The Monkey River baseline study : basic and applied research for monitoring and assessment in southern Belize [electronic resource] /

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The Monkey River Baseline Study: Basic and Applied Research for Monitoring and Assessment in Southern Belize
(Under the Direction of CATHERINE M. PRINGLE)

The Monkey River Baseline Study had three specific objectives: (1) to describe fish communities, river habitat, and water chemistry; (2) to characterize and map impact "hotspots" along the river; and (3) to modify and apply the United States Department of Agriculture stream visual assessment protocol (SVAP). Compositional attributes of the Monkey River fish assemblage showed clear distributional patterns, and assemblage structure related significantly to abiotic factors at local- and landscape-scales. A new spatially explicit methodology was developed to estimate the relative expected intensity of stresses to aquatic ecosystems based on mapped stress-sources along a river. Results of SVAP application indicated that the tool was well suited for application in southern Belize with minimal modifications. Recommendations for future work include expansion of baseline research to five additional watersheds in southern Belize, validation of predictions for impact mapping, and creation of a training program to promote consistency of SVAP application.

INDEX WORDS: Monkey River, Belize, Stream ecology, Rivers, Monitoring, Assessment, Fish assemblages, Mapping, SVAP

THE MONKEY RIVER BASELINE STUDY: BASIC AND APPLIED RESEARCH FOR MONITORING AND ASSESSMENT IN SOUTHERN BELIZE

by

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CHAPTER 1

INTRODUCTION

The Monkey River watershed in southern Belize, Central America, is part of a larger landscape management area known as the Maya Mountain Marine-Area Transect (MMMAT). The MMMAT is a one million-acre corridor, connecting the Maya Mountains to the Belize Barrier Reef that has been recognized for its high conservation value and potential for preservation of biodiversity and critical habitats (BCES 1990; Heyman et al. 1995; Programme for Belize 1995). The area encompasses 29 of 78 vegetation types found in Belize (BCES 1990), and contains seven protected areas including the Bladen Nature Reserve, the "jewel" of the Belize protected areas system. The MMMAT is home to numerous rare and endangered species, including jaguar (*Panthera onca goldmani*), ocelot (*Felis pardalis*), margay (*Felis wiedii*), Baird's tapir (*Tapirus bairdii*), manatee (*Trichechus manatus*), Morelet's crocodile (*Crocodylus moreleti*), and scarlet macaw (*Ara macao*).

The MMMAT consists of six watersheds that feed Port Honduras in the coastal zone. Of these six watersheds, the Monkey River is the largest and most heavily polluted. Multiple stressors affect the Monkey River ecosystem and have potential secondary effects on the coastal zone and the Belize Barrier Reef. Land uses in the watershed include intensive banana, mango, and citrus cultivation, timber extraction, and shrimp aquaculture. Riparian forest clearing and sediment runoff from these activities threaten local biodiversity and ecological integrity (Esselman and Boles in press).

Sediment and agrochemical pollution entering the coastal zone threaten primary productivity of mangroves and seagrass beds (Heyman et al. 1995), endanger offshore fisheries, and potentially compromise coral recruitment (Hunte and Wittenberg 1992).

Human settlements are similarly affected by pollution. Inhabitants of Monkey River Village, at the river's mouth, report loss of a potable water source, population declines in river fishes traditionally used for subsistence, and reduced flow (Harris Coleman, Monkey River Village, pers. comm.). Altered river hydrologic regime has been identified as a potential cause of severe beach erosion experienced by the community, resulting in the collapse of several homes into the sea. Community members now question the quality of the river on which their village has relied for over a century.

Heyman et al. (1995) clearly identified the need for a river monitoring system in the MMMAT to assess river degradation, describe ecosystem conditions, and provide scientific information to conservation practitioners. For these reasons, the Monkey River Baseline Study was developed as a first step toward a comprehensive system of river monitoring in the MMMAT.

The scientific aim of this study was not to test specific hypotheses but to ask broad descriptive questions designed to: (1) document the current ecological state of the river; (2) help prioritize future research activities; and (3) inform local stakeholders as to river condition. The paucity of river research in Central America (see Pringle et al. 2000) and Belize (Esselman and Boles in press) necessitates such descriptive studies prior to hypothesis testing.

This study was completed in conjunction with the Belize-based Toledo Institute for Development and Environment (TIDE) and The Nature Conservancy (TNC). Within

The Nature Conservancy Freshwater Initiative, the MMMAT has been given the status of "Demonstration Site". According to the Freshwater Initiative, demonstration sites "…are expected to test new or expanded applications of conservation strategies, monitor the variables expected to respond to the strategies, and evaluate the biological impact of those actions" (TNC 1999). This thesis documents both new and expanded applications for rapidly assessing ecosystem condition, and also describes basic ecosystem patterns for the first time.

The Monkey River Baseline Study had three specific objectives: (1) to describe fish communities, river habitat, and water chemistry; (2) to characterize and map impact "hotspots" along the river; and (3) to modify the United States Department of Agriculture Natural Resource Conservation Service stream visual assessment protocol (SVAP) to be MMMAT-appropriate. Each of these objectives is detailed in its own chapter in this document. The second chapter details the first objective, and was written for scientific publication. The third and fourth chapters describe the second and third objectives respectively, and were originally written as consultancy reports for a general audience of Belizean stakeholders.

Literature Cited

Belize Center for Environmental Studies (BCES). 1990. Belize Critical Habitat Survey. Unpublished report, Belize Center for Environmental Studies, Belize City.

Esselman, P.C. and E. Boles. In press. Status and future needs of limnological research in Belize. In R.G. Wetzel and B. Gopal (eds.) Limnology in Developing Countries, volume 3. International Association of Limnology.

Heyman, W., W. Maheia, S. Franklin, and L. Nicolait. 1995. Maya Mountain-Marine Area Transect: A Synthesis to Assist in Integrated Planning and Management. Unpublished report, Belize Center for Environmental Studies, Punta Gorda, Belize.

Hunte, W. and M. Wittenberg. 1992. Effect of eutrophication and sedimentation on juvenile corals. Marine Biology 114: 625-631.

Pringle, C.M., F.N. Scatena, P. Paaby-Hansen, and M. Núñez-Ferrera. 2000. River conservation in Latin America and the Caribbean. Pages 42-77 in P.J. Boon, B.R. Davies, and G.E. Petts (eds.), Global Perspectives on River Conservation: Science, Policy, and Practice. John Wiley and Sons Ltd, New York, NY.

Programme for Belize. 1995. Towards a National Protected Areas System Plan for Belize. Programme for Belize and Inter-American Development Bank, Belize City.

The Nature Conservancy (TNC). 1999. Watershed Action: Partnering for Conservation Breakthroughs. http://www.freshwaters.org/ccwp/action.html.

CHAPTER 2

LANDSCAPE- AND LOCAL-SCALE INFLUENCES ON FISH ASSEMBLAGE COMPOSITION AND STRUCTURE IN THE MONKEY RIVER, BELIZE[1]

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[1] Esselman, P.C. 2001. To be submitted to Environmental Biology of Fishes.

Abstract

This paper focuses on how abiotic phenomena influence fish assemblages of the 120 km long Monkey River in southern Belize, Central America. Specifically, I investigated: (1) how distance from the sea influences fish assemblages at the watershed scale, and (2) how abiotic factors at two scales (landscape and local) influence assemblages in the headwaters. Results showed that the Monkey River assemblage consisted of three faunal groups in the headwaters, coastal plains, and the delta. The former two groups were dominated by freshwater and salt-tolerant species, and the delta group largely consisted of marine species. Distance from sea was significantly negatively related to assemblage richness, diversity, and evenness.

In headwater streams, both landscape- (longitudinal position, elevation, and geology) and local-scale (stream size and habitat structure) variables were important structuring factors. Headwater pool richness was negatively related to distance from sea. Elevational differences (low, medium, high categories) in richness and diversity proved significant in riffle habitats, with middle elevation riffles having the highest values, followed by low then high elevation stations. Significantly greater fish densities and herbivore abundances were present in stations located in granite/metasedimentary geology versus stations underlain by extrusive/limestone rocks, a result potentially tied to phosphorus-enriched waters in the former geology. Pool assemblage diversity was positively related to variance in substrate size at extrusive/limestone stations only, suggesting that heterogeneous substrates promote diversity in these streams. Significant local-scale relationships that held across geologic types included a negative relationship

between species diversity in runs and average depth, and a positive relationship between run species richness and average estimated fish cover.

Previous studies in Central American freshwater streams have suggested that faunal zonation can result from geomorphic discontinuities or strong physicochemical gradients (e.g., across the freshwater/marine ecotone), and that local variables (such as habitat size and heterogeneity) strongly influence fish assemblage structure. Results from this study suggest that faunal zonation can occur in the absence of dispersal barriers or strong environmental discontinuities. Results from this study also suggest that local variables are important in some habitats, but that responses are meso-habitat specific (e.g., different in riffles, runs, and pools), and that the strength of landscape-level abiotic factors often override the local-level variables. Consideration of longitudinal position, elevation, and geology is recommended in future studies.

Introduction

Our understanding of abiotic factors influencing Central American fish assemblages is generally acknowledged to be weak (Lowe-McConnell 1987). Foundational work in the region has focused on landscape-scale patterns in assemblage composition and structure (Rodiles-Hernández et al. 1999), local-scale fish-habitat relationships in small streams (Gorman and Karr 1978; Angermeier and Schlosser 1989; Winemiller 1983), or both (Bussing and Lopez 1977, Lyons and Schneider 1990, Winemiller and Leslie 1992). With one exception (Rodiles-Hernández et al. 1999), all of these studies were completed in Costa Rica or Panama where the assemblage is distinctive from the north (Bussing 1976).

This work was completed in the northern part of the region (Belize) and focused on both of the spatial scales evaluated in prior studies (landscape and local). Part of the landscape-level analysis presented here is similar to previous studies on basin-wide longitudinal patterns in the region in that it examines distinctions in the assemblage relative to distance from sea. The analysis of headwater streams presented here differs from prior studies in that (1) it explicitly incorporated landscape-scale considerations other than longitudinal position, and (2) it was conducted on larger streams than most of those studied previously.

The specific questions addressed are:

1. How do fish assemblage composition and structure (species richness, diversity, and evenness) change along a longitudinal gradient from the mountains to the sea?

2. Does longitudinal position have an obvious effect on assemblage structure in headwater pool, run, and/or riffle habitats?
3. Does headwater assemblage structure reflect underlying geology?
4. How do local factors, such as stream size and habitat structure, relate to assemblage structure in pools, runs, and riffles?

Materials and methods

Site description

The rivers of southern Belize flow from the Maya Mountains east-southeast to the Caribbean Sea. The area receives in excess of 3000 mm of precipitation annually in distinct wet and dry seasons, which cause periods of flooding and drought. Most precipitation occurs during the wet season from July - October when river discharges account for approximately 84% of the annual total (Heyman and Kjerve 1999). The dry season is characterized by low precipitation and stable base flow conditions with occasional low flood pulses.

The Monkey River is the fourth largest river in Belize with a total drainage area of 1,275 km^2 (Lee and Stednick 1995). The river consists of three major branches that drain the Maya Mountains, join in the coastal plain, and enter the Caribbean Sea as a sixth order stream (Figure 2.1). The headwaters drain two distinctive geologies (Bateson and Hall 1977). The Bladen Branch of the river drains the Bladen Volcanic Member, a regionally anomalous zone of acidic extrusive volcanic rocks ringed by Cretaceous limestone. On the other side of the watershed, the Swasey Branch drains granite and metasedimentary rocks more typical of the Maya Mountains massif. Between these larger branches lies the Trio Branch, which shares both geologies and enters the Bladen Branch as a 5th order tributary (Bateson and Hall 1977).

The headwaters of the Monkey River are blanketed by tropical broadleaf forest, and are entirely protected in three contiguous reserves. In the coastal plain, all branches flow through a matrix of human-influenced landscape types including intensive banana and citrus cultivation, gravel mining, and subsistence agriculture. Sedimentation, trophic alteration, and nutrient enrichment from these activities have been identified as potential threats to aquatic ecological integrity (Chapter 3; Esselman and Boles in press). The lower reaches, from the Bladen-Swasey confluence to the Caribbean, are largely undeveloped and currently utilized for ecotourism activities by local communities.

Sampling stations were selected randomly from trunk streams of fourth order or greater within six distinct physiographic regions (Figure 2.2, Table 2.1). Within each region three stations were selected with the exception of the Swasey mid-elevation region (R5) where six were selected (to accommodate its greater size and human influence) for a total of 21. Two stations on the lower Trio Branch were mostly dry when visited and dropped from this analysis, and one station (PR01) was added on the Bladen Branch where data were collected during training exercises. In all, eight stations from the headwaters, nine from the coastal plain, and three from the low-lying Monkey River delta (Figure 2.3) were included in this analysis.

Sampling methods

Habitat structure. All fieldwork for this project was completed from February - April 2000 when rivers were at base-flow level. Methods for physical habitat sampling were adapted from approaches outlined by Simonson et al. (1993) and Gorman and Karr (1978). Station lengths equaled 39 times the estimated mean stream width, within which 13 transects were established to measure channel features including wetted width, water depth, dominant substrate, fish cover type and extent, and habitat type (e.g., riffle, run, pool, backpool). Depth and substrate were measured at five equidistant points across each transect. Pebble counts were performed at “representative” riffle, run, and pool habitats in each reach (Wolman 1954). For each pebble count sample, 100 randomly selected clasts were measured to the nearest millimeter, except for large boulders, which were recorded at a size of 550 mm, and sand, which was recorded as 1 mm. The presence of bedrock was also recorded, but not attributed a size value. At each transect, the relative extents of different fish cover types (Table 2.2) were rated. Values of 0-4 were assigned according to the percentage of a 5 m zone on either side of each transect line that each cover type occupied (0=cover type absent; 1=0-10% covered; 2=10-40%; 3=40-75%; 4=>75%).

Water quality. A YSI/Grant portable water quality lab was used to measure dissolved oxygen, temperature, conductivity, and turbidity in the field. One 250 mL water sample was also collected at each station. After collection, water samples were immediately placed in a dark cooler on ice, frozen within 36 hours, and later analyzed at the University of Georgia Institute of Ecology analytical chemistry laboratory. In the lab, samples were filtered and analyzed for pH, then digested (persulfate digestion) and analyzed for total phosphorus and total nitrogen using automated colorimetry. Soluble reactive phosphorus (SRP) and nitrates (NO_3^-) were also determined using automated colorimetry (APHA 1993).

Fishes. Slightly different collection methods were used to sample fishes in clear headwater streams versus more turbid coastal plain and delta stations. In the headwaters, where fish cover is evenly distributed and waters are clear (4 – 7 m underwater visibility), all wadable habitats were sampled in the daytime using a Smith-Root backpack electrofisher. Shock samples were collected in representative pool, run, riffle, and back-pool habitats by making one pass through each habitat type available. Sample area was visually estimated, and sample shocking time recorded. Riffle samples generally involved shocking downstream to a 2 m x 5 m seine (5 mm mesh), while run and shallow pool samples generally involved selectively shocking and dip-netting fishes near cover (boulders, woody debris, undercut banks, etc.), and those encountered while walking.

An underwater visual technique was devised to sample headwater pools deeper than one meter. This method involved 10-minute timed snorkel counts along transects perpendicular to the direction of flow. Transects were uniformly spaced 15 m apart in all available pool habitat at a station. Maximum horizontal underwater visibility was measured using a #10 tin can painted with a black and white pattern (Helfman 1983), and the width of each transect was estimated. These values were multiplied to calculate the sample area for each transect. During the timed transects, each observer visually identified and counted individuals of all species on an underwater writing cuff (Helfman

1983) excluding the ubiquitous and highly abundant central tetra (*Astyanax aeneus*). Common species were generally counted first followed by cryptic and nocturnal species that had to be searched for more intensively (e.g., *Gobiomorus dormitor*, *Awaous banana*, *Rhamdia laticauda*). It is likely that cryptic species were underrepresented in our samples. The same four observers were trained prior to fieldwork and made all observations. To avoid recounts and chasing fishes ahead of the observers, all transects in a pool were assessed simultaneously if possible, and movement between transects was accomplished only along the banks.

At coastal plain stations, shocking in the daytime yielded a narrow sample of the assemblage because much of the fish diversity was harbored in pool habitats inaccessible to a wading electrofishing crew. For this reason, at the recommendation of local fishermen, all coastal plain habitats were sampled during the moonless portion of the night, except riffles, which were still electro-shocked during the day. This adjustment proved more effective, though it introduces a discontinuity in the methods for headwater versus coastal plain run and pool habitats. Pools in the coastal plain were too turbid to sample visually, so angling and trotlines were employed to add species to the sample.

All fishes were identified to species in the field (using Greenfield and Thomerson 1997) and released if positively identified. Uncertain identifications were preserved in 10% formalin for later confirmation, as were voucher specimens. Voucher collections were deposited in the Georgia Museum of Natural History (Athens, GA, USA) and at St. John’s College (Belize City, Belize).

Analysis. Data from physical transects were pooled according to habitat type and used to calculate mean wetted width, mean water depth, and mean fish cover ratings for each habitat. Because more frequent width estimates were available for pool habitats (from underwater visual samples), these values were used to calculate mean width. Pebble count data were used to calculate the mean particle size and standard deviation of particle sizes for each habitat type. Additionally, the Shannon-Wiener diversity index ($H' = \sum_{i=1}^{n} p_1 \ln p_1$; where n = the number of categories and p_1 = the percent of category i in the total sample) was used to calculate the diversity of depths, substrate size classes (from pebble count data), and fish cover (Table 2.2).

Longitudinal patterns in assemblage composition were investigated using multivariate methods. To examine patterns in compositional similarity between stations (stations by species) as well as similarities of species distributions (species by station), all fish data were compiled to create species presence/absence matrices which were then clustered using the unweighted pair group method using arithmetic means (UPGMA) with Jaccard’s coefficient as a measure of similarity. Species that were captured at only one station were omitted from the analysis. Non-metric multidimensional scaling (with varimax rotation) was also used to ordinate the station-by-species matrix to test for the consistency of group designations. These analyses were accomplished using PC-ORD® software for Windows (McCune and Mefford 1999).

After verifying the normality of the data, watershed-scale patterns in assemblage structure (richness, diversity, and evenness) were tested against distance from sea using regression analysis. Species diversity was calculated from pooled shock samples using the Shannon-Wiener diversity index.

The analysis of abiotic relationships to assemblage structure in headwater streams proceeded by first testing for relationships with landscape level variables (longitudinal position, elevation, and geology), then for relationships with local measures of habitat size and structure. These steps were applied in each of three habitat types—pools, runs, and riffles—at eight stations in the headwaters. Shock samples were pooled within riffle and run habitats to calculate species richness, diversity (Shannon-Wiener index), and density (individuals m^{-2}). In pools, data from underwater visual transects were averaged to calculate pool richness, diversity, and density.

One-way analysis of variance (ANOVA) was used to test for significant differences between abiotic and biotic variables of streams originating in different geologic types (extrusive/limestone vs. granite/metasediments). ANOVA was also used to compare abiotic and biotic variables among three elevation categories. Correlation analysis was used to test for collinearity between independent variables, and least squares regression analysis was used to evaluate the strength of relationships between measures of assemblage structure and longitudinal position, stream size, and habitat diversity.

Results

Fishes

A total of 5,714 fishes were captured using electrofishing, angling, and trotlines. An additional 6,113 fishes were counted during underwater visual assessment. The assemblage consisted of 39 species in 21 families (Table 2.3). Poeciliids were numerically dominant, making up 39% of individuals captured, followed by characins

(25%), and cichlids (20%). Cichlidae was the most speciose family (8 spp.), followed by Poeciliidae (6 spp.).

Longitudinal patterns. The species by station cluster revealed two major groups in the fauna, roughly aligned with species affinities for freshwater (Figure 2.4). Group A consisted of common to very common obligate freshwater and salt-tolerant fishes with wide distributions across the longitudinal gradient. Within group A, two subgroups were evident. Subgroup A_1 consisted of nearly ubiquitous species that occurred at greater than 16 stations. These fishes represented the core of the overall fauna. Subgroup A_2 consisted of common species that occurred at between 10 to 15 stations. Within A_2, several small clusters existed representing species with affinities for headwaters versus coastal plain habitats. Group B consisted predominantly of saltwater species that occurred only at the three delta stations in low abundances. *Joturus pichardi*, which occupied its own branch on the dendrogram, is a large catadromous mullet that was captured at two of the high elevation stations only.

The station by species dendrogram revealed three groupings (headwaters, coastal plain, and delta) (Figure 2.5). The headwaters fauna consisted of the “core group” (cluster A_1 above) plus several common species specialized to high elevations. The coastal plain fauna consisted of the core group plus several common species with affinities for flatwaters. Deltaic stations consisted of the core group plus saltwater species identified in cluster B in the species by station dendrogram (Figure 2.6). Station TR03, a high elevation station on the Trio Branch, grouped alone. Careful examination of the similarity matrix generated from Jaccard’s coefficient revealed that the TR03 assemblage was compositionally most similar to other high elevation stations but had lower richness (13 spp. vs. mean=17.29 spp.). The separation of MR01 from the other Monkey River (MR) stations is a result of additions of marine species to this fauna (e.g, *Anchoviella belizensis*, *Megalops atlanticus*, *Citharychthys spilopterus*).

Results from ordination of the station by species dissimilarity matrix mirrored results from cluster analysis, revealing three faunal groups in the headwaters, coastal plains, and the delta (Figure 2.7). The first axis of the ordination accounted for most of the variance in the data set (Axis 1 r^2=0.69, Axis 2 r^2=0.15).

Linear regression of richness, diversity, and evenness against distance from sea yielded several significant relationships (Figure 2.8). Richness was negatively related to distance from sea (r^2=0.42, p<0.01). Diversity (r^2=0.65, p<0.0001) and evenness (r^2=0.65, p<0.0001) were also negatively related to distance from sea, but only when two extreme values were excluded from the analysis. Unusually low diversity and evenness scores at both SW01 and SW02 resulted from the dominance of the shortfin molly (*Poecilia mexicana*), which comprised more than 60% of the catch. At the other coastal plain stations *P. mexicana* had a mean relative abundance of 33% (range=20%-47%).

