic net was placed level with the stream bed and the rocks raked in a one m^2 area to free any organisms upstream of the net. All rocks were examined and brushed clean to remove case-builders and clinging invertebrates. The net was then emptied into a bucket and the organisms removed and preserved in alcohol. Each successive sample was taken either immediately upstream or to the side of the previous sample to avoid any disturbance of future sites. The insects were identified to the family level and as morpho species thereafter.

Velocity readings were taken at each of the 48 sample sites, as well as the stream depth and width. Water samples taken at each of the 12 sites were evaluated for turbidity using a spectrophotometer (it is thought that the variance of turbidity within the clustered site replicates would vary by an insignificant amount, so 12 samples were taken rather than 48). All water samples were taken on the same day to avoid complications due to rainfall.

Statistical Analysis

Shannon-Weiner Indices (SWI) of Diversity were obtained for each of the 48 samples. These indices were used in a Nested ANOVA and the differences between the four post-road sites and four recovery sites on the each of the rivers evaluated, to isolate any potential difference in the recovery rate of

Rio Nuevo. Nested ANOVAs were also performed to contrast the species richness of the upstream, post-road, and recovery sites; as well as for the total number of individuals found in each sample. The data for turbidity, stream width, sample depth, and velocity were evaluated for trends associated with diversity (SWI) using the Spearman-Rank Correlation Coefficient. Turbidity was contrasted with average site diversity. The level of significance for all tests was set at p=.05.

Results

Averages of diversity (SWI) revealed that the lowest levels of diversity were recorded at the post-road and recovery sites of Rio Nuevo (Table 1). These sites also exhibited the most dramatic reductions in species abundance and richness from the upstream sample. Quebrada Máquina had the highest average species diversity for all three sites.

The Nested ANOVA that contrasted post-road and recovery sites indicated that only Rio Nuevo differed significantly from the other rivers in terms of site diversity (vs. Máquina, P<.0001; vs. Sucia, p<.0001; Guacimal, p<.0001). Species richness was found to be significantly different between Rio Nuevo and Rio Guacimal (p=.0014), and Rio Nuevo and Quebrada Máquina (p=.0011). The ANOVA indicated a significant difference in numbers of individuals between Rio Guacimal and Rio Nuevo (p=.0005), Quebrada Sucia (p=.005), and Quebrada Maquina (p=.0249).

Water velocity was shown to be positively correlated with species diversity (Spearman-Rank, p=.01241; Fig. 1). Likewise, it was indicated that an increase in stream width was significantly correlated with an increase in invertebrate diversity (p=.0018, Fig. 2). Neither turbidity nor stream depth were correlated with diversity of the sites.

Discussion

Numerous studies have indicated that natural and undisturbed aquatic systems will display a high level of diversity, including the presence of sensitive species (Lehmkuhl, 1979). Conversely, it has been shown that at high degrees of disturbance, organismal life is greatly diminished or completely absent (Resh *et al.*, 1988). The results obtained in this study strongly indicate that Rio Nuevo is a highly damaged aquatic ecosystem, but it is necessary to consider all possible factors before stating this conclusion.

The construction of roads and bridges along rivers is often associated with increased sediment loading and a subsequent decrease in water oxygen levels (Whittaker, 1975). Although all four rivers were shown to have some degree of reduced diversity just after the roads; Quebrada Máquina, Rio Guacimal, and Quebrada Sucia all displayed significant recovery capacity downstream of the road, returning to a level of diversity similar to the upstream sites. Rio Nuevo, however, exhibited greatly reduced resilience at its "recovery" site. It is important to note that there were no other sources of pollution between the latter two sites in this river. This river exhibited relatively high diversity upstream of the disturbance, and since small differences in turbidity were shown to have an insignificant effect upon species diversity, it can be concluded that the disturbance altering the invertebrate communities in Rio Nuevo goes beyond that of the road alone.

Previous studies have shown that physical characteristics of streams greatly effect stream invertebrate composition and diversity (Resh *et al.*, 1988). The positive correlations between both stream width and diversity, and velocity and diversity, seem to suggest that these trends may explain the decreased diversity of the river after the road. However, although it is true that Rio Nuevo is relatively slow and narrow, the average upstream diversity was very high. The pre-road diversity values were higher, in fact, than the values obtained for both Quebrada Sucia and Rio Guacimal. The velocity of Rio Nuevo actually increases after the road, suggesting that the sharp decline in invertebrate organisms is due to a cause other than stream speed or width.