Headwater streams. Headwater stations were located between 59 and 79 river kilometers from sea and ranged in size from 11 to 27 m wide and 507 to 1170 m long. All stations were located within a completely forested landscape with the exception of SW08, which had some scattered subsistence farms outside the riparian zone. Proportions of major habitat types (riffle, run, pool) were variable across stations (Table 2.4).

Means comparisons for all physicochemical variables between branches revealed a pronounced pattern relative to geology (Table 2.5). Bladen Branch stations (extrusive/limestone geology) were characterized by neutral pH, high conductivity, elevated nitrogen values, and low phosphorus values (SRP=0.002 mg l^{-1} at all Bladen stations). Swasey and Trio (granite/metasedimentary) exhibited the opposite pattern, with basic pH, low conductance, and low nitrogen values. However, Swasey had high phosphorus (SRP=0.025-0.039 mg l^{-1}), while the one Trio station sampled fell closer to Bladen levels (SRP=0.003 mg l^{-1}). N:P ratios indicated that Bladen was potentially phosphorus limited (N:P=243.37), Trio was potentially nitrogen limited (N:P=7.37), as was Swasey (N:P=0.74) (Horne and Goldman 1994).

Richness in pools was negatively related to distance from sea (r^2=0.90; p<0.01, excluding SW07)(Figure 2.9). SW07 was excluded from this regression because of exceptionally low richness, perhaps in relation to high water velocities and/or unusually low pH (6.9 compared to a mean of 9.2 at stations in the same geologic type).

When elevation was tested as a continuous variable, it was clear that the variable was best expressed categorically based on natural groupings in the data. Categorical comparison of assemblage attributes across low, medium, and high elevational groups revealed that middle elevation stations had the highest species richness and diversity values, with the low elevation group next, followed by the high elevation group with the lowest values. Tukey-Kramer tests of all pairs (alpha=0.05) revealed significant differences in richness values between medium and high elevation stations (Figure 2.10a), and significant differences in diversity values between all three elevational groups (Figure 2.10b).

No significant differences were found between means of species richness or diversity between geologies. However, pool habitats in the granite/metasedimentary geology supported significantly greater densities of fishes (F_5= 36.52, $p<0.01$) when the smallest pool sampled (BL04) was excluded (Figure 2.11). Stations in the granite/metasedimentary geology also had significantly greater relative abundances of herbivorous individuals in runs (F_4=7.88, $p<0.05$) and riffles (F_6=5.8, p=0.05), and increased percent herbivorous species in runs (F_4=7.32, p=0.05).

A number of local-scale variables were significantly related to measures of assemblage structure. Regression of species diversity against the standard deviation of pool pebble count sizes revealed a strong positive linear relationship in Bladen pools (r^2=0.98 $p<0.01$), whereas points for Swasey and Trio pools were scattered widely (Figure 12). No other relationships to local pool variables were obvious from regression analysis. In run habitats, species richness was positively related to average fish cover in runs (r^2=0.75, $p<0.05$), and species diversity was negatively related to average depth of run habitats (r^2=0.77, p=0.05) when TR03 was excluded from the analysis (Figure 2.13). No local scale patterns were evident in riffle habitats at an alpha level of 0.05. At an alpha level of 0.10, species diversity was negatively related to substrate diversity (r^2=0.59, p=0.07).

Discussion

Longitudinal compositional patterns

As would be predicted for a Central American stream with no major barriers to fish dispersal (Welcomme 1985), the general pattern seen in the Monkey River assemblage was continual addition of species downstream with only a few deletions. Deleted species included the diadromous mugilids *Joturus pichardi* and *Agonostomus monticola*, and *Heterandria bimaculata*, a widely dispersed livebearer that is adapted to survive in low order streams. *H. bimaculata* has been reported in low-gradient areas (Greenfield and Thomerson 1997) and may have been poorly represented in this study because most fishing occurred at night. The presence of the large herbivorous *J. pichardi* (max. SL=540 mm at SW09) in headwater cascade habitats represents the first collection of this species in Belize (Greenfield and Thomerson 1997).

Three distinct faunal groups were obvious in the assemblage: a headwaters group, a coastal plains group, and a separate marine-influenced delta group. Two prior studies of watershed-scale longitudinal patterns in Central American systems also reported biotic zonation, but influenced by different factors. Winemiller and Leslie (1992) reported high species turnover between four characteristic habitats across a freshwater/marine ecotone along a short gradient on the Caribbean slope of Costa Rica. In each habitat studied, nearly unique assemblages existed, a fact that the authors attributed to habitat size and salinity. Rodiles-Hernández et al. (1999) reported waterfall-induced longitudinal zonation in an inland tropical rainforest river in southern Mexico, with continual addition of species downstream and little species deletion. The most downstream station sampled in Monkey River was located at the upper extent of the freshwater-marine interface and contained the most distinctive assemblage because of the addition of several marine species (*Anchoviella belizensis, Megalops atlanticus*, *Citharichthyes spilopterus*). Had sampling continued to the ocean, it is likely that elements from the headwaters/coastal plain zone would have been replaced by wholly marine assemblages similar but with less well-developed lagoon groups to those reported from Costa Rica (Winemiller and Leslie 1992). Results from this study suggest that faunal zonation can occur in the absence of dispersal barriers or strong environmental discontinuities like the freshwater-marine interface.

Headwater assemblage structure

Results from the investigation of the headwater fish assemblage supported the hypothesis that the fish assemblage is likely structured by combinations of variables from both landscape and local-scales. Each of the three landscape level variables considered (distance from sea, geology, and elevation) showed relationships to biotic variables. The only other Central American study of fish assemblages that considered any of these variables found that distance from sea was strongly correlated with species richness, evenness, and diversity in a short coastal drainage on the Osa Peninsula in southwestern Costa Rica (Lyons and Schneider 1990). The fact that pool richness was negatively related to distance from sea in the Monkey River headwaters speaks to the strength of this landscape-level variable over local-scale variables even across a very short headwater longitudinal gradient of 20 km.

Geology was another important landscape-level variable influencing the structure of the headwater fish assemblage. Clear differences existed in the water chemistry between granite/metasedimentary versus extrusive/limestone geology, though a direct causal relationship between geology and chemical differences has yet to be proven. Differences in pH and conductivity may be related to the presence of limestone that buffers acidic waters coming off the extrusive rocks of the Bladen Volcanic Member (contributing cations in the process). Potential causal mechanisms for patterns in nutrient chemistry, particularly the increased ambient phosphorus levels in the Swasey Branch, are less clear. Because the Swasey headwaters are entirely forested, it is unlikely that the cause is anthropogenic. Studies from Costa Rica have indicated that geothermally modified groundwater can cause elevated phosphorus levels in streams near volcanic mountain ranges (Pringle and Triska 1991). Pringle and Triska (2000) reported that such surface-subsurface water interactions are largely the result of physical and chemical processes acting on the geological template. They also commented that general patterns in the occurrence of distinctive geothermal water types in Central America can be identified by examining maps for stream names that indicate geothermal modification (e.g., Agrio=sour, Salitral=salty, Caliente=hot). Only one creek name in the Swasey area, Salada Creek, infers the potential presence of “salty” geothermally modified water.

Whatever the mechanism, the presence of elevated phosphorus levels in Swasey Branch has multiple biological implications (Pringle and Triska 2000). Phosphorus is considered the most common growth-limiting factor in freshwaters (Horne and Goldman 1994). Streams with elevated phosphorus levels are generally expected to support greater primary production of algae and macrophytes if sunlight is not limiting. Estimates of in-stream aquatic vegetation in Monkey River headwater streams supported this expectation, although pH may also prove to be an important factor controlling plant growth. The

Swasey and Trio Branches both support luxuriant growth of the aquatic angiosperm *Apinagia sp*., while Bladen Branch habitats support little to no macrophyte growth and little periphyton (personal observation). *Apinagia* is an attached macrophyte in the family Podostemaceae, that has been reported from northern and central South America (Cook et al. 1974). The presence of this long-stemmed macrophyte has important implications for stream trophic structure and habitat structure. Increases in primary production have been shown to cascade up food webs to cause increased growth rates and biomass at higher trophic levels (Peterson et al. 1993; Harvey et al. 1998). With plant matter constituting a substantial component of the diets of tropical fishes (Wootton and Oemke 1992), it seems likely that assemblages would respond positively to increased availability of plant forage, although Allan (1995) commented that macrophytes are rarely consumed directly by herbivores. *Apinagia* also provides increased cover/refugia for fishes (Table 4). The presence of a related species in the Podostemum family in southeastern North American streams has been correlated with dramatic increases in invertebrate abundances and biomass, another important food source for fishes (Freeman and Wallace 1984, Grubaugh and Wallace 1995, Grubaugh et al. 1997).

Increased densities of individuals in pools and increased relative richness and abundance of herbivores in riffles and runs in granite/metasedimentary geology may support the hypothesis that increased primary production leads to a bottom-up response at higher trophic levels. It is also possible that the assemblage is responding to increased cover provided by the plant. The presence of *Apinagia* as a source of cover in granite/metasedimentary areas may override the importance of substrate size variation that was so strongly related to pool species diversity in extrusive/limestone areas without the macrophyte.

Local-scale studies relating measures of habitat size and habitat structure to fish community structure have been more numerous in Central America than studies of landscape-scale attributes. Bussing and Lopez (1977) reported that in several Costa Rican drainages fish distributions were determined by stream velocity, stream size, and interspecific interactions, and that fish samples with high species diversity came from areas with highly diverse habitats. Gorman and Karr (1978) found that measures of habitat structure (Shannon-Weiner diversity of depths and substrates) were positively related to species diversity in small Panamanian streams. Angermeier and Schlosser (1989) reported positive relationships between species richness and habitat size (wetted width, volume) as well as habitat complexity (diversity of depth, substrate, and velocity). Winemiller (1983) also reported a positive relationship between stream size (especially wetted width) and species richness in the Rio Claro in Corcovado National Park in southwest Costa Rica. Results from these studies generally indicate that, at least for southern Central American streams, both habitat size and habitat structure are important in determining the structure of stream fish assemblages.

Results from the Monkey River also revealed relationships between measures of habitat size and structure and fish assemblage structure. These relationships were strongest in run habitats where species diversity was negatively related to a local measure of size (average depth) and richness positively related to a measure of habitat structure (average extent of fish cover). In riffles, only a weak negative relationship between species diversity and substrate diversity was apparent, while in extrusive/limestone pools, standard deviation of particle sizes related positively to species diversity. Reasons for stronger local effects in runs are unknown.

Whatever the structuring mechanisms, compared to other studies from the southern part of Central America, it seems that relationships between local scale factors and Monkey River assemblage structure may be less strong. Whether this pattern can be attributed to distinctions between northern and southern assemblages, larger stream size, or other factors will be tested in future research. Because other studies did not evaluate the importance of landscape-level factors, little comparison can be made there.

In summary, at the watershed-scale the Monkey River assemblages can be broken into three faunal groups relative to major longitudinal zones. In headwaters streams, both landscape- and local-scale variables are important factors structuring headwater fish assemblages. Responses to abiotic factors varied on a habitat by habitat basis suggesting that different structuring forces are acting in each, with runs in particular showing strong ties to local-level factors. Headwater fish assemblages may be structured differently in certain habitats (e.g., pools) relative to geologic differences, and a potential bottom-up response to increased primary production at Swasey and Trio stations is hypothesized.

Further research is needed to clarify relationships and causal mechanisms for habitat differences in the different geologic types. In particular, the exact nature of the mechanisms driving limnological differences between river branches is a crucial next research question. In the Central American region, future consideration of the affects of landscape-level abiotic factors in stream fish assemblage structure is warranted.

Acknowledgements

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Literature Cited

Allan, J.D. 1995. Stream Ecology: Structure and Function of Running Waters. Chapman and Hall, New York, NY.

Angermeier, P.L. and I.J. Schlosser. 1989. Species-area relationships for stream fishes. Ecology 70: 1450-1462.

American Public Health Association (APHA). 1993. Standard Methods for the Examination of Water and Wastewater. Port City Press, Baltimore, MD.

Bateson, J.H. and I.H.S. Hall. 1977. The Geology of the Maya Mountains Belize. Oxford University Press, London.

Bussing, W.A. 1976. Geographical distribution of the San Juan ichthyogauna of Central America, with remarks on its origin and ecology. Pages 157-175 in T.B. Thorson (ed.), Investigations into the Ichthyofauna of Nicaraguan Lakes, University of Nebraska Press, Lincoln, NE.

Bussing, W.A. and M.I. Lopez. 1977. Distribucion y aspectos ecologicos de los peces de las cuencas hidrograficas de Arenal Bebederoy Tempisque, Costa Rica. Revista de Biologia Tropical 25: 13-37.

Esselman, P.C. and E. Boles. In press. Status and future needs of limnological research in Belize. In R.G. Wetzel and B. Gopal (eds.) Limnology in Developing Countries, volume 3. International Association of Limnology.

Freeman, M.C., and J.B. Wallace. 1984. Production of net-spinning caddisflies (Hydropsychidae) and black flies (Simuliidae) on rock outcrops in a small southeastern Peidmont stream. Hydrobiologia 112: 3-15.

Greenfield, D.W. and J.E. Thomerson. 1997. Fishes of the Continental Waters of Belize. University Press of Florida, Gainesville, FL.

Gorman, O.T. and J.R. Karr. 1978. Habitat structure and stream fish communities. Ecology 59: 507-515.

Grubaugh, J.W. and J.B. Wallace. 1995. Functional structure and production of the benthic community in a Piedmont river: 1965-1957 and 1991-1992. Limnology and Oceanography 40: 490-501.

Grubaugh, J.W., J.B. Wallace, and E.S. Houston. 1997. Production of benthic macroinvertebrate communities along a southern Appalachian river continuum. Freshwater Biology 37: 581-596.

Harvey, C.J., B.J. Peterson, W.B. Bowden, A.E. Hershey, M.C. Miller, L.A. Deegan, and J.C. Finlay. 1998. Biological responses to fertilization of Oksrukuyik Creek, a tundra stream. Journal of the North American Benthological Society 17: 190-209.

Helfman, G.S. 1983. Underwater methods. Pages 349-369 in L.A. Nielsen and D.L. Johnson (eds.), Fisheries Techniques. American Fisheries Society, Bethesda, MD.

Heyman, W.D. and B. Kjerve. 1999. Hydrological and oceanographic considerations for integrated coastal zone management in southern, Belize. Environmental Management 24: 229-245.

Horne, A.J. and C.R. Goldman. 1994. Limnology. McGraw-Hill Inc., New York, NY.

Lee, M.D. and J.D. Stednick. 1995. Environmental Water Quality Monitoring Program: Final Report and Annexes. Department of the Environment, Government of Belize, Belmopan, Belize.

Lowe-McConnell, R.H. 1987. Ecological Studies in Tropical Fish Communities. Cambridge University Press, Cambridge, England.

Lyons, J. and D.W. Schneider. 1990. Factors influencing fish distribution and community structure in a small coastal river in southwestern Costa Rica. Hydrobiologia 203: 1-14.

McCune, B. and M.J. Mefford. 1999. PC-ORD: Multivariate Analysis of Ecological Data, Version 4. MjM Software Design, Gleneden Beach, OR.

Peterson, B.J., L. Deegan, J. Helfrich, J.E. Hobbie, M. Hullar, B. Moller, T.E. Ford, A. Hershey, A. Hilter, G. Kipphut, M.A. Lock, D.M. Fiebig, V. McKinley, M.C. Miller, J.R. Vestal, R. Ventullo, and G. Volk. 1993. Biological responses of a tundra river to fertilization. Ecology 74: 653-672.

Pringle, C.M. and F.J. Triska. 1991. Effects of geothermal groundwater on nutrient dynamics of a lowland Costa Rican stream. Ecology 72: 951-965.

Pringle, C.M. and F.J. Triska. 2000. Emergent biological patterns in streams resulting from surface-subsurface water interactions at landscape scales. Pages 167-193 in J.B. Jones and P.J. Mulholland (eds.), Surface-Subsurface Interactions in Stream Ecosystems. Academic Press, New York, NY.

Rodiles-Hernández, R., E. Díaz-Pardo, and J. Lyons. 1999. Patterns in the species diversity and composition of the fish community of the Lacanja River, Chiapas, Mexico. Journal of Freshwater Ecology 14: 455-468.

Simonson, T.D., J. Lyons, and P.D. Kanehl. 1993. Guidelines for evaluating fish habitat in Wisconsin streams. General Technical Report NC-164. U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, St. Paul, MN.

Welcomme, R.L. 1985. River fisheries. FAO Fisheries Technical Paper 262: 1-330.

Winemiller, K.O. 1983. An introduction to the freshwater fish communities of Corcovado National Park, Costa Rica. Brenesia 21: 47-66.

Winemiller, K.O. and M.A. Leslie. 1992. Fish assemblages across a complex, tropical freshwater/marine ecotone. Environmental Biology of Fishes 34: 29-50.

Wolman. 1954. A method of sampling coarse river-bed material. Transactions of the American Geophysical Union 35: 951-956.

Wootton, J.T. and M.P. Oemke. 1992. Latitudinal differences in fish community trophic structure, and the role of fish herbivory in a Costa Rican stream. Environmental Biology of Fishes 35: 311-319.

Table 2.1. Six distinct physiographic regions of the Monkey River based on geology, morphology, and gradient.

Region	Sub-basin	Geology	Morphology	Gradient
R1	Bladen (headwaters)	Extrusive volcanic/ limestone	Riffle-run-pool	High-medium
R2	Trio (headwaters)	Metasediments/granite	Riffle-run-pool	High-medium
R3	Swasey (headwaters)	Metasediments/granite	Riffle-run-pool	High-medium
R4	Bladen (mid-elevation)	Quaternary sediments	Run-pool (some riffles)	Medium-low
R5	Swasey (mid-elevation)	Quaternary sediments	Run-pool (some riffles)	Medium-low
R6	Monkey River	Quaternary sediments	Meandering flatwater	Low

Table 2.2. Depth, substrate, and fish cover categories used in diversity calculations with the Shannon-Wiener index. Within each fish cover category, values between 0 and 4 were assigned based on the percent of a 10 m wide zone around the transect occupied by the cover type (0=cover absent; 1=1-10% covered; 2=10-40%; 3=40-75%; 4=>75%). These weighted values were summed for all cover types at each transect then used in calculations.

		Category							
		1	2	3	4	5	6	7	8
Depth	Range (cm)	0-25	25-50	50-75	>75				
	Description	Very shallow	Shallow	Moderate	Deep				
Substrate	Diameter (mm)	0.06-2	2-16	16-64	64-250	250-4000			
	Description	sand	fine gravel	coarse gravel	cobble	boulder	bedrock		
Cover	Description	filament. algae	macro-phytes	lg. woody debris	sm.woody debris	overhang. vegetation	boulders	undercut banks	artificial structures

Table 2.3. List of families and species captured and observed during this study. Letters in parentheses represent freshwater affinities for each species (P=peripheral division; S=secondary division; Pr=primary division).

	Number captured		
Family and species	Electrofishing	Visual assessment	Hook and line
Megalopidae (P)			
Megalops atlanticus	0	0	2
Engraulidae (P)			
Anchoviella belizensis	1	0	0
Characidae (Pr)			
Astyanax aeneus	1181	0	0
Brycon guatemalensis	76	460	16
Hyphessobrycon compressus	241	285	0
Ariidae (P)			
Ariopsis assimilis	4	0	19
Pimelodidae (Pr)			
Rhamdia guatemalensis	25	0	0
Rhamdia laticauda laticauda	117	28	0
Belonidae (P)			
Strongylura timucu	11	0	0
Peociliidae (S)			
Belonesox belizanus	58	2	0
Gambusia luma	130	31	0
Heterandria bimaculata	57	77	0
Poecilia mexicana	1626	1714	0
Xiphophorus helleri	90	47	0
Xiphophorus maculatus	1	0	0
Atherinidae (P)			
Atherinella sp.	292	227	0
Syngnathidae (P)			
Microphis brachyurus	1	0	0
Synbranchidae (S)			
Ophisternon aenigmaticum	85	0	0
Centropomidae (P)			
Centropomus ensiferus	7	0	0
Centropomus parallelus	3	0	0
Lutjanidae (P)			
Lutjanus griseus	3	0	0
Lutjanus jocu	5	0	0
Gerreidae (P)			
Eucinostomus melanopterus	109	0	0
Eugerres plumieri	9	0	0
Haemulidae (P)			
Pomadasys crocro	10	34	0
Cichlidae (S)			
Cichlasoma maculicauda	171	418	28
Cichlasoma meeki	103	45	0
Cichlasoma robertsoni	105	85	0
Cichlasoma salvini	317	100	1
Cichlasoma spilurum	520	2355	0

Cichlasoma urophthalmus	9	0	0
Petenia splendida	10	4	0
Mugilidae (P)			
Agonostomus monticola	190	182	0
Joturus pichardi	7	11	0
Eleotridae (P)			
Gobiomorus dormitor	46	1	0
Eleotris amblyopsis	2	0	0
Gobiidae (P)			
Awaous banana	24	7	0
Achiridae (P)			
Achirus declivus	1	0	0
Paralychthyidae (P)			
Cytharichthys spilopterus	1	0	0
TOTAL	5648	6113	66

Table 2.4. Selected station-level physical habitat variables for headwater sampling stations (and units). Dist. fr. Sea=distance from sea; Elev.=elevation.