An examination of the family composition of the various sites yields new insight into the health of the aquatic ecosystem. Biotic Indices given by Lehmkuhl (1979), assign a value ranging from zero to five to aquatic invertebrates, a value of zero indicating extreme intolerance to pollution, and a value of five indicating an ability to survive in great amounts of pollution (Table 2). Rio Nuevo's upstream samples contained numerous Plecopterans (Families Perlidae and Nemouridae) that both have a BI of 0, as well as a caddis flies (Family Molannidae) which have a BI of 1. The presence of these indicators of stream health, coupled with the high level of diversity of the site, is evidence of the pristine condition of Rio Nuevo before the introduction of contaminants. After the road to Santa Elena, however, when organismal life was present, it consisted solely of members of the Family Hydropsychidae (BI=4), earthworms, and flat worms. All of these are indicators of very disturbed areas. It should also be noted that 3/8 of the downstream samples completely lacked invertebrate life

Quebrada Sucia, at first glance, follows the same trends as the other two controls - a slight dip in diversity after the river, then increase of diversity at the recovery site. However, the bulk of the species and individuals at the upstream site are those that are tolerant of moderate-to-high levels of disturbance (Baetidae, BI=2.5; Hydropsychidae, BI=4; Chironomidae, BI=5). Bearing this in mind, the health of the river actually appears to improve after the river, where more sensitive families are found (Plecopterans, etc.). Several residents of the community, when asked to explain this trend, stated that there is a cattle farm upstream, near the Hotel Heliconia, where large amounts of cattle dung are actively being deposited in the river. It is thought that this is the best explanation for why the region before the road displays this disturbance-adapted community.

It is well known among ecologists that selection of perfect natural controls is impossible, as there are a multitude of variables that may confound the data. Selection is especially difficult in areas with strong anthropogenic influences, as these add many more dimensions to the investigation. The rivers used as controls in this study were sufficiently suited for comparison, but were far from pristine, unpreturbed habitats. Trash lined the bank of the Rio Máquina; trash was collected with nearly every sample in Quebrada Sucia; a trash dump, located behind the Cascada discotheque in the Quebrada Máquina, festered in the water; and foul-smelling wastes issued from the cheese factory. It is also very difficult to isolate the points at which other contaminants may be entering the streams, since many houses line the banks and many area residents seem to think of the streams as depositories for trash, gray water, and other wastes.

Two trends strongly provide evidence that the point source pollution from Santa Elena is having dramatic effects on the invertebrate communities of Rio Nuevo. The first is the prolonged depression in species diversity after the road, the point where the contaminants enter the stream. This failure to recover from the disturbance caused by the road itself (increased sedimentation, etc.) is significantly different from the other streams. Secondly, the post-pollutant stream contains a very different type of community than before the road, all bioindicators of extremely poor conditions.

The residents of Santa Elena, in cooperation with government officials, must begin to investigate less environmentally stressful methods of waste disposal. As ecotourism grows in this area, the number of buses that await oil changes will increase, the amount of gray water produced will increase, the amount of trash produced will increase, and the potential detrimental impact on local natural systems will increase. The short-sighted practices of carelessly depositing oil and gray water waste into the water systems must be realized and stopped. Clean water is not only important for invertebrate diversity, it is important for all levels of life, including human.

References

Brewer, R. 1979. Principles of Ecology. Saunders County Publishing, Philadelphia.

Guillozet, P.H. Habitat Heterogeneity and Species Diversity of Aquatic Macroinvertebrates in a Monteverde Stream. Unpublished data. 1993.

Lehmkuhl, D.M. 1979. How to Know the Aquatic Insects. Wm. C. Brown Company Publishers, Dubuque.

Resh, V.H., A.V. Brown, A.P. Covich, M.E.Gurtz, H.W. Li, G.W. Minshall, S.R. Reice, A.L. Sheldon, J.B. Wallace, and R.C. Wissmar. The Role of Disturbance in Stream Ecology. Journal of the North American Benthological Society 7(4):433-455.

Soulé, Michael E. 1986. Conservation Biology: The Science of Scarcity and Diversity.