Station	Dist. fr. sea (km)	Elev. (masl)	Station length (m)	Average width (m)	Average depth (m)	Riffle habitat (%)	Pool habitat (%)	Run habitat (%)	Canopy cover (%)
BL04	73.27	90	644	11.35	29.62	23.08	15.38	61.54	42.37
BL05	74.46	100	702	23.88	26.49	41.54	18.46	35.38	58.53
BL06	78.63	140	585	22.78	39.54	43.08	21.54	29.23	70.76
PR01	62.66	63	1170	17.24	36.19	29.23	41.54	23.08	38.32
SW07	59.38	50	780	26.74	92.70	16.92	69.23	7.69	35.02
SW08	60.41	55	780	16.14	69.57	47.69	43.08	18.46	34.06
SW09	76.20	125	624	15.80	61.28	23.08	23.08	53.85	57.71
TR03	72.22	95	507	24.60	53.85	35.38	53.85	10.77	43.56

Table 2.5. A comparison of water quality parameters from Bladen stations versus Swasey/Trio stations according to distinctions between underlying geologies. Analysis of variance revealed that differences for all values were significant at the 0.05 level or higher. Values in parentheses are standard errors. NO3=Nitrates; TPN=Total persulfate nitrogen; SRP=soluble reactive phosphorus; TPP=total persulfate phosphorus; N:P=nitrogen to phosphorus ratio %Aqu.Veg.=estimated percent of reach covered with aquatic vegetation. Mean fish cover rating is the average value from cover ratings (see Methods) across all transects at a station. No data were available for pH and nutrient chemistry for station PR01.

	Geology		ANOVA			
Parameter (units)	Bladen	Swas./Trio	n	F-stat	df	p=
pH[*]	7.10 (0.07)	9.20 (0.05)	6	620.16	4	<0.0001
Conductivity (mS cm^{-3})	0.23 (0.01)	0.08 (0.01)	8	145.43	6	<0.0001
NO_3 (mg l^{-1})	0.22 (0.02)	0.01 (0.02)	7	52.54	5	0.0008
TPN (mg l^{-1})	0.36 (0.04)	0.23 (0.04)	7	7.38	5	0.0419
SRP (mg l^{-1})[**]	0.00 (0.00)	0.03 (0.00)	6	46.02	4	0.0025
TPP (mg l^{-1})[**]	0.02 (0.01)	0.05 (0.01)	6	9.55	4	0.0400
N:P (molar ratio)	252.47 (25.0)	5.77 (24.6)	7	55.69	5	0.0007
%Aqu.Veg.	1.00 (5.33)	37.50 (5.33)	8	23.48	6	0.0029
Mean fish cover rating	3.19 (0.26)	5.40 (0.26)	8	35.46	6	0.0010
Mean pool depth (m)	0.73 (0.11)	1.12 (0.11)	8	6.36	6	0.0465
Run Substrate Diversity	0.95 (0.04)	1.21 (0.04)	6	34.15	4	0.0043

[*] SW07 excluded

[**] TR03 excluded

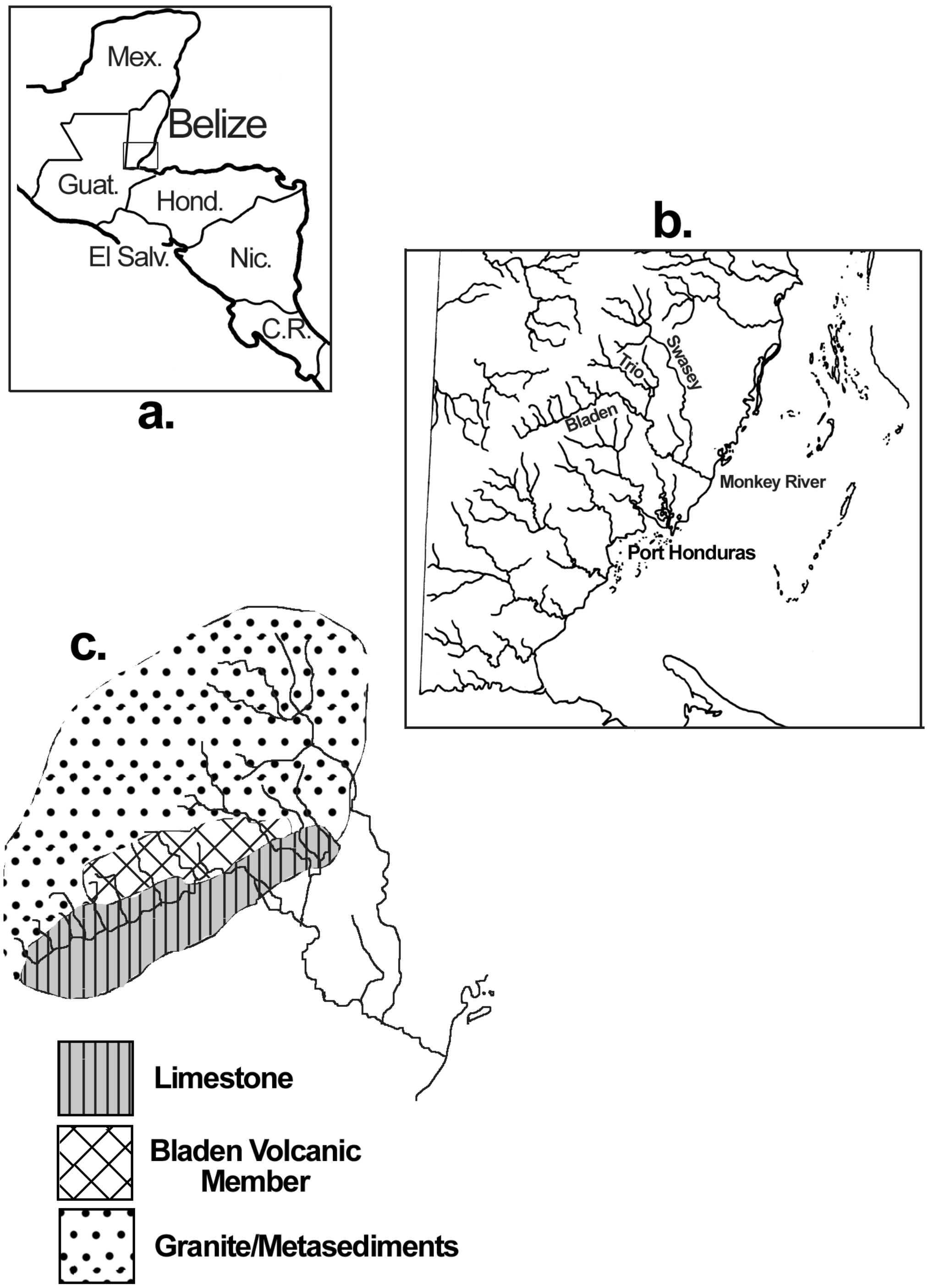


Figure 2.1. Belize location (a), major branches of the Monkey River (b), and geology types in the Monkey River headwaters (c).

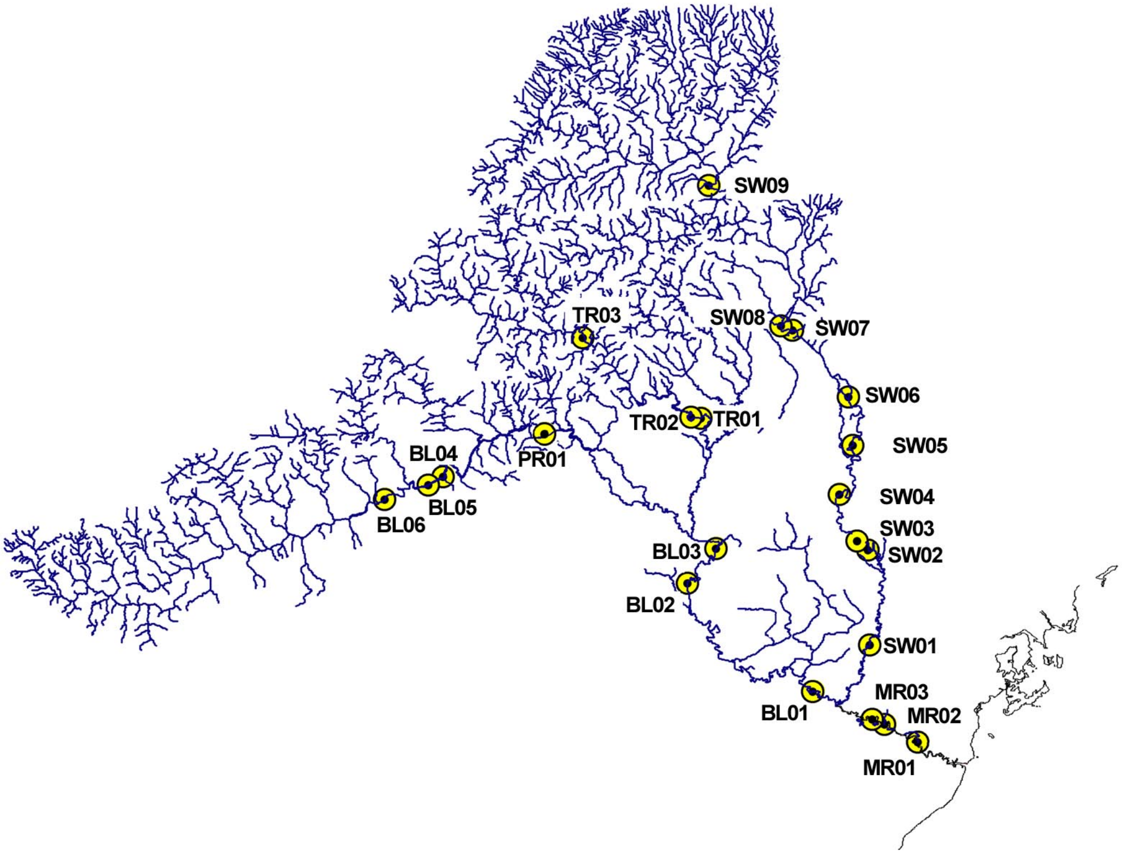


Figure 2.2. Map of all stations sampled for fishes and physicochemical properties on three major branches of the Monkey River. Two of these stations (TR01 and TR02) were mostly dry and not included in this analysis, and one station on the Bladen Branch (PR01) was added. BL=Bladen Branch station; TR=Trio Branch station; SW=Swasey Branch station.

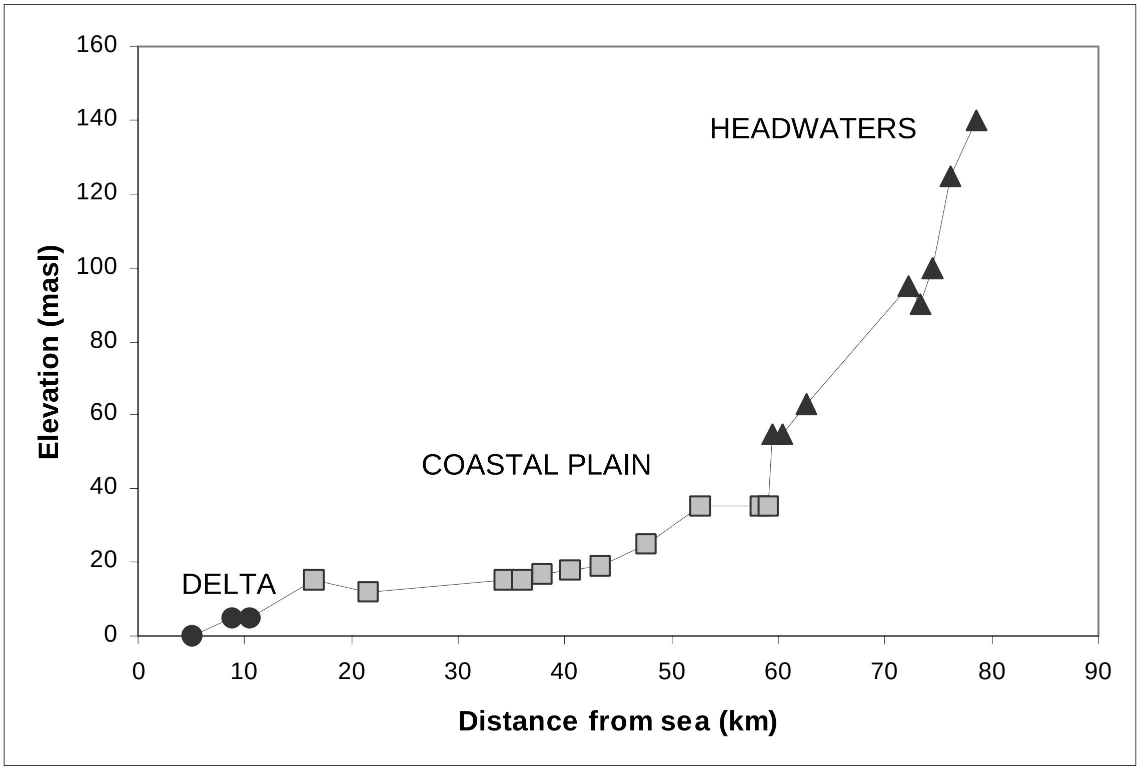


Figure 2.3. Elevation (m) versus distance from sea (km) with location of sampling stations along the continuum. Headwater areas grade into the coastal plain, before entering the low-lying Monkey River delta.

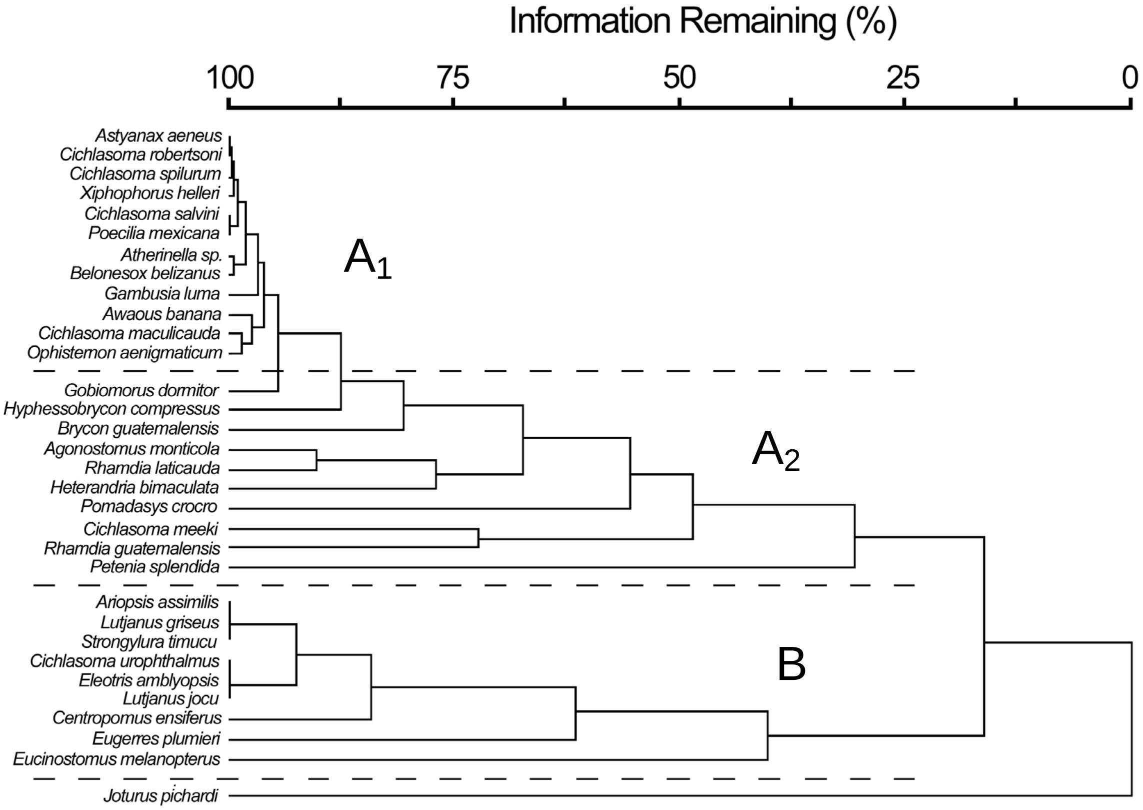


Figure 2.4. Cluster dendrogram showing faunal groupings based on presence or absence of species at twenty sampling stations. Cluster A_1 consists of very common species that occurred at more than 16 stations. Cluster A_2 consists of “common” species that occurred at between 10 and 15 stations. Cluster B consists of saltwater species that occurred at the lowest elevation stations in the delta.

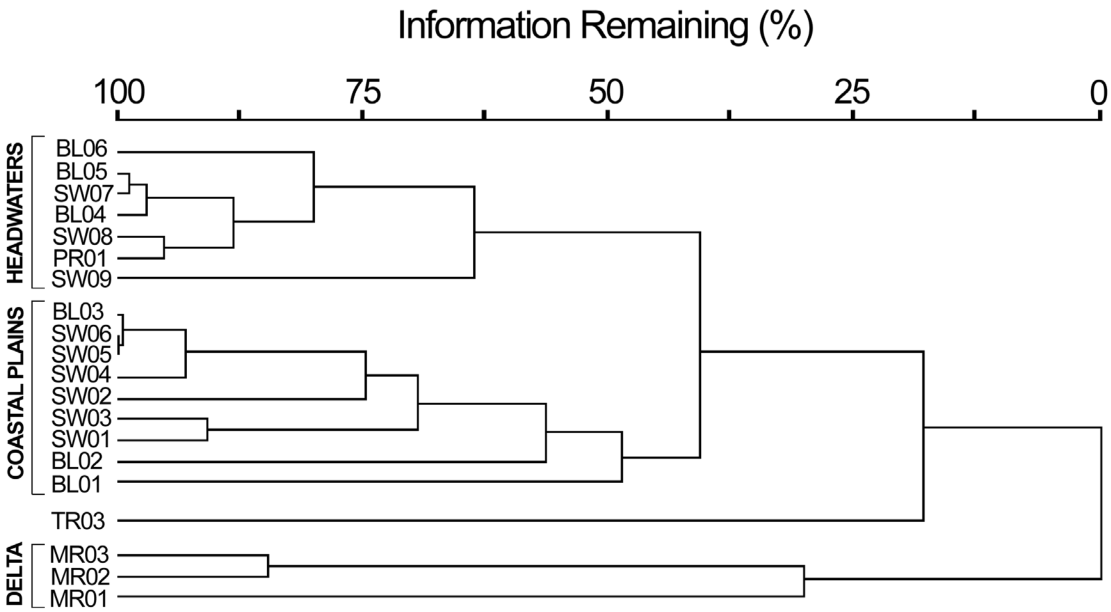


Figure 2.5. Cluster dendrogram showing similarities between species compositions at all twenty stations. Stations grouped according to longitudinal position (headwaters, coastal plains, and delta) based on similarities between fish assemblages. TR03 is a headwater station that clustered separately as an artifact of the clustering technique.

Headwater group	**Coastal plain group**	**Delta group**
Heterandria bimaculata		
Joturus pichardi		
Agonostomus monticola		
Rhamdia laticauda	*Rhamdia laticauda*	
Astyanax aeneus	*Astyanax aeneus*	*Astyanax aeneus*
Brycon guatemalensis	*Brycon guatemalensis*	*Brycon guatemalensis*
Belonesox belizanus	*Belonesox belizanus*	*Belonesox belizanus*
Gambusia luma	*Gambusia luma*	*Gambusia luma*
Poecilia mexicana	*Poecilia mexicana*	*Poecilia mexicana*
Xiphophorus helleri	*Xiphophorus helleri*	*Xiphophorus helleri*
Atherinella sp.	*Atherinella sp.*	*Atherinella sp.*
Ophisternon aenigmaticum	*Ophisternon aenigmaticum*	*Ophisternon aenigmaticum*
Pomadasys crocro	*Pomadasys crocro*	*Pomadasys crocro*
Cichlasoma robertsoni	*Cichlasoma robertsoni*	*Cichlasoma robertsoni*
Cichlasoma spilurum	*Cichlasoma spilurum*	*Cichlasoma spilurum*
Cichlasoma salvini	*Cichlasoma salvini*	*Cichlasoma salvini*
Cichlasoma maculicauda	*Cichlasoma maculicauda*	*Cichlasoma maculicauda*
Gobiomorus dormitor	*Gobiomorus dormitor*	*Gobiomorus dormitor*
Awaous banana	*Awaous banana*	*Awaous banana*
	Hyphessobrycon compressus	*Hyphessobrycon compressus*
	Eucinostomus melanopterus	*Eucinostomus melanopterus*
	Petenia splendida	*Petenia splendida*
	Rhamdia guatemalensis	
	Xiphophorus maculatus	
	Microphis brachyurus	
	Cichlasoma meeki	
		Megalops atlanticus
		Anchoviella belizensis
		Ariopsis assimilis
		Strongylura timucu
		Centropomus ensiferus
		Centropomus parallelus
		Lutjanus griseus
		Lutjanus jocu
		Eugerres plumieri
		Cichlasoma urophthalmus
		Eleotris amblyopsis
		Achirus declivus
		Cytharichthys spilopterus

Figure 2.6. Species lists for each of the three faunal groups.

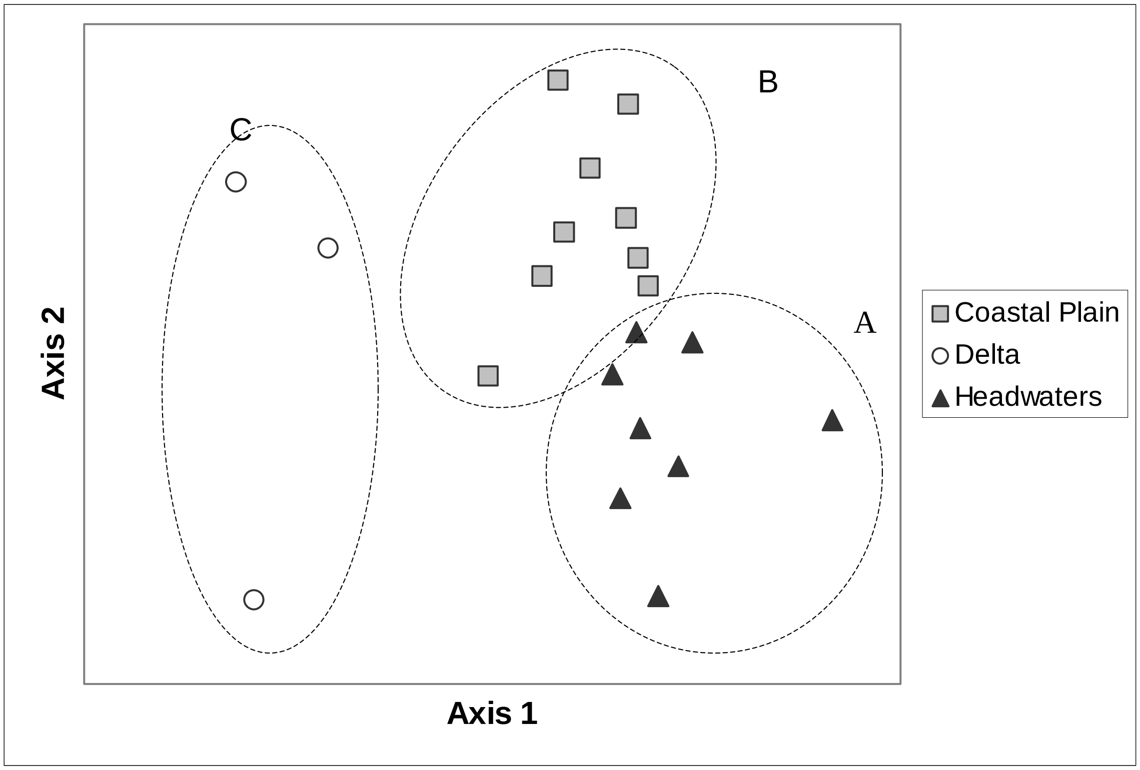


Figure 2.7. NMS ordination of the station by species presence absence matrix revealed three assemblage groups concordant with cluster analysis. Group A consisted of headwaters stations, group B of coastal plain stations, and group C consisted of a distinctive marine-influenced fauna in the delta.

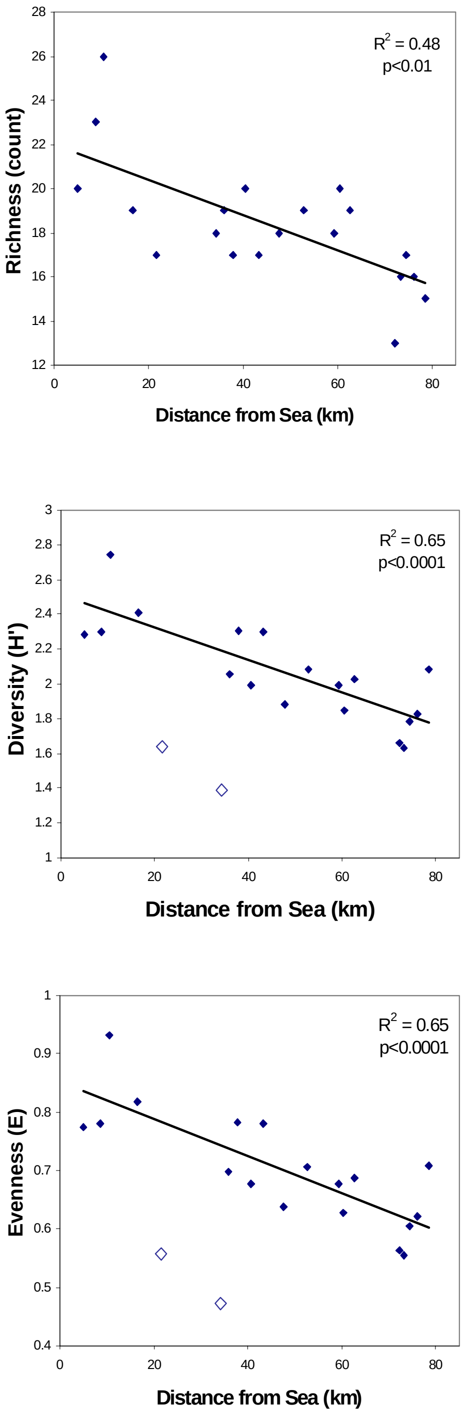


Figure 2.8. Species richness, diversity, and evenness against distance from sea. Significant relationships for diversity and evenness occurred only after the stations indicated by hollow diamonds were excluded from the analysis (SW01 and SW02; see Results for explanation).

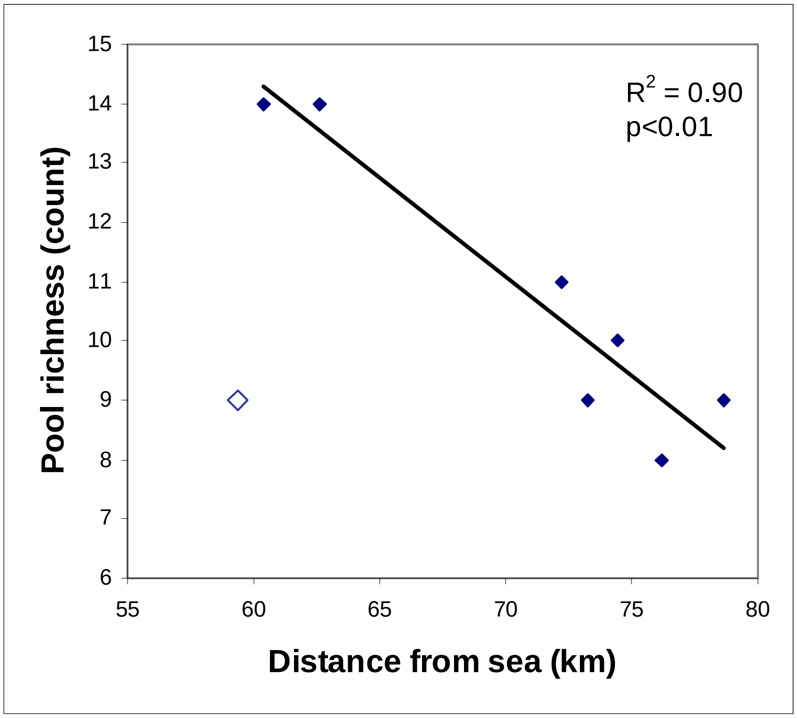


Figure 2.9. Longitudinal relationships between distance from sea and headwater pool richness. The indicated point in the scatter plot is SW07, which was excluded from the calculation of the regression to illustrate the relationship.

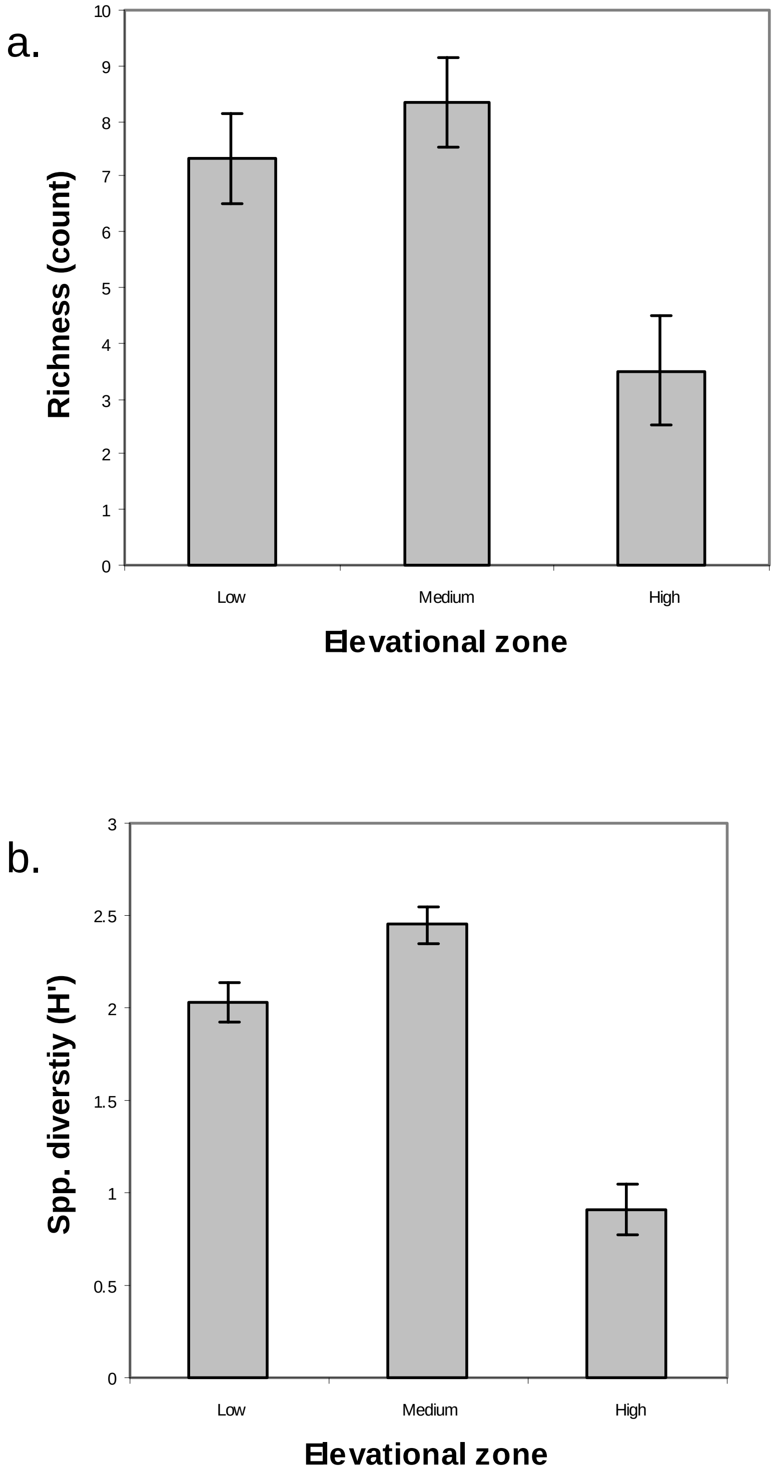


Figure 2.10. Headwater riffle richness (a) and species diversity (b) by elevational zone (+/- 1SE).

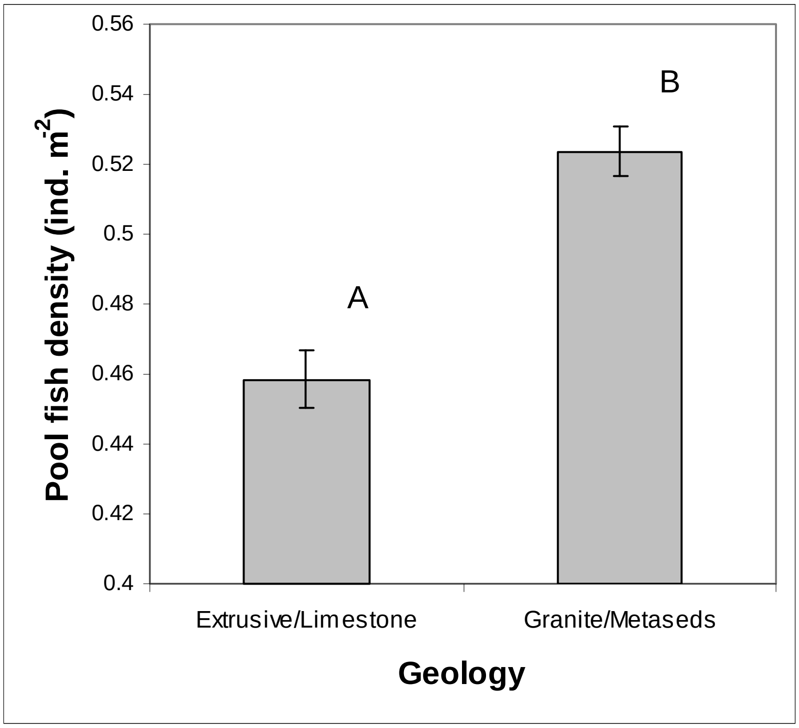


Figure 2.11. Density of individuals in headwater pools in different geologies.

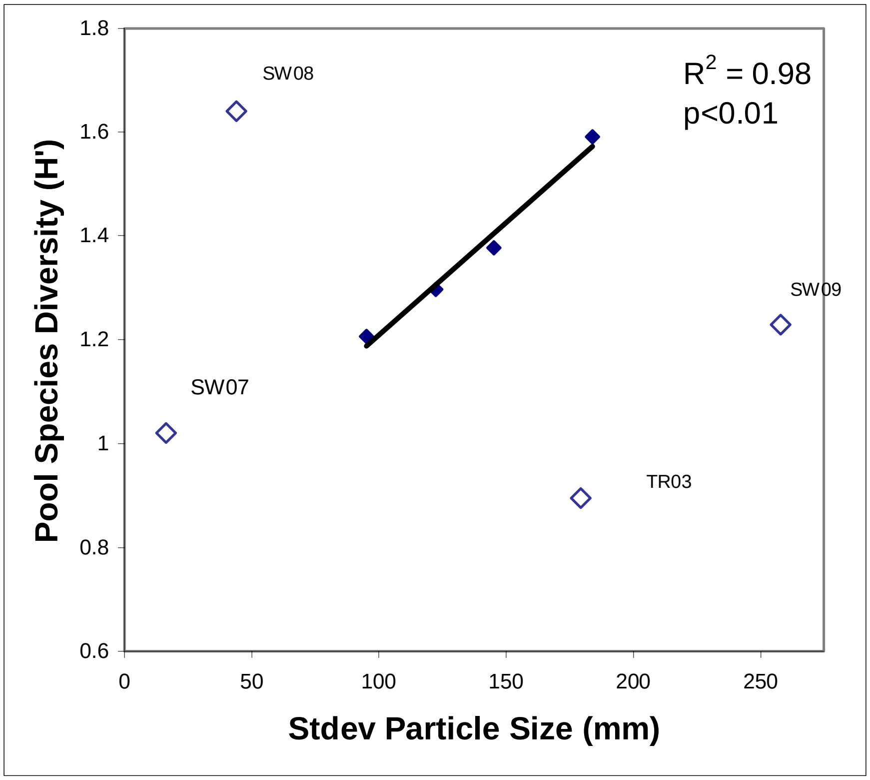
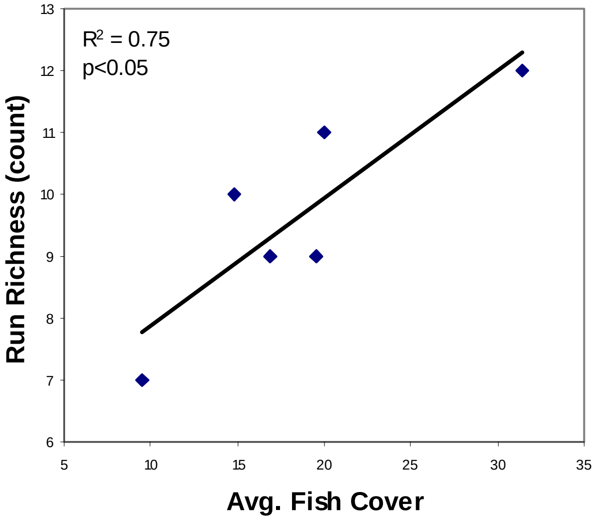


Figure 2.12. Scatter plot of species diversity against the standard deviation of pool pebble count sizes. A strong linear relationship existed for the four stations in extrusive/limestone geology (dark), but not for the granite/metasedimentary stations (hollow).



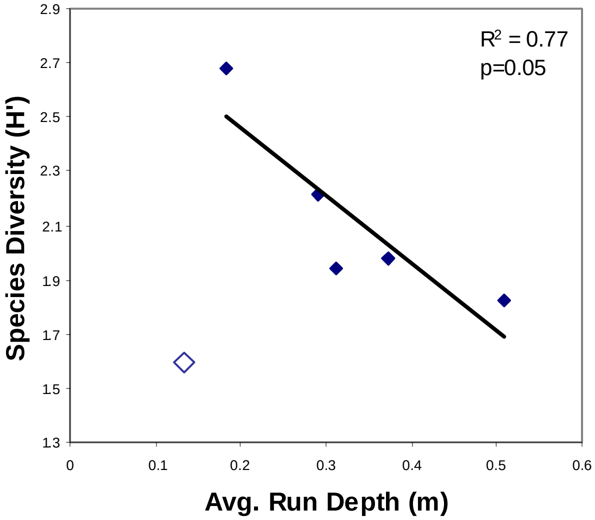


Figure 2.13. Run richness versus average fish cover rating, and run species diversity (H') versus average run depth (m). TR03 was excluded from the second regression (hollow).

CHAPTER 3

MAPPING IMPACT HOT-SPOTS: PREDICTING STRESSES TO AQUATIC ECOSYSTEMS THROUGH USE OF SPATIALLY EXPLICIT STRESS-SOURCE INFORMATION[1]

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[1] Esselman, P.C. 2001. To be submitted to Environmental Monitoring and Assessment.

ABSTRACT

To maintain healthy streams and rivers it is necessary to minimize the negative impacts of human activities. Before this can be done, it is necessary to understand *what* the impacts are, *where* they are occurring. In this paper, these two questions--what and where--are answered for the Monkey River, Belize. Using a handheld global positioning system (GPS), a scientist and a group of watershed residents mapped all obvious human activities along the Monkey River and its branches. This information was then used to predict stresses to the aquatic ecosystem. The information was also used to create maps of expected "hotspots" of human impact—places where the greatest threats to river health are occurring.

From this process, the following predictions were made:

(1) Human influences are most intense on the Swasey Branch of the Monkey River, especially in the Cowpen area and near the Southern Highway crossing. Other high impact areas are Bladen Branch near the Southern Highway crossing and at Trio Farm.

(2) The most serious threat to the river system is excess sediment in the river channel caused mostly by loss of riparian (riverside) forests and by agricultural drainage ditches.

(3) Two other potentially serious threats include: (a) changes to the basic food web of the river caused by removing riparian forests and by fishing pressures, and (b) greater nutrient levels originating from agricultural activities.

With these predictions, it is possible to direct scientific research efforts and go directly to the stress-sources and start working with land-users toward creative solutions.

This impact mapping method can be easily transferred to other rivers. It is especially suited for organizations in developing countries lacking training and funding to carry out more resource intensive assessments.

INTRODUCTION

Since it’s foundation in 1951, The Nature Conservancy (TNC) has grown to become one of the world’s leading private, international conservation groups. TNC’s stated long-term goal is the “survival of all viable native species and communities through the design and conservation of portfolios … within ecoregions” (TNC 2000). Nested within these “portfolios” are priority sites, found both in the U.S. and internationally, that range from local- to landscape-level in scale. In an attempt to achieve their goals most efficiently, TNC has streamlined a site-based framework for developing conservation strategies and measuring conservation success known as “site conservation planning” (SCP).

The SCP framework incorporates three key concepts: (1) scales of biodiversity and geography, (2) site functionality, and (3) functional landscapes. Through the first concept, TNC attempts to encourage conservation efforts at multiple levels of ecological organization (species, communities, ecosystems, etc.), and geographic scale (local to regional). The second concept, site functionality, is a measure of how well a site maintains the viability of its defined conservation targets (e.g., a population of endangered fish). Lastly, “functional landscapes” are maintained by selecting conservation targets that, if protected, would protect other ecosystem components at multiple scales within the landscape (TNC 2000). The specific planning methodology used to incorporate these three concepts at sites has come to be known as the “five-S” approach.

The five-S’s are systems, stresses, sources, strategies, and success. Each represents a different step in a planning process that culminates in the identification of priority conservation targets (systems), an understanding of *critical threats* facing those targets (stresses and sources), an outline of specific strategies to abate these threats (strategies), and measures to gauge the success of conservation actions (success; Figure 3.1). After successful application of the five S's a conservation management group should have a site conservation plan that, in specific terms, states what ecosystem attributes they are attempting to conserve at their site, how those are threatened, what strategic actions they will take to abate these threats, how much this will cost, and how they will measure their success. With improved information about ecological and human aspects of conservation sites, the five-S process can be revisited in an adaptive fashion to create updated site conservation plans.

The five S approach provides an effective framework for organizing conservation planning at the site level. But there are two other S's that provide the foundation of even this framework: *sound science*. Sound science is the crucial building block to site conservation planning, especially in the early stages. Defining conservation targets (systems) and determining critical threats (stresses and sources) necessitate a thorough understanding of ecosystem components, patterns, and processes. Reliance on offsite science (mostly from temperate latitudes) can only go so far. Unfortunately, in many developing countries such as Belize, Central America, the science has not yet been done locally or is in the early stages. Thus conservation organizations in these countries base many decisions around the collective historical experiences of indigenous and local peoples. While this traditional knowledge base is often exceedingly accurate and well developed, these sources of knowledge, with some exceptions (see Calheiros et al. 2000), are rarely legitimized well enough to withstand dispute. Though not entirely indisputable, scientifically based information is less questionable and thus can be more useful to conservation organizations.

The first TNC site in Latin America and the Caribbean to create a site conservation plan was the Maya Mountain Marine Area Transect (MMMAT), in southern Belize, Central America. The MMMAT is a million-acre ridge-to-reef corridor consisting of six watersheds that feed a mangrove-lined coastal embayment (Port Honduras) and the southern tip of the Belize barrier reef (Heyman and Kjerve 1999; Figure 3.2). According to Heyman et al. (1995), “Port Honduras represents the core of a naturally functioning, highly productive ecosystem where watersheds support coastal wetlands and thus support near shore fisheries production”. A Belizean non-governmental organization and TNC partner, the Toledo Institute of Development and Environment (TIDE), has made conservation of the MMMAT one of its central goals.

As part of its efforts to manage the MMMAT, TIDE completed a draft MMMAT SCP in May 2000 (TIDE 2000). This SCP was the product of several workshops attended by TIDE staff, field personnel from communities in the MMMAT, and local scientists (including the author of this paper). The two highest priority conservation targets (systems) that emerged from this process were “riparian terrestrial communities” and “aquatic communities”, which were critically threatened by “habitat destruction caused by agricultural land clearing” and “water quality degradation caused by agricultural practices” respectively (TIDE 2000). Definitions of terms like “aquatic communities” and “water quality degradation” remained fairly vague through the process as only a coarse level of analysis was involved in this first planning effort. Refinement of the MMMAT SCP will focus on more specific ecosystem components (e.g., fish communities or anadromous fishes instead of "aquatic communities") as well as better-defined stresses (e.g., sedimentation or nutrient loading instead of "water quality degradation") and sources (e.g., agricultural drainage ditches or riparian buffer clearing instead of "agricultural practices"). Although the first draft of the MMMAT SCP was a valuable and important effort, it was generally hindered by a lack of solid information about (1) ecosystem components suitable for designation as conservation targets; (2) the severity and scope of stresses, and (3) a knowledge of the geographic extent and intensities of stress-sources.