Whittaker, R.H. 1975. Communities and Ecosystems. Macmillan Publishing Co., New York

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TABLE 1. *Average Diversity, Richness, and Abundance for the 12 Sites*

	Ave. # Spp	Ave. # Ind.	Ave. Diversity
Rio Nuevo			
Upstream	10.5	49.25	1.629
Post-Road	1	1	0.173
Recovery	0.75	1	0.275
Rio Maquina			
Upstream	10.75	30.75	1.712
Post-Road	6	17.5	1.301
Recovery	9	41.75	1.628
Quebrada Sucia			
Upstream	4.75	13	1.642
Post-Road	5.5	26.5	1.379
Recovery	5.5	38.75	1.513
Rio Guacimal			
Upstream	10.75	55	1.132
Post-Road	6.25	66.75	1.323
Recovery	8.5	50.75	2.14

Table 2. *Biotic Indices from Several Sampled Invertebrates (adapted from Lehmkuhl, 1979)*

Taxonomic Group	Pollution Tolerance Score
Plecoptera	
Nemouridae	0
Perlidae	0
Ephemeroptera	
Baetidae	2.5
Ephemerellidae	0.5
Tricorythidae	2
Odonata	
Gomphidae	0.5
Coenagriaonidae	3
Trichoptera	
Hydropsychidae	4
Molannidae	1
Coleoptera	
Tipulidae	2

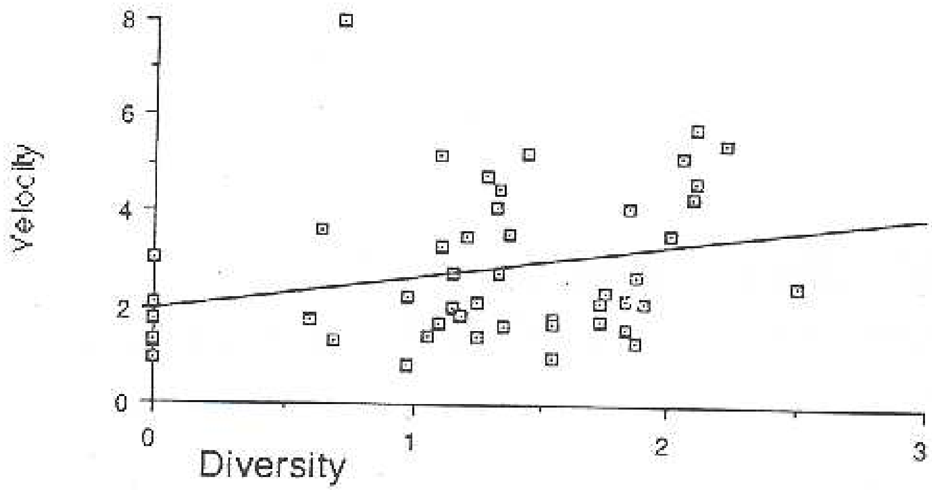

Figure 1. Spearman-Rank Correlation Between Velocity and Diversity (SWI) for each of the 48 sites

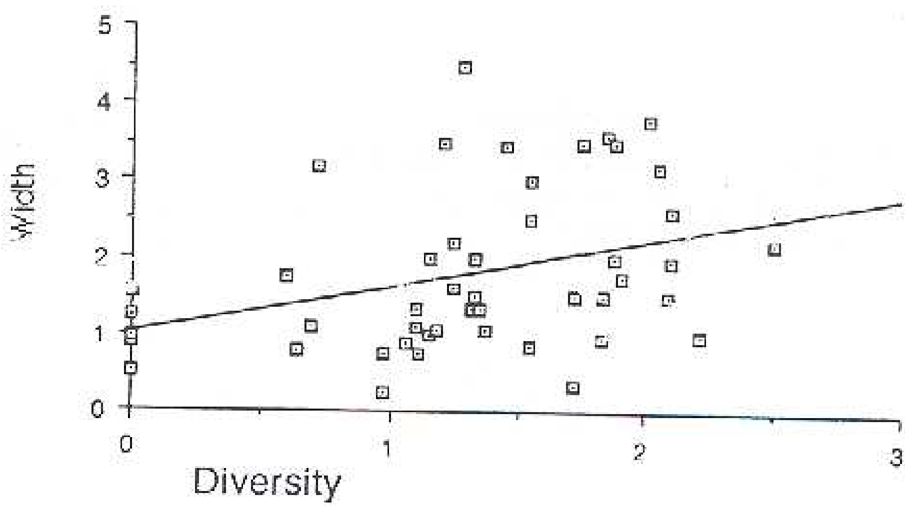

Figure 2. Spearman-Rank Correlation Between Stream Width and Diversity (SWI) for the 48 sites