In an attempt to alleviate the latter two hindrances, mapping of stress-sources along the Monkey River was completed during two field seasons in mid-1999 and early 2000. This exercise was designed to address critical threats to the "aquatic communities" conservation target. Stress-sources were GPS-located, described, and photographed in the field, and then mapped using GIS. Using the source data to make inferences about stresses to aquatic communities, it was possible to predict the likely *severity* and *scope* of identified stresses, thereby addressing the second hindrance. Being able to predict severity and scope allowed for the relative ranking of stresses within the five-S methodology, a crucial step in the critical threats analysis. This report presents the results of the stress-source surveys and describes a process for converting source point data into a form that is more visually meaningful and useful to the site conservation planning process. Data interpretations, utility of the approach, and considerations for field-validation are presented in the Discussion.

STUDY SITE

The Monkey River watershed is the largest drainage in the MMMAT with an estimated drainage area of 1292 km^2 (Heyman et al. 1995) and an estimated total annual discharge of 2.0 x 10^9 m^3--a quantity approximately equal to the combined annual discharge of the remaining five MMMAT watersheds (Heyman and Kjerve 1999). More than 80% of this discharge occurs during four months of the year (June – September) during of the rainy season (Heyman and Kjerve 1999). The main stem of the river receives water and sediment from two major sub-catchments, the Bladen Branch, and the Swasey Branch. A third sub-catchment, the Trio Branch, enters Bladen Branch at the base of the Maya Mountains. The Monkey River flows through all of the four major landforms found in southern Belize including: (1) the Maya Mountain highlands; (2) karstic limestone relief; (3) rolling and undulating lowlands; and (4) coastal flatlands (Heyman et al. 1995). The river discharges into the Caribbean Sea as a sixth order stream.

Along with being the largest drainage in the MMMAT, the Monkey River is also the most heavily impacted by human activities. Approximately 66% of land cultivated for bananas in Belize is located in the Monkey River watershed, resulting in heavy agrochemical and fertilizer use, water pumping for irrigation, clearing of riparian buffers, and altered runoff in portions of the drainage (Usher and Pulver 1994). Over a thousand acres of citrus and a large mango plantation are also located in the watershed, again contributing agrochemicals and sediments to the river via runoff drains. Additionally, nine human settlements are located in the watershed. Results of human settlement include intensive fishing and hunting pressures, use of the river for laundry and washing, extensive deforestation due to slash and burn agriculture, and roads (personal observation).

Aquatic science in the watershed has been limited to a general biodiversity report (Macrae and Meerman 1995), localized fish sampling (Greenfield and Thomerson 1997), and four years of hydrologic records (Rudolf Williams, Chief Hydrologist, National Hydrologic Service).

METHODS

A seven-step process was developed to convert the stress-source point data into stress-specific “source intensity” maps. The end products of this process are color-coded maps showing expected intensity of stress-sources (“hot spots”) on a reach-by-reach basis for the entire drainage. The methods followed in each step are detailed below.

Step 1. *Map stress-sources*. Stress-source data were collected in June and July 1999 and February - April 2000 by making systematic observations along the main stems of the Bladen, Swasey, and Monkey Rivers (in kayaks and canoes). Excursions originated from points above direct human influence and culminated at the river mouth. All clearly identifiable human activities along the banks were spatially located using a Garmin 12XL handheld GPS, classified into one of eleven “stress-source classes” (Table 3.1), textually described, and photographed. Raw data were mapped using Arc Info® and Arc View® GIS software at TIDE headquarters in Punta Gorda, Belize. Two access-limited areas of the river that experience moderate human influence could not be visited and mapped were lower Trio Branch and the San Pablo community area on the upper Swasey.

Step 2. *Identify stress/stress-source associations*. Each stress-source was linked to the corresponding stresses to which it contributes (Table 3.2). Linkages were based on the scientific literature and professional judgment (Table 3.3).

Step 3. *Rank sources*. For each stress, sources were ranked on a scale of "significance of contribution" (Very high, High, Medium, Low) using criteria established by The Nature Conservancy. Final ranks were determined by combining ranks from the following two factors (TNC 2000, page VI-2):

"Degree of contribution to the stress – The contribution of a source, acting alone to the full expression of a stress, assuming the continuation of the existing management/conservation situation. Does (or did) the particular source make a very large or substantial contribution to causing the current stress, or a moderate or low contribution?

Irreversibility – The reversibility of the stress caused by the source. Does (or did) the source produce a stress that is irreversible, reversible at extremely high cost, or reversible with moderate or little investment?"

Combining ranks[*] from these factors (using a pre-established combining table; TNC 2000, page A-9) resulted in an overall source rank of Very High, High, Medium, or Low

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[*] Rankings for contribution and irreversibility were made based on professional judgment in the absence of quantitative information (see "The Need for Validation" below).

(Table 3.4). For the purpose of source intensity mapping, numeric values were assigned to each source rank (Very high=10, High=7.5, Medium=5, Low=2.5) to allow for addition of source scores in discrete river segments.

Step 4. *Segment river*. Using the 'Measure' tool in Arc View®, a map of the river was segmented into 1 km reaches in an upstream direction from the river mouth. Segments were reset at confluences with major tributaries (e.g., the Bladen and Swasey branch confluences with Monkey River), and each segment was labeled. These segments became the basis for comparing source intensities. Segments were outlined using Adobe Photoshop® in preparation for color coding with the same program (Step 6).

Step 5. *Tally source rank scores in each segment.* The segmented river map (from step 4) was overlain, on a stress-by-stress basis, with source point data from step 1. For example, for the stress "Altered flow regime", the points marking "drainage ditches", "water pumping", and "in-stream gravel mining" were displayed on the segmented map. Then, within each segment, source rank scores (from step 3) associated with these points were added and entered into a table to keep track of overall segment scores for each stress. Building on the example above, if segment BL001 had two drainage ditches in it (source rank score=5) and only one water pump-house (score=5) then the tally for BL001 would equal (2 DD x5)+(1 PH x5). Thus, 15 would be the *relative source intensity* for segment BL001.

<u>Step 6</u>. *Create source intensity maps*. At the completion of step 5, for each stress type, each segment had a source intensity score associated with it. Categorical break points were established by dividing the value of the highest scoring segment (from all stress categories) by four to assign levels of significance to specific segment tallies. Each level was color coded for mapping: Very high (red), High (yellow), Medium (bright green), and Low (dark green). Segments with no stress-sources were left colorless. In our example, if the score for segment BL001 fell in the low range, it would be colored dark green on the map.

<u>Step 7</u>. *Create "overall expected stress intensity" map*. It was informative at the end of the analysis to aggregate segment scores across stresses to create a map of overall expected stress intensities. This map showed the stream segments expected to be experiencing the most intense combined stress. At the completion of this step, nine maps, one for each stress type and one showing overall source intensity, were ready for evaluation and incorporation into the management process.

RESULTS

Figure 3.3 displays all stress-source points mapped during this effort. At this point in the process (before conversion) areas of high stress appear as blobs of colored dots. Figures 3.4 through 3.12 display completed relative source intensity maps for each stress type.

A total of 167 stress-source points were mapped along the Monkey River and tributaries. By far the most commonly located stress-sources were community use and no riparian buffer (Figure 3.13). Of all points measured, 70.1% (117) occurred along the Swasey Branch, 26.9% (45) occurred along Bladen Branch, with 3.0% (5) occurring on the main stem of the Monkey River. Many of these points occurred in aggregations, or represented the presence of multiple stress-sources at the same location. In general, river segments running through commercial banana farms showed the highest densities of stress-sources followed by segments close to human communities and roads.

Sums of all source intensities (across segments) on a stress-by-stress basis indicated that sedimentation was expected to be the most intense type of stress, followed next by trophic alteration, then nutrient loading (Figure 3.14). The geographic spread ("scopes") of source intensities were relatively even between stress types with the exception of habitat fragmentation, which occurred in only four segments (Table 3.5). Sources contributing to nutrient loading were the most widespread occurring in 36 of 104 measured segments.

DISCUSSION

A cursory glance at the source intensity maps revealed great similarities in scope and severity of source intensities with the exceptions of altered flow regime and habitat fragmentation, which showed reduced values. At this predictive level of analysis, altered flow regime and habitat fragmentation should not be discarded, but left for further evaluation as information improves. Of the six remaining stresses, their scopes and severities seemed quite similar. In the absence of clear visual distinctions based on scrutiny of the maps, it was useful to compare numerical measures of total source intensities (severity) (Figure 3.14) and frequencies (scope) (Table 3.5)

Predicted stresses were ranked from most intense to least intense by determining proportional ranks for severity (as a proportion of the most severe stress) and scope (as a proportion of the most frequent stress), and then averaging these ranks. The rank order that emerged after considering both scope and severity was: (1) sedimentation (most intense); (2) trophic alteration; (3) nutrient loading; (4) thermal alteration; (5) toxins/contaminants; (6) habitat alteration; (7) flow alteration; and finally, (8) habitat fragmentation (Figure 3.15).

From this analysis, the following *tentative* conclusions were drawn:

1. Sedimentation, trophic alteration, and nutrient loading (in that order) were the three "critical stresses" to aquatic communities of the Monkey River as of the completion of data collection in April 2000.
2. Direct habitat alteration, thermal alteration, and toxins/contaminants represent substantial secondary threats.
3. Altered flow regime and habitat fragmentation are considered less serious threats based on the relatively low number of stress-sources contributing to these threats, though further research may very well reveal important relationships missed in this analysis.

Impact Mapping and the MMMAT SCP

As stated in the introduction, the first MMMAT-SCP draft proceeded with very coarse landscape-level ecosystem targets, limited information about severity and scope of stresses, and little substantive knowledge of the geographic extent and intensity of stress-sources. Identifying a suite of appropriate conservation targets at multiple levels of biological organization will take much time and research. In the meantime, according to the first MMMAT SCP, “aquatic communities” stand as one of the priority targets for the site. The results of the Monkey River stress-source mapping project presented in this report not only alleviate the “geographic extent of stress-sources” gap, but offer an alternative to estimating stress “severity and scope” in the absence of local research.

The reasoning behind using stress-sources as surrogates for stresses is that *all stresses originate somewhere*. Understanding the locations, frequencies, and contributions of each stress-source allow for the derivation of better-informed hypotheses (better guess-work). And while locations and frequencies are easy to quantify, a quantitative understanding of the physical contributions each stress-source makes to stresses has yet to be gained. Although literature and personal field observation substantiate the individual stress/stress-source associations (Table 3.3), many unforeseen relationships between human activities and aquatic community stress undoubtedly exist. Furthermore, in the absence of a good understanding of relative contributions of different sources to a stress, it is difficult to confidently rank sources regarding their contribution to a stress and irreversibility. In the absence of this good information, guarded conclusions based on personal experience and the literature must suffice. In the meantime, research plans should be drawn to remedy information gaps.

The Need for Validation

Determination of stress ranks should not be considered the end of a research process as much as a starting point for future research. Ideally, each assumption made during this process would be validated with field research. Obviously, given limited time and resources, only the most crucial questions will receive attention.

This particular exercise identified sedimentation, trophic alteration, and nutrient loading as likely starting points for scientific inquiry. The weak links in the determination of these critical threats were, first, the absence of a quantitative understanding of the relative contributions of each source to the stresses, and second, absence of real measures of stresses in the ecosystem. I will use the predicted most critical threat, sedimentation, to illustrate a validation approach to verify source intensity projections.

Sedimentation

Sediment in streams can originate from natural or anthropogenic sources and can occur in suspended (particles in the water column), deposited (particles on the stream bed), or hyporheic (particles in the matrix of the stream bottom) forms (Metzeling et al. 1995). Two main sediment origins in rivers are the river channel itself (from the bed or the banks), and non-channel sources, such as bare soils that reach the stream through sheet flow or tributaries (Wood and Armitage 1997). Human activities tend to accelerate sedimentation delivery and accumulation in streams.

Stream biota are broadly affected by the presence of sediment in streams. Freshwater flora may be affected via smothering by deposited material and reduction of light levels by suspended sediments (thereby reducing primary production). Studies of the impacts of suspended sediment on fishes have shown reduced growth rates, reduced feeding efficiency of visual predators, decreased oxygen uptake, altered diet, increased stress, increased incidence of disease, altered behavior and displacement (Metzeling et al. 1995). Deposited sediments also affect fishes by reducing usable habitat areas for feeding, spawning, egg laying, and hatching. Suspended sediments affect aquatic macroinvertebrates in similar ways to fishes (mortality, reduced oxygen uptake, displacement)(Wood and Armitage 1997).

Contributions. Sediments reaching the Monkey River (and other rivers of the MMMAT) originate from numerous sources. Major within-stream sources of sediment include banks that have been cleared of their vegetation (most often in association with commercial and subsistence agricultural activities), in-stream gravel mining, and channelization. In-stream gravel mining is known to widen and deepen channels, cause upstream erosion, as well as erosion in a downstream direction (Kondolf 1997). Non-channel sources of sediment to the Monkey River include drainage ditch outlets that channel water, sediment, and other products (e.g., toxins) from banana plantations to the river channel. Cattle grazing (Owens et al. 1996) and road building (Cline et al. 1982) are two other activities that exacerbate sedimentation.

Of the sources mentioned above, the expected dominant contributors of sediment to the Monkey River are de-vegetated banks, drainage ditches, and in-stream gravel mining (in that order; personal observation). An empirical study of the relative contributions of these and other sources will help describe the problem in explicit terms, and will help with prioritization of amelioration strategies. Methodologically, measurement of bed-load sediments in rivers is difficult (Leopold et al. 1992), thus it will be best to first attempt to quantify sediment loss directly from their sources, rather than from the stream channel itself. Because sediment movement increases predictably as a power function of discharge (Kondolf 1997), mathematical modeling may be the most promising approach to studying and predicting relative contributions from different sources.

The methods used to accomplish this task will vary according to the source being measured. Estimation of soil loss from de-vegetated banks may be best accomplished using precision surveying equipment. Again, because of the relationship with flow, most sediment transport occurs during three months of the wet season (Heyman and Kjerve 1999). Eroding banks in de-vegetated zones near banana or milpa agriculture should be surveyed at a minimum, once before, during, and after the wet (erosion) season, or more frequently (e.g., before and after every flood event of a known magnitude) as the situation allows. Rates of sediment loss from multiple banks could be used to create and validate a mathematical model for estimating sediment loss from denuded banks for use in future evaluations.

Sediment loss from drainage ditches could be measured at the source during rain events when rates of erosion are likely to peak. Observations of sediment deltas extending from banana and citrus drains even during the dry season lend credence to the fact that sediment can be transported to the channel year round from banana plantations (particularly because farms are irrigated and always creating outflow). Because of this, background levels of sediment delivery should be documented during the dry season, perhaps by measuring total suspended solids and turbidity from the effluent stream leaving the ditch. Because the drainage ditches are stationary and relatively static (like a weir), stage/discharge relationships would be easy to establish. Correlation of sediment movement (as measured by turbidity and total suspended solids) and discharge from drainage ditches could be useful in predicting and modeling sediment movement from drainage ditches. Measurement and statistical incorporation of rainfall, drainage area of ditch networks, and discharge could strengthen the predictive capacity of models.

Sediment loss from gravel mining sites will be more difficult to evaluate. Disruption of streambeds by mining has been shown to cause increased suspended sediment load and turbidity (Brown et al. 1998). Regular monitoring of total suspended solids and turbidity directly above, within, and below active and recently abandoned mining sites would be useful for isolating effects of specific mines. Sediment movement caused by gravel mining is likely to be highly variable depending on in-channel mining location, extraction rate, extraction method, and sediment control measures taken (if any).

<u>Real effects of sediments</u>. Studies of in-stream biota are necessary to understand the real effects and extent of sediment stress to aquatic communities. In studies of fishes in the temperate zone, effects of sedimentation caused by riparian forest clearing showed decreases in stream fishes that require clean substrates for reproduction (such as species that broadcast fertilized eggs into gravel) and feeding. Those species that guard their young in nests and live in deeper slower water showed increased relative abundances in response to higher sedimentation (Jones et al. 1999). According to Berkman and Rabeni (1987), reduced abundances of benthic insectivores and herbivores have also been observed in fish communities. If suitable indicator species or functional guilds are present in the Monkey River, then fishes may be an excellent indicator of sedimentation.

Many studies have also documented the effects of sediment on stream invertebrates. Chutter (1968) reported deleterious effects on certain mussels (via interruption of respiration and feeding) and snails (via life-cycle interruption), representatives of which occur in Monkey River. Community responses by macroinvertebrates have been observed in multiple studies, and include reduction of densities, abundances, and diversity caused by sediment from road building (Nuttall and Bielby 1973; Cline et al. 1982). Macroinvertebrates show promise for measuring biotic responses to sediment, though taxonomic expertise and lab time are drawbacks. Boles (1998) has already started to focus on macroinvertebrates as bioindicators in Belize waters.

Many issues must be considered before designing monitoring programs. Scientists must choose projects that tie directly and substantially to management goals, and attempt to design projects that may be transferable to other drainage basins in Belize and the Caribbean. Due to the compounding stresses obvious in the relative source intensity maps, a large part of the scientific challenge will be to isolate the effects of one stress or another.

CONCLUSIONS

This chapter attempts to lay a logical framework for decision-making in the face of conservation necessity and information scarcity. Spatially explicit, easily collected information about stress-sources was used to infer expected stress intensities drawing on criteria determined by the Nature Conservancy. Results of this analysis are directly applicable to Site Conservation Planning in the Maya Mountain Marine Area Transect in southern Belize. However, the seven-step method presented here should be transferable to other locations.

It was tentatively concluded that sedimentation, trophic alteration, and nutrient loading (in that order) were the critical stresses to aquatic communities of the Monkey River, followed by direct habitat alteration, thermal alteration, toxins/contaminants, altered flow regime and habitat fragmentation (in decreasing order of importance). These results should be used guardedly to guide conservation planning and research prioritization, not to draw definitive conclusions about the real scope and severity of stresses to aquatic ecological communities. Validation of source contribution rankings and the real scope and severity of stresses based on physical and biological data will help solidify stress rankings.

The stress analysis framework presented here is only as sound as the assumptions behind it, which to date have been based on scientific research from temperate latitudes (see Pringle 2000) and educated opinions. Continual and open scrutiny of stress/stress-source associations and rankings will benefit the realism and solidity of the inferences and hypotheses derived from exercises such as these. In the end, this tool represents a large step forward for organizations like TIDE that have the daunting task of planning and implementing sustainable development strategies in the face of substantial resource and information limitations. The approach is best suited to situations where scientifically based information is needed in the most rapid and inexpensive way possible. Thus it is perfect for application in the MMMAT, Belize, Central America, and beyond.

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LITERATURE CITED

Benstead, J.P., J.G. March, C.M. Pringle, and F.N. Scatena. 1999. Effects of low-head dams and water abstraction on migratory tropical stream biota. Ecological Applications 9: 656-668.

Berkman, H.E., and C.F. Rabeni. 1987. Effect of siltation on stream fish communities. Environmental Biology of Fishes 18: 285-294.

Boles, E. 1998. Developing a Community Based Rapid Watershed Assessment Protocol Focusing on the Sibun River Watershed in Belize as a Case Study. Ph.D. Dissertation. Jackson State University, Jackson, MS.

Brookes, A. 1986. Response of aquatic vegetation to sedimentation downstream from river channelization works in England and Wales. Biological Conservation 38: 352-367.

Brown, A.V., M.M. Lyttle, and K.B. Brown. 1998. Impacts of gravel mining on gravel bed streams. Transactions of the American Fisheries Society 127: 979-994.

Calheiros, D.F., A.F. Seidl and C.J.A. Ferreira. 2000. Participatory research methods in environmental science: local and scientific knowledge of a limnological phenomenon in the Pantanal wetland of Brazil. Journal of Applied Ecology 37: 684-696.

Chutter, F.M. 1969. The effects of silt and sand on the invertebrate fauna of streams and rivers. Hydrobiologia 34: 29-37.

Cline, L.D., R.A. short, and J.V. Ward. 1982. The influence of highway construction on the macroinvertebrates and epilithic algae of a high mountain stream. Hydrobiologia 96: 149-159.

Edwards, E.D., and A.D. Huryn. 1996. Effect of riparian land use on contributions of terrestrial invertebrates to streams. Hydrobiologia 337: 151-159.

Extence, C.A., 1978. The effects of motorway construction on an urban stream. Environmental Pollution 17: 245-252.

Greenfield, D.W. and J.E. Thomerson. 1997. Fishes of the Continental Waters of Belize. University Press of Florida, Gainesville, FL.

Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An ecosystem perspective of riparian zones. BioScience 41: 540-551.

Gurtz, M.E., G.R. Marzolf, K.T. Killingbeck, D.L. Smith, J.V. McArthur. 1988. Hydrologic and riparian influences on the import and storage of coarse particulate organic matter in a prairie stream. Canadian Journal of Fisheries and Aquatic Science 45: 655-665.

Harmon, M.E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R. Sedell, G.W. Lienkaemper, K. Cromack Jr., and K.W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecology Research 15: 133-302.

Heyman, W.D. and B. Kjerve. 1999. Hydrological and oceanographic considerations for integrated coastal zone management in southern Belize. Environmental Management 24: 229-245.

Heyman, W., W. Maheia, S. Franklin, and L. Nicolait. 1995. Maya Mountain-Marine Area Transect: A Synthesis to Assist in Integrated Planning and Management (draft). Belize Center for Environmental Studies, Belize City.

Jones, E.B.D., G.S. Helfman, J.O. Harper, and P.V. Bolstad. 1999. Effects of riparian forest removal on fish assemblages in southern Appalachian streams. Conservation Biology 13: 1454-1465.

Kondolf, G.M. 1997. Hungry water: effects of dams and gravel mining on river channels. Environmental Management 21: 533-551.

Leopold, L.B., M.G. Wolman, and J.P. Miller. 1992. Fluvial Processes in Geomorphology. Dover Publications, Inc., Mineola, New York.

Line, D.E., W.A. Harman, G.D. Jennings, E.J. Thompson, and D.L. Osmond. 2000. Nonpoint-source pollutant load reductions associated with livestock exclusion. Journal of Environmental Quality 29: 1882-1890.

Lowrance, R., L.S. Altier, J.D. Newbold, R.R. Schnabel, P.M. Groffman, J.M. Denver, D.L. Correll, J.W. Gilliam, and J.L. Robinson. 1997. Water quality functions of riparian forest buffers in Chesapeake Bay watersheds. Environmental Management 21: 687-712.

Lowrance, R., R. Todd, J. Fail Jr., O. Hendrickson Jr., R. Leonard, and L. Asmussen. 1984. Riparian forests as nutrient filters in agricultural watersheds. BioScience 34: 374-377.

Mas-Pla, J., J. Montaner, and J. Sola. 1999. Groundwater resources and quality variations caused by gravel mining in coastal streams. Journal of Hydrology 216: 197-213.

Macrae, E.M., J.C. Meerman, and T. Boomsma. 1995. Monkey River Special Development Area Biodiversity Study. Belize Tropical Forest Studies, Belmopan, Belize.

Metzeling, L., T. Doeg, and W. O’Connor. 1995. The impact of salinization and sedimentation on aquatic biota. Pages 126-136 in R.A. Bradstock, T.D. Auld, D.A.

Keith, R.T. Kingsford, D. Lunney, and D.P. Sivertsen (eds.) Conserving Biodiversity: Threats and Solutions. Surrey Beatty and Sons, Australia.

Miller, R.R. 1982. Pisces. Pages 486-501 in S.H. Hurlbert and A.Villalobos-Figueroa (eds.) Aquatic biota of Mexico, Central America, and the West Indies. San Diego State University, San Diego, CA.

Murphy, M.L., C.P. Hawkins, and N.H. Anderson. 1981. Effects of canopy modification and accumulated sediment on stream communities. Transactions of the American Fisheries Society 110: 469-478.

The Nature Conservancy (TNC). 2000. The Five-S Framework for Site Conservation: Second Edition, Volumes I and II. The Nature Conservancy, Arlington, Virginia.

Neary, D.G., P.B. Bush, and J.L. Michael. 1993. Fate, dissipation and environmental effects of pesticides in southern forests: A review of a decade of research progress. Environmental Toxicology and Chemistry 12: 411-428.

Nutall, P.M., and G.H. Bielby. 1973. The effects of china-clay waste on stream invertebrates. Environmental Pollution 5: 77-86.

Osborne, L.L., and D.A. Kovacic. 1993. Riparian vegetated buffer strips in water-quality restoration and stream management. Freshwater Biology 29: 243-258.

Owens, L.B., W.M. Edwards, and R.W. Van Keuren. 1996. Sediment losses from a pastured watershed before and after stream fencing. Journal of Soil and Water Conservation 51: 90-94.

Peterjohn, W.T. and D.L. Correll. 1984. Nutrient dynamics in an agricultural watershed: Observations on the role of a riparian forest. Ecology 65: 1466-1475.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. BioScience 47: 769-784.

Pringle, C.M. 2000. River conservation in tropical versus temperate latitudes. Pages 317-384 in P.J. boon, B.R. Davies, and G.E. Petts (eds.), Global Perspectives on River Conservation: Science, Policy, and Practice. John Wiley & Sons Ltd., New York.

Quddus, M.A. 1980. Use of synthetic detergents in Malaysia. Environmental Conservation 7: 287-288.

Sandecki, M. 1989. Aggregate mining in river systems. California Geology 42: 88-94.

Snyder, N.J., S. Mostaghimi, D.F. Berry, R.B. Reneau, S. Hong, P.W. McClellan, and E.P. Smith. 1998. Impact of riparian forest buffers on agricultural nonpoint source pollution. Journal of the American Water Resources Association 34: 385-395.

Toledo Institute for Development and Environment (TIDE). 2000. Site Conservation Plan: Maya Mountain Marine Area Transect (draft). Toledo Institute for Development and Environment, Punta Gorda, Belize.

Usher, W. and E. Pulver. 1994. Evaluation of Pesticide and Fertilizer Usage in Bananas and Potential Risks to the Environment. Natural Resource Management and Protection Project, Government of Belize, and United States Agency for International Development, Belmopan, Belize.

Wood, P.J. and P.D. Armitage. 1997. Biological effects of fine sediment in the lotic environment. Environmental Management 21: 203-217.

Table 3.1. Stress-source classes used to identify human activities along the banks of the Monkey River and tributary streams.

Stress Source Class	**Description**
Channelization	A place where the active stream channel has been diverted to a new, man-made channel.
Community Use/Access	An area commonly used by local residents for laundry, recreation, drinking water, and/or fishing.
Drainage Ditch	A point of discharge for artificial drainage channels originating in commercial banana or citrus fields.
Grazing	An area of livestock grazing within the riparian zone or stream channel.
In-stream Gravel Mining	An area where sand and gravel beds are being commercially mined and extracted as a source of building aggregate.
No Riparian Buffer	Areas where naturally occurring vegetation has been completely cleared to the bank.
Thin Riparian Buffer	Areas where buffer exists, but at levels less than the nationally mandated 66 foot buffer.
Road access	A location where a road has been cut to the river or crosses the river.
Sandbag Dam	A point in the channel where sandbags have been stacked to create a temporary impoundment across the stream to facilitate water pumping.
Water Pumping (irrigation)	A point along the channel where water is abstracted for agricultural irrigation or some other purpose.
Other	Any other activity not listed above.

Table 3.2. Eight stress types delineated through an analysis of the types of stress-sources located during mapping exercises. Stresses defined here represent a refinement of previous classifications for aquatic communities in the MMMAT.

Stress	**Description**
Sedimentation	Artificially high amounts of sediment in the stream channel from in-stream and external sources. "Chokes up" the streambed, alters habitat, and affects biota.
Nutrient loading	Elevated amounts of growth limiting nutrients (Nitrogen and Phosphorus) in the water beyond limits of natural variation. Alters food webs, creates algal blooms, and causes eutrophication.
Toxins contaminants	Presence of pesticides, herbicides, heavy metals, chlorine, oil and gas, and other artificial agents that harm living organisms.
Altered flow regime	The changing of natural patterns of flow to which freshwater and coastal organisms have adapted to survive. Caused by damming of rivers, changing drainage patterns (e.g., adding drainage ditches), excessive water pumping, and lowering of water table.
Thermal alteration	Water temperatures that have been changed to beyond the natural range of variation. Affects the metabolism, reproduction, and life cycles of many aquatic organisms.
Direct habitat alteration	Direct change of river habitats via removal of key elements (e.g., tree falls, overhanging vegetation, gravel bars) or changing of the volume of available habitat (e.g., gravel mining, dewatering).
Direct trophic alteration	Fundamental changes to the river food web. Could manifest in low trophic levels (e.g., leaf litter vs. photosynthesis), and/or high ones (e.g., removal of fishes, shrimps).
Habitat fragmentation	Disconnection of portions of the stream channel from one another through channel obstructions such as dams. Migratory biota (e.g., mountain mullet) are often heavily impacted.

Table 3.3. Stress/stress-source relationships and the scientific literature used to justify these relationships. When no scientific literature was available, personal observation was used to justify relationships.

Stress	Sources	References
Sedimentation	No riparian buffer	Wood and Armitage 1997; Osborne and Kovacic 1993; Lowrance et al. 1997
	Drainage ditches	Usher and Pulver 1994
	In-stream gravel mining	Brown et al. 1998; Sandecki 1989; Kondolf 1997
	Channelization	Brookes 1986
	Grazing	Metzeling et al. 1995; Owens et al. 1996
	Road access	Cline et al. 1982; Extence 1978, Metzeling et al. 1995
	Thin buffer	Wood and Armitage 1997
Nutrient loading	Drainage ditches	Usher and Pulver 1994
	No riparian buffer	Osborne and Kovacic 1993; Lowrance et al. 1997; Snyder et al. 1998; Peterjohn and Correll 1984; Lowrance et al. 1984
	Community use	Quddus 1980
	Grazing	Line et al. 2000
	Thin riparian buffer	
Toxins/Contaminants	Drainage ditches	Usher and Pulver 1994;
	No riparian buffer	Usher and Pulver 1994, Lowrance et al. 1997; Neary et al. 1993
	In-stream gravel mining	
	Thin riparian buffer	Lowrance et al. 1997; Neary et al. 1993
Altered flow regime	Drainage ditches	Poff et al. 1997
	Water pumping	Poff et al. 1997
	In-stream gravel mining	Mas-Pla et al. 1999
Thermal Alteration	No riparian buffer	Osborne and Kovacic 1993; Gregory et al. 1991;
	Drainage ditches	
Direct habitat alteration	No riparian buffer	Gregory et al. 1991, Harmon et al. 1986
	In-stream gravel mining	Brown et al. 1998, Sandecki 1989; Kondolf 1997
	Channelization	Brookes 1986
	Water pumping	
Direct trophic alteration	No riparian buffer	Murphy et al. 1981; Gurtz et al. 1988; Edwards and Huryn 1996; Gregory et al. 1991, Harmon et al. 1986
	Community use	
Habitat fragmentation	Sandbag dam	Benstead et al. 1999

Table 3.4. Stresses to aquatic communities, their corresponding sources, and source scoring criteria. V=very high; H=high; M=medium; L=low.

Stress	**Sources**	**Cont.**	**Irrev.**	**Source Rank**	**Rank Score**
Sedimentation	No riparian buffer	V	H	Very High	10
	Drainage ditches	H	H	High	7.5
	In-stream gravel mining	M	H	Medium	5
	Thin Buffer	M	H	Medium	5
	Road access	M	H	Medium	5
	Channelization	L	H	Medium	5
	Grazing	L	H	Medium	5
Nutrient loading	Drainage ditches	V	M	High	7.5
	No riparian buffer	V	M	High	7.5
	Thin riparian buffer	M	M	Medium	5
	Community use	L	M	Low	2.5
	Grazing	L	M	Low	2.5
Toxins/Contaminants	Drainage ditches	V	M	High	7.5
	No riparian buffer	H	M	Medium	5
	Thin riparian buffer	M	M	Medium	5
	In-stream gravel mining	L	M	Low	2.5
Altered flow regime	Drainage ditches	H	M	Medium	5
	Water pumping	H	M	Medium	5
	In-stream gravel mining	L	M	Low	2.5
Thermal Alteration	No riparian buffer	VH	M	High	7.5
	Drainage ditches	L	M	Low	2.5
Direct habitat alteration	No riparian buffer	H	M	High	7.5
	In-stream gravel mining	M	M	Medium	5
	Water pumping	M	M	Medium	5
	Channelization	M	M	Medium	5
Direct trophic alteration	No riparian buffer	H	H	High	7.5
	Community use	H	H	High	7.5
Habitat fragmentation	Sandbag dam	L	L	Low	2.5

Table 3.5. The geographic scopes of stress-sources for each stress as measured by the frequencies and percentages of all segments measured that contained at least one stress-source (out of 104). Proportional ranks show all scores as a proportion of the most frequently occurring stress (nutrient loading).

Stress	Frequency	Percentage	Prop. Rank
Nutrient loading	36	34.6	1.0
Sedimentation	35	33.7	0.97
Thermal alteration	35	33.7	0.97
Toxins/contaminants	34	32.7	0.94
Trophic alteration	33	31.7	0.92
Direct habitat alteration	29	27.9	0.81
Flow alteration	25	24.0	0.69
Habitat fragmentation	4	3.8	0.11

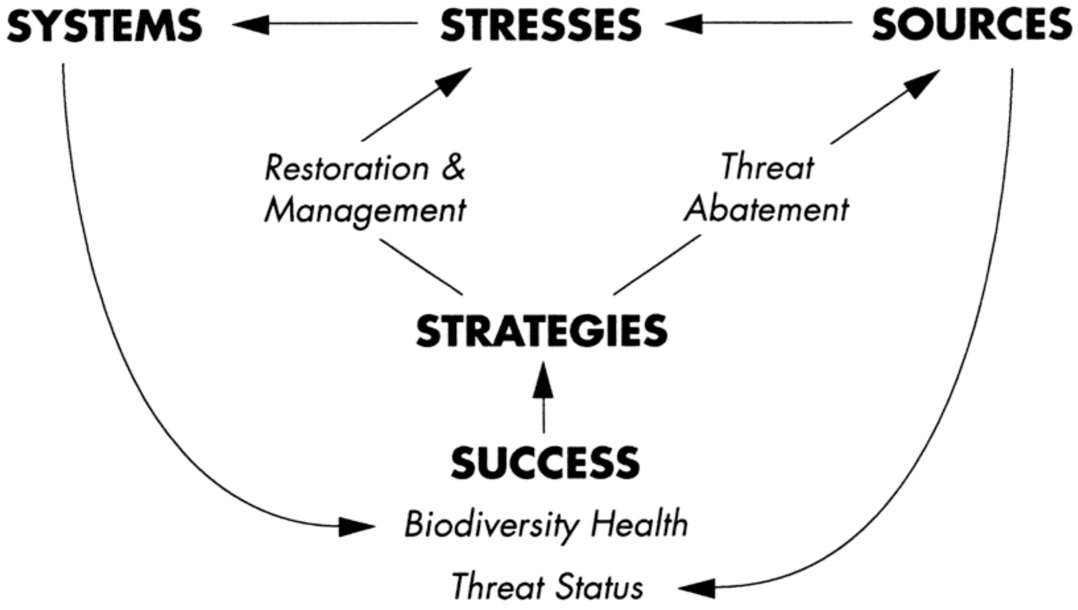

Figure 3.1. Flow diagram showing the relationships between the five-S's (from TNC 2000).

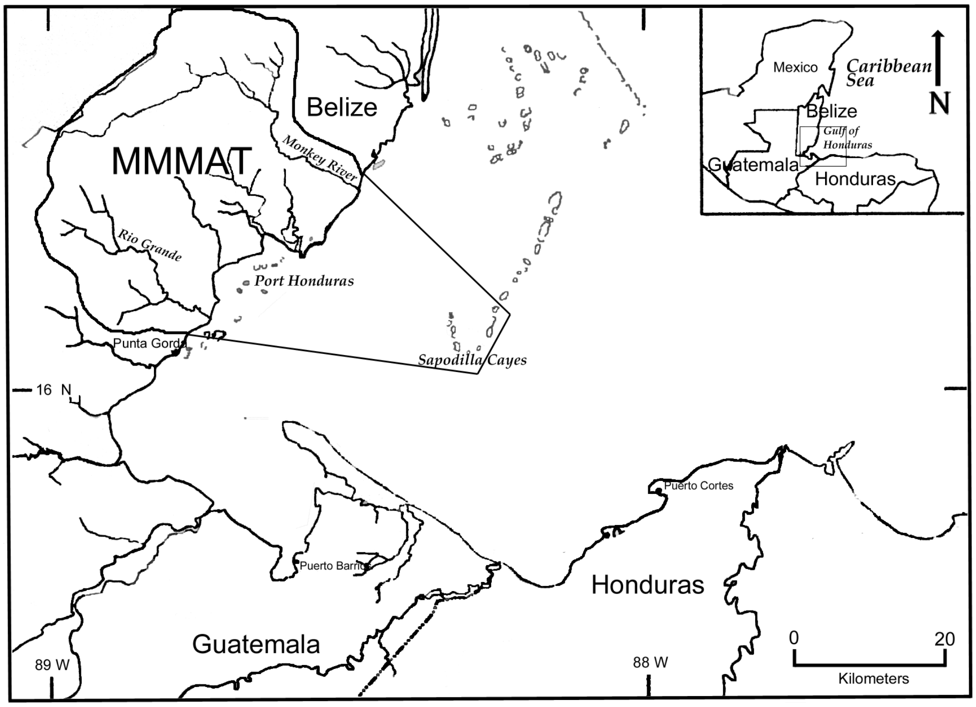

Figure 3.2. Functional boundaries of the Maya Mountain Marine Area Transect (MMMAT) stretching from the ridge of the Maya Mountains to Port Honduras and the southern Belize barrier reef.

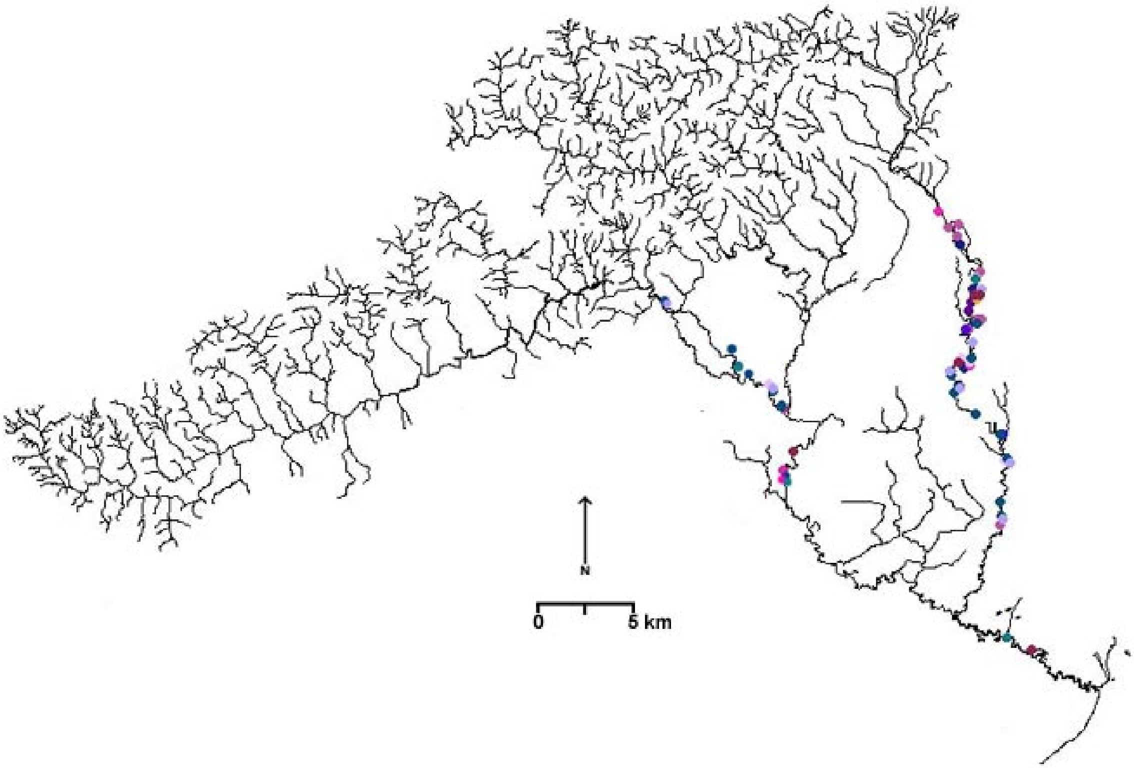

Figure 3.3. Monkey River watershed showing all mapped sources. The complexity of this map makes it difficult to interpret without interacting directly with the GIS platform.

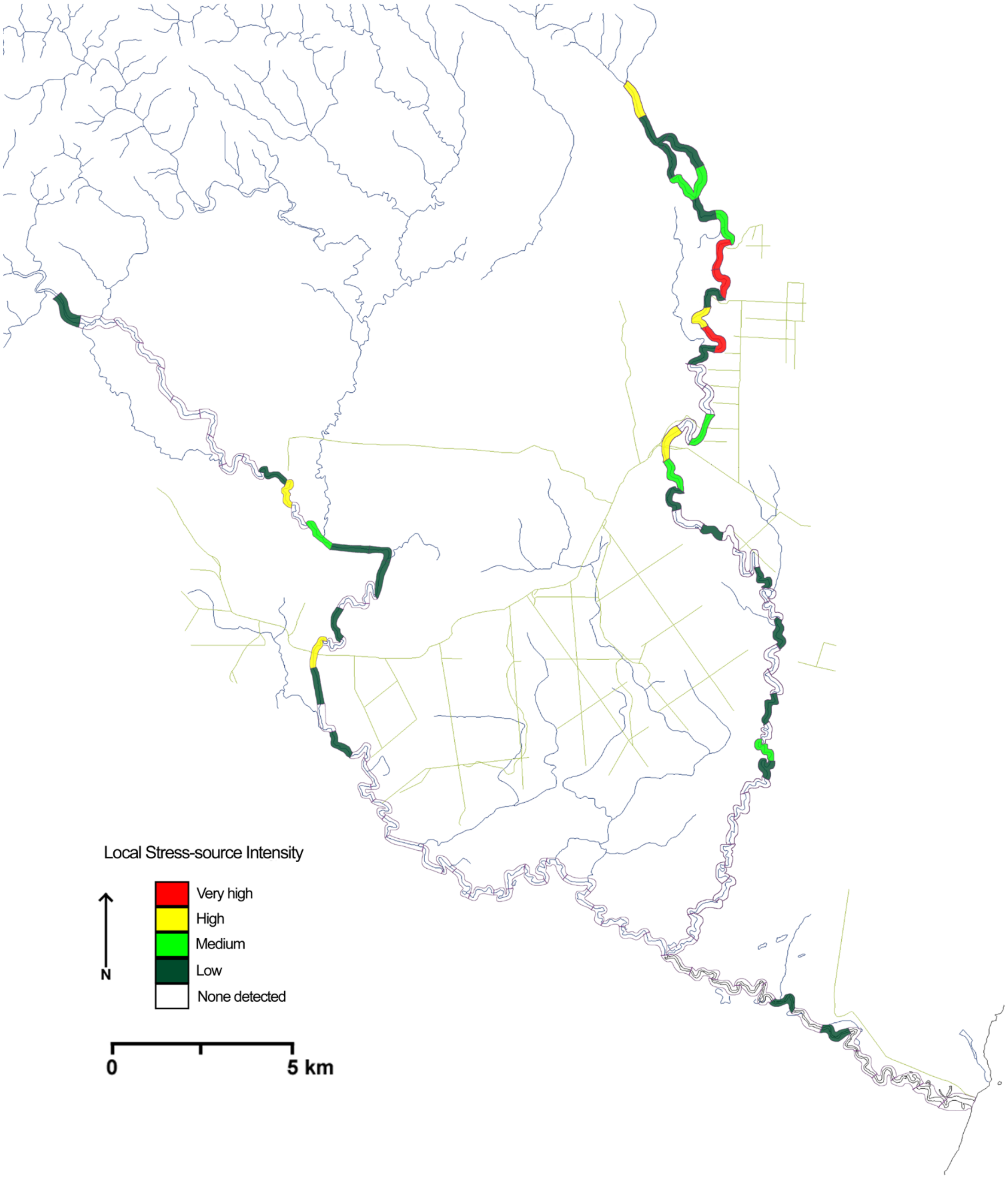

Figure 3.4. ‘Sedimentation’ stress-source intensity map. The Bladen Branch is highlighted on the left and the Swasey on the right. They meet to form the Monkey River. Headwaters areas were not assessed because there were no obvious human impacts in most places.

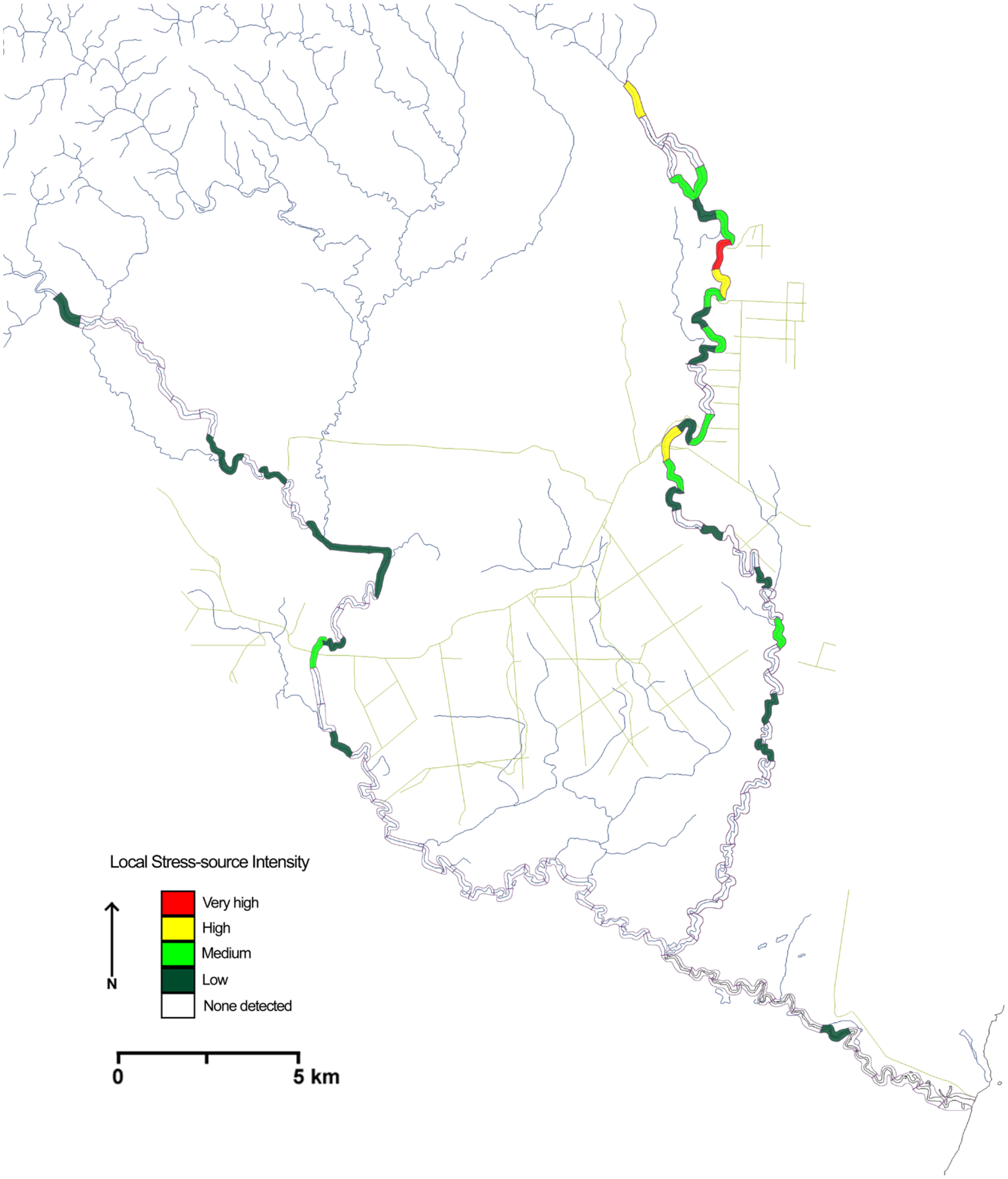

Figure 3.5. ‘Direct trophic alteration’ stress-source intensity map. The Bladen Branch is highlighted on the left and the Swasey on the right. They meet to form the Monkey River. Headwaters areas were not assessed because there were no obvious human impacts in most places.

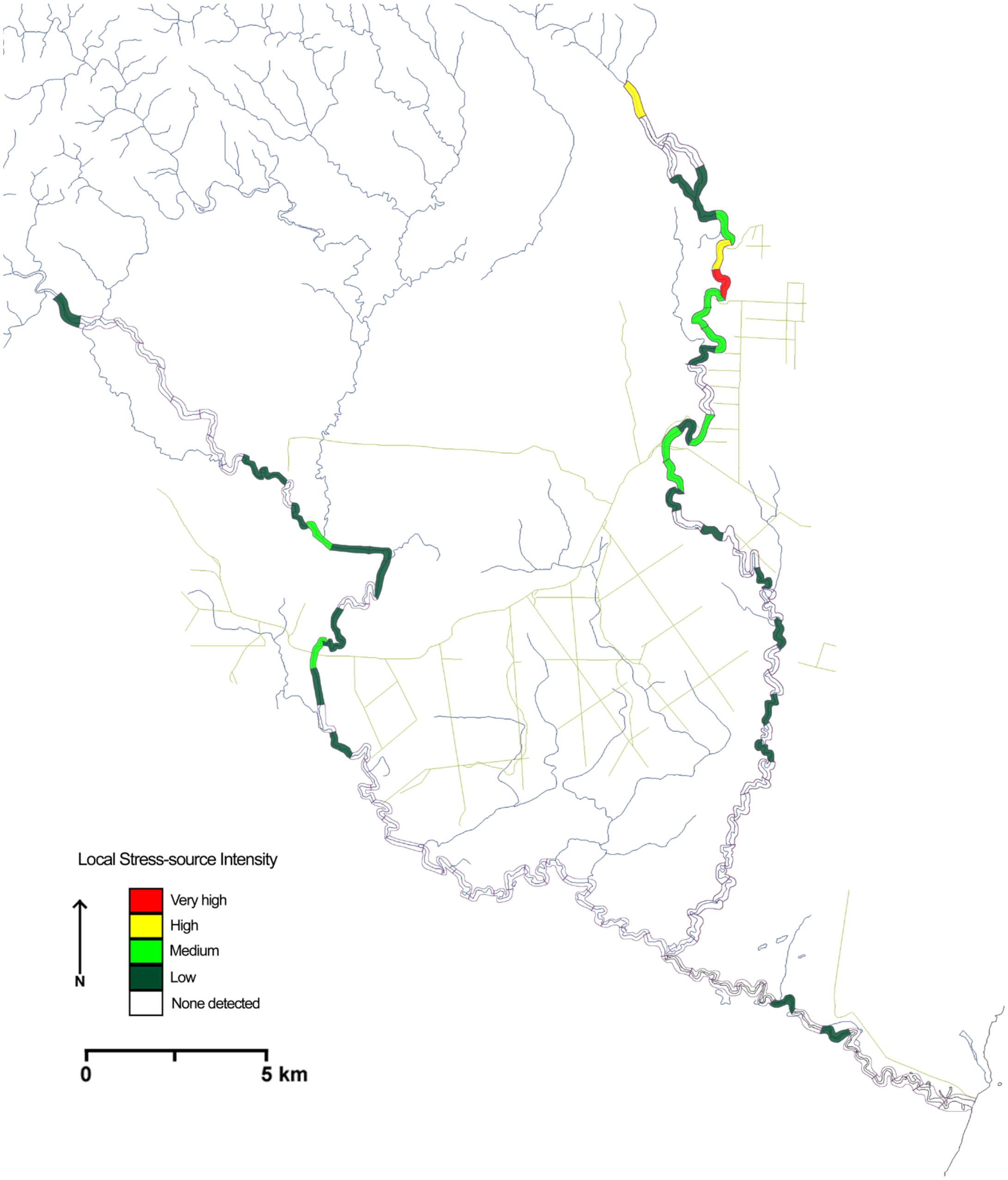

Figure 3.6. ‘Nutrient loading’ stress-source intensity map. The Bladen Branch is highlighted on the left and the Swasey on the right. They meet to form the Monkey River. Headwaters areas were not assessed because there were no obvious human impacts in most places.

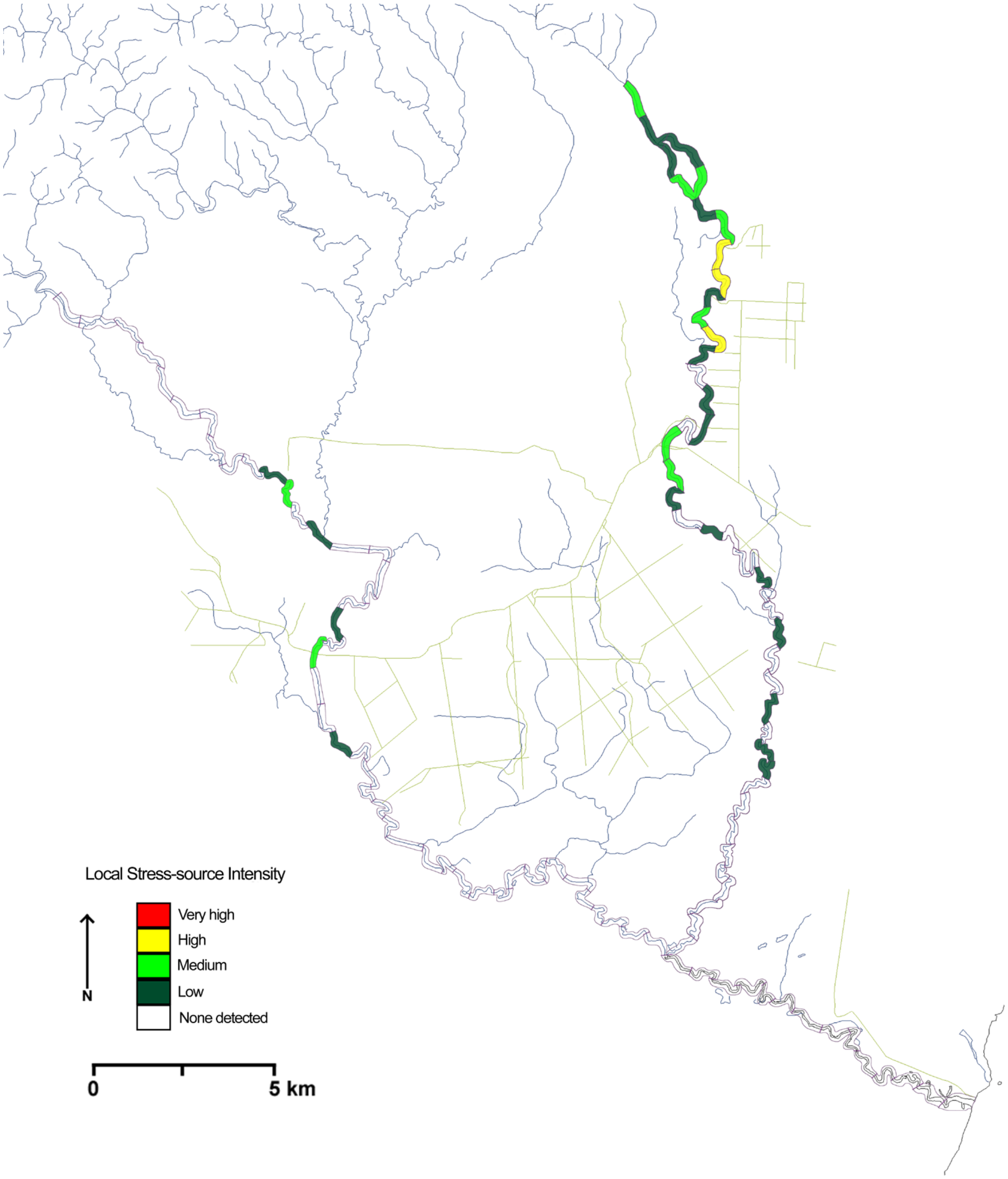

Figure 3.7. ‘Direct habitat alteration’ stress-source intensity map. The Bladen Branch is highlighted on the left and the Swasey on the right. They meet to form the Monkey River. Headwaters areas were not assessed because there were no obvious human impacts in most places.

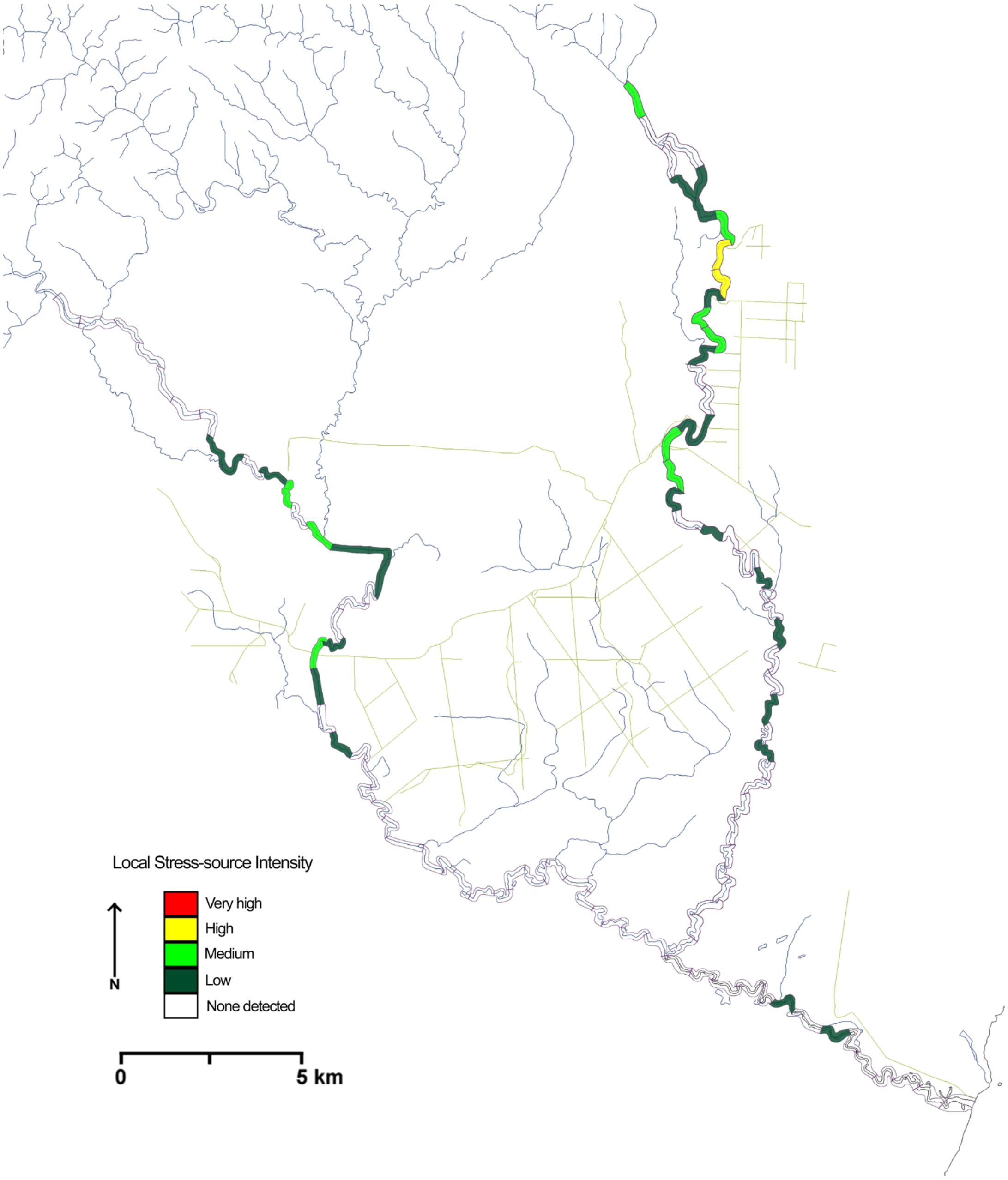

Figure 3.8. ‘Thermal alteration stress-source intensity map. The Bladen Branch is highlighted on the left and the Swasey on the right. They meet to form the Monkey River. Headwaters areas were not assessed because there were no obvious human impacts in most places.

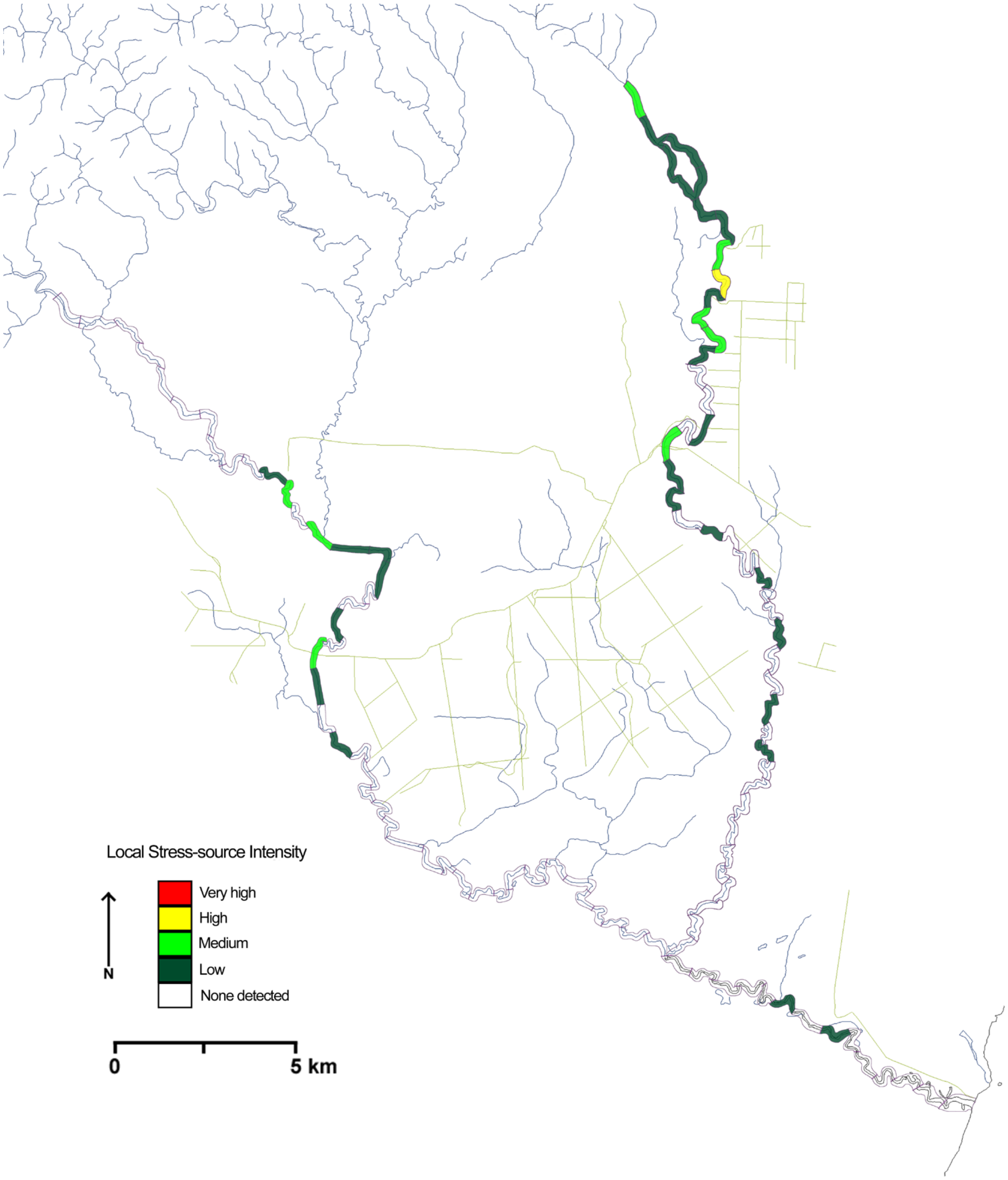

Figure 3.9. ‘Toxins/contaminants’ stress-source intensity map. The Bladen Branch is highlighted on the left and the Swasey on the right. They meet to form the Monkey River. Headwaters areas were not assessed because there were no obvious human impacts in most places.

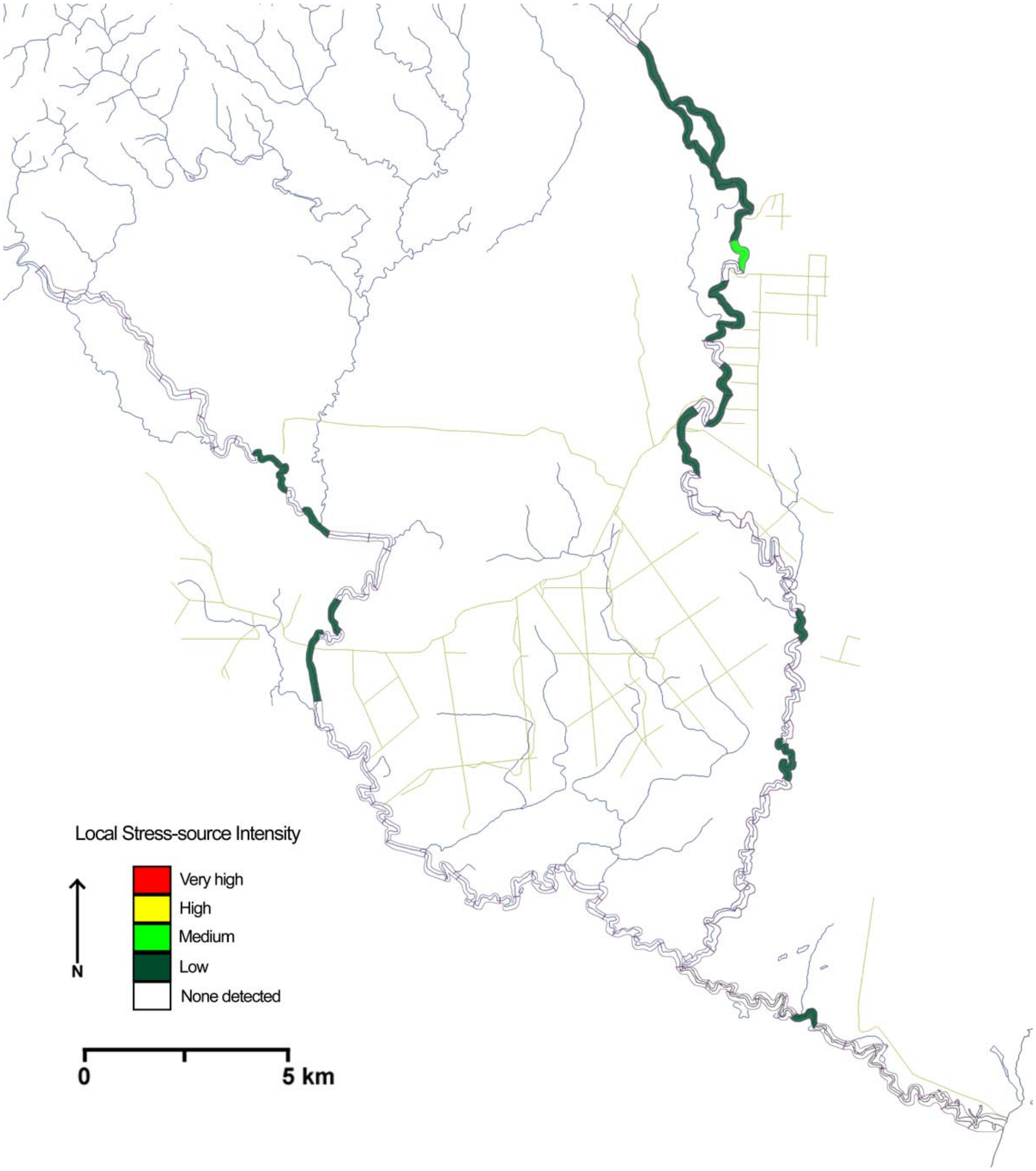

Figure 3.10. ‘Altered flow regime’ stress-source intensity map. The Bladen Branch is highlighted on the left and the Swasey on the right. They meet to form the Monkey River. Headwaters areas were not assessed because there were no obvious human impacts in most places.

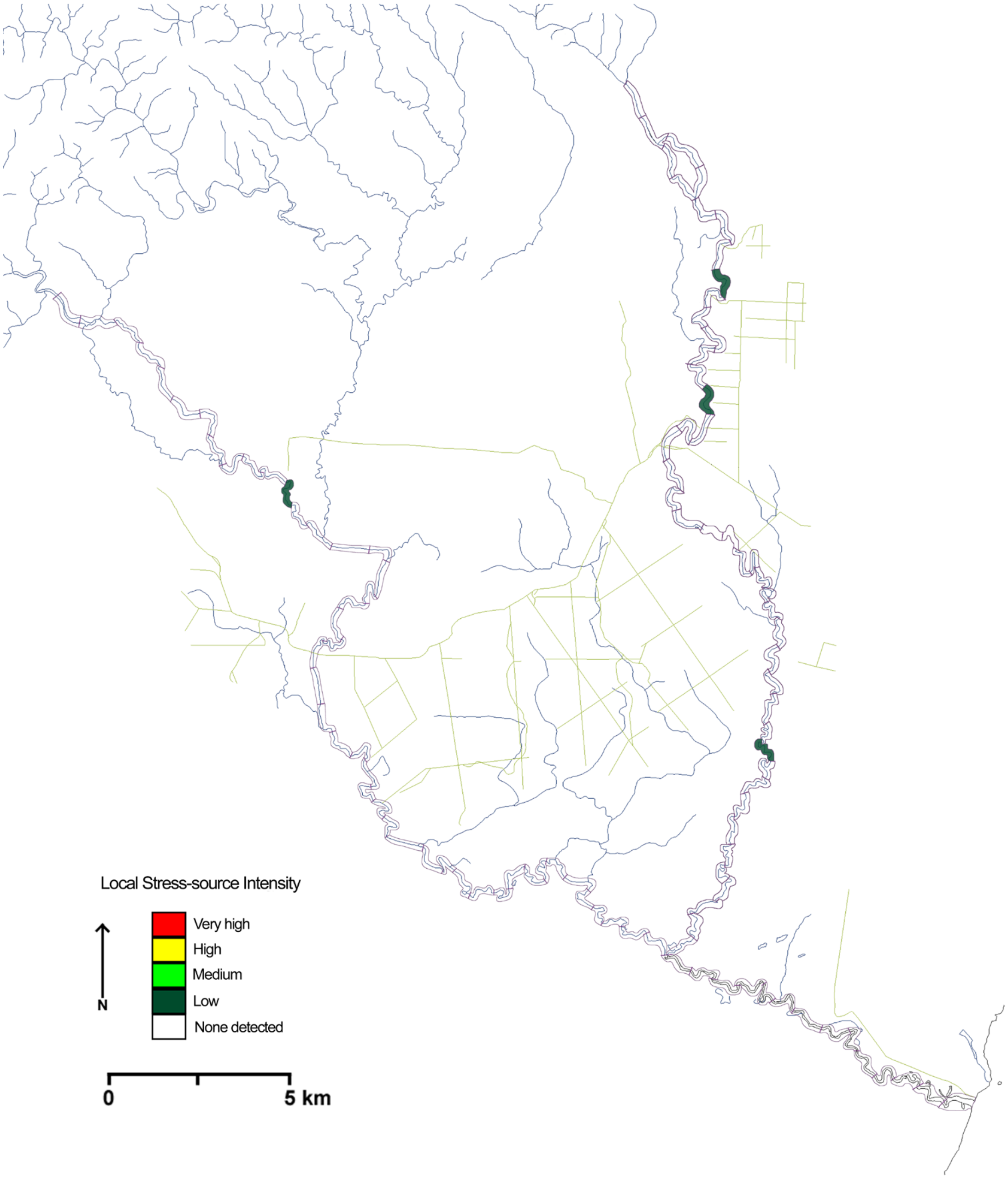

Figure 3.11. ‘Habitat fragmentation’ stress-source intensity map. The Bladen Branch is highlighted on the left and the Swasey on the right. They meet to form the Monkey River. Headwaters areas were not assessed because there were no obvious human impacts in most places.

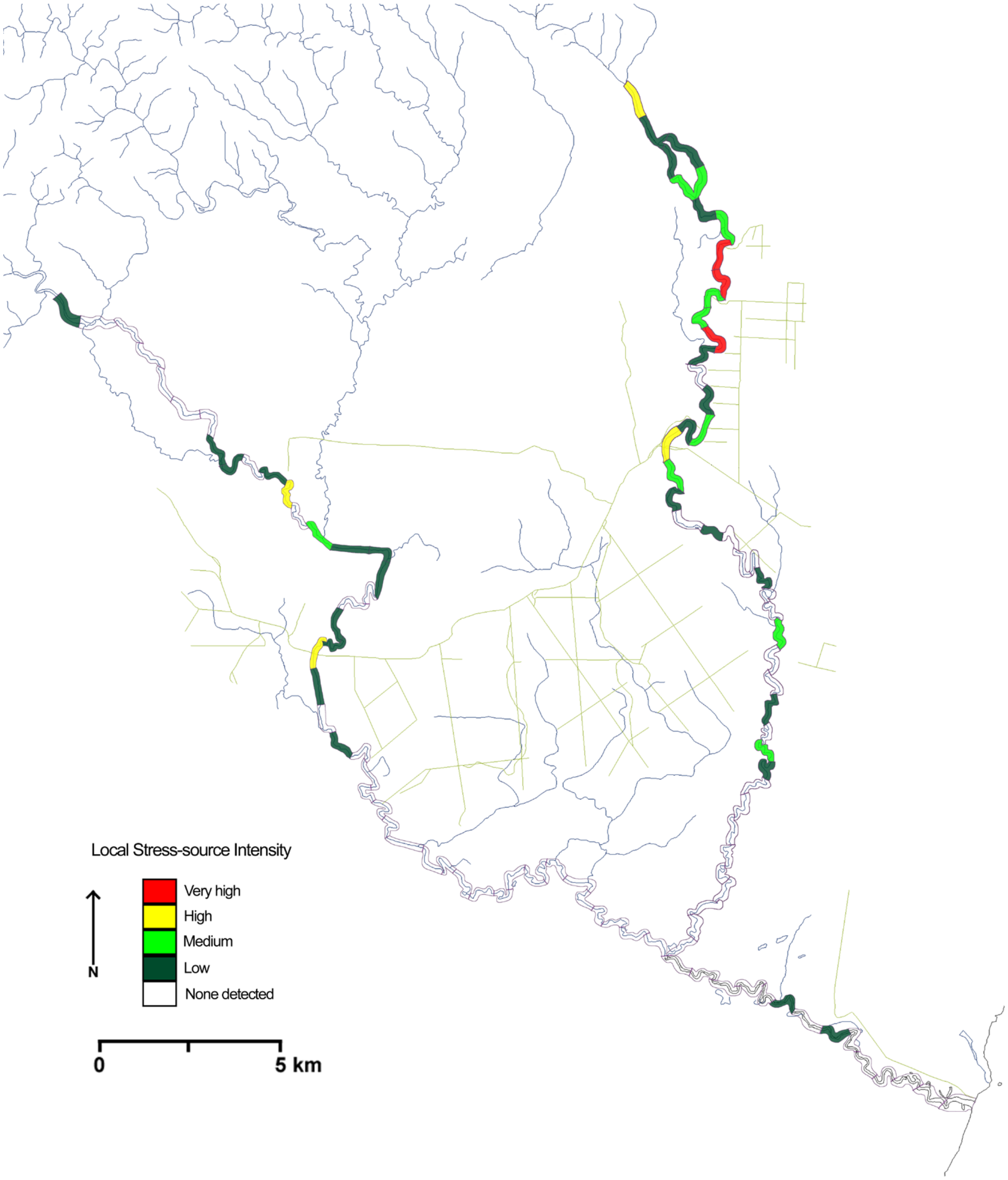

Figure 3.12. ‘Overall’ stress-source intensity map. This map shows aggregated source intensity scores for each segment across all stress-types. The Bladen Branch is highlighted on the left and the Swasey on the right. They meet to form the Monkey River. Headwaters areas were not assessed because there were no obvious human impacts in most places.

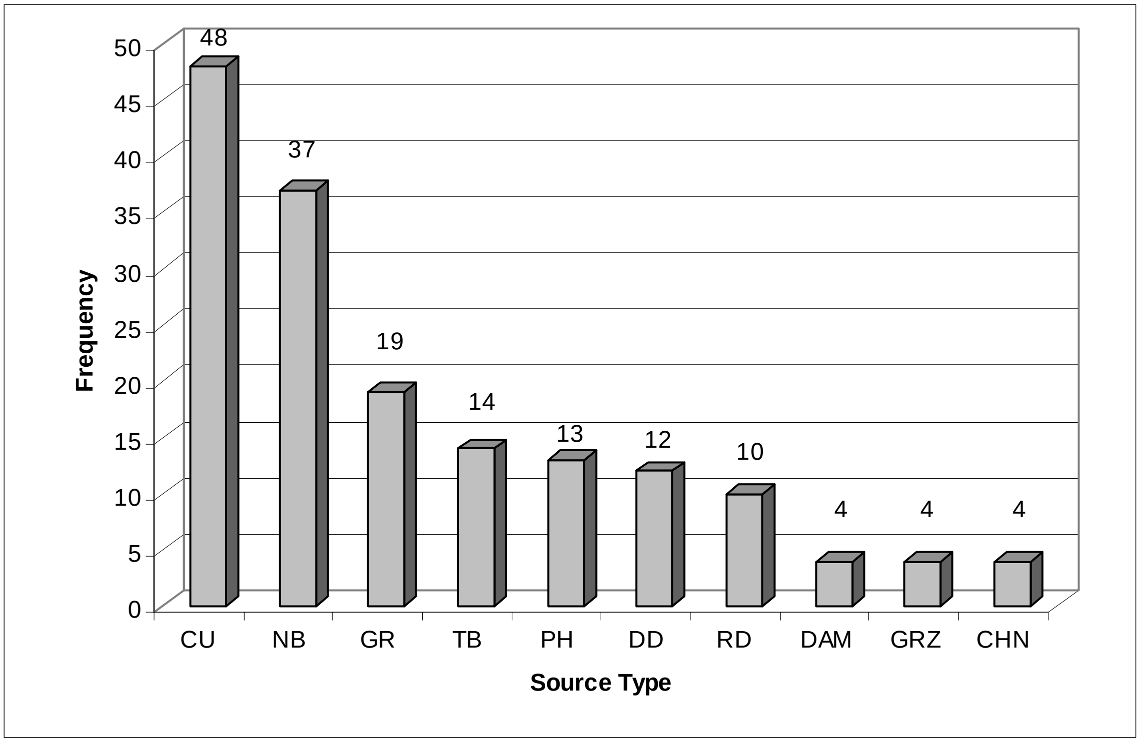

Figure 3.13. Frequency occurrences of each source type. CU=Community use; NB=No riparian buffer; GR=In-stream gravel mining; TB=Thin riparian buffer; PH=Pumphouse; DD=Drainage ditch; RD=Road access or crossing; DAM=temporary sandbag dam; GRZ=Cattle grazing in the stream; CHN=Channelization.

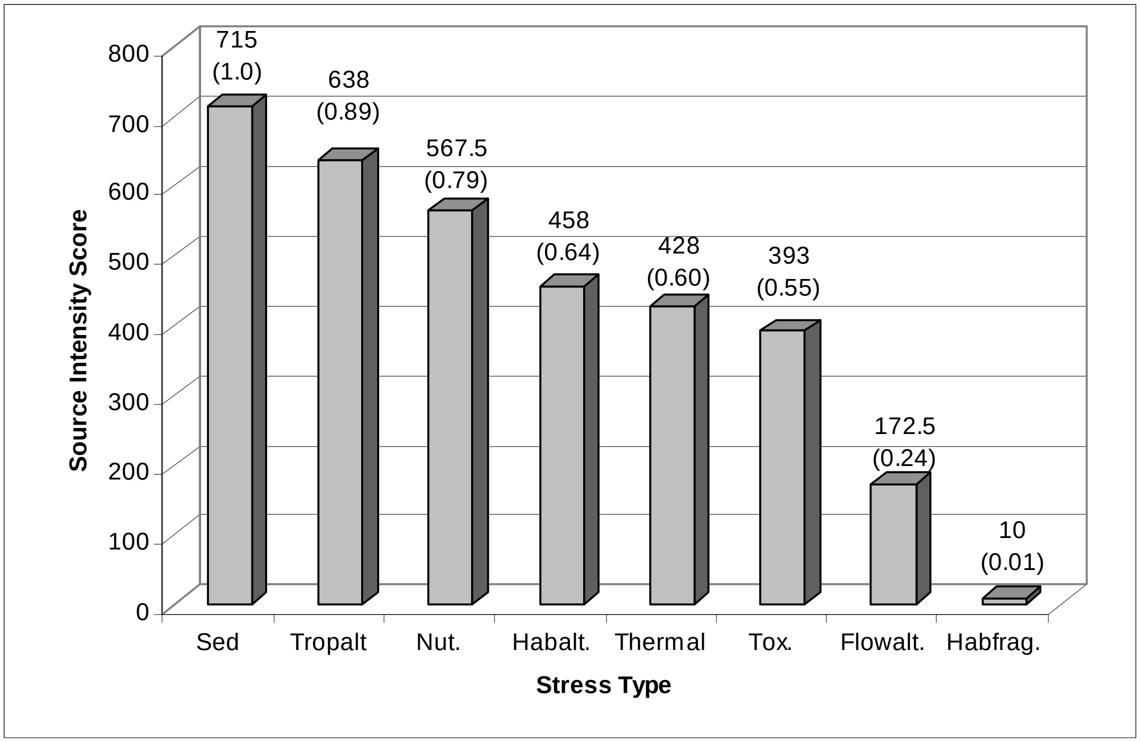

Figure 3.14. Relative source intensities summed for each stress across all stream segments with proportional rank represented in parentheses. These values can be considered a surrogate (in the absence of better data) for “stress severity” within the five-S stress ranking process. Sed.=Sedimentation; Tropalt.=Trophic alteration; Nut.=Nutrient enrichment; Habalt.=Direct habitat alteration; Thermal=Altered thermal regime Tox.=Toxins/contaminants; Flowalt.=Altered flow regime; Habfrag.=Habitat fragmentation.

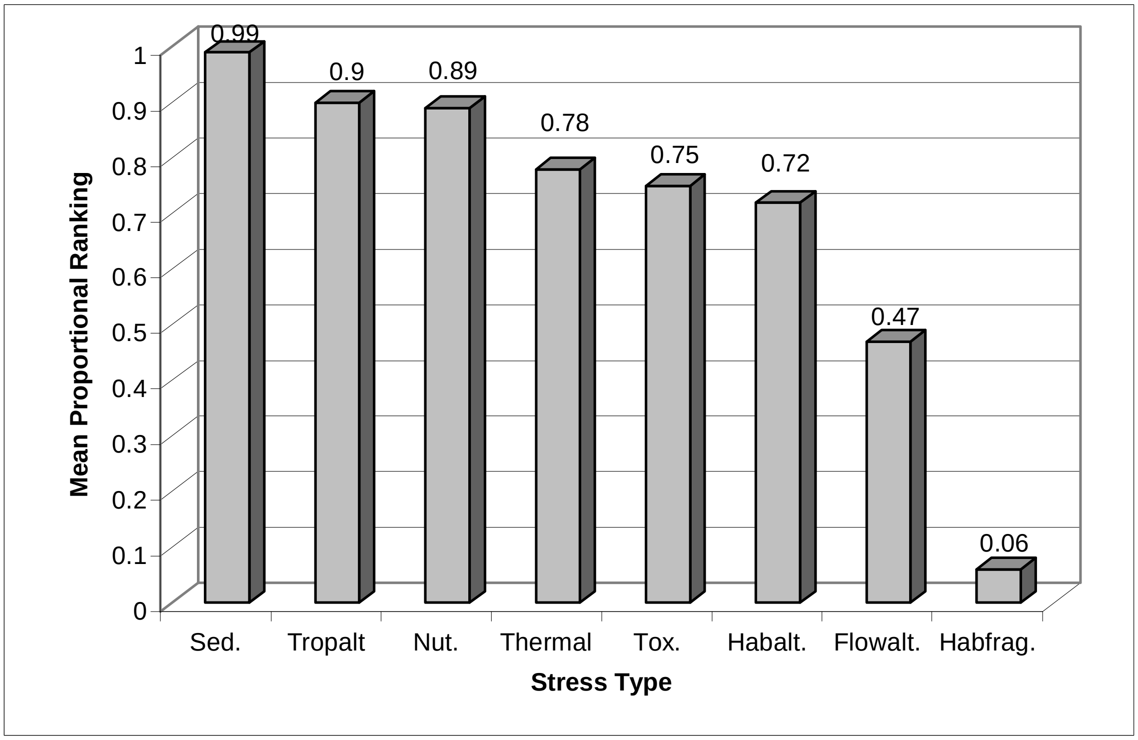

Figure 3.15. Overall stress ranks determined by averaging proportional ranks from measures of severity (Figure 14) and scope (Table 4). Sed.=Sedimentation; Tropalt.=Trophic alteration; Nut.=Nutrient enrichment; Thermal=Altered thermal regime Tox.=Toxins/contaminants; Habalt.=Direct habitat alteration; Flowalt.=Altered flow regime; Habfrag.=Habitat fragmentation.

CHAPTER 4

APPLICATION OF THE STREAM VISUAL ASSESSMENT PROTOCOL (SVAP) IN THE MAYA MOUNTAIN-MARINE AREA TRANSECT, BELIZE[1]

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[1] Esselman, P.C. 2001. To be submitted to Environmental Monitoring and Assessment.

ABSTRACT

The Stream Visual Assessment Protocol (SVAP) is a visually-based assessment tool designed to provide a qualitative statement about stream health. The original SVAP was developed by the United States Department of Agriculture Natural Resource Conservation Service (NRCS) for use across the United States. The protocol is suitable for application by non-scientists (e.g., community volunteers, government officers, private sector compliance specialists) after brief training. A slightly modified SVAP version was pilot-tested in the Monkey River to assess its performance in the Maya Mountain Marine Area Transect, Belize. Performance was tested in terms of precision and ease-of-use, and accuracy was inferred by comparing SVAP rankings of stations with subjective rankings made by experienced field observers. Results of performance tests indicated that SVAP was well suited for application in the MMMAT. The precision of the tool was shown to be very high, perhaps because of relatively clear-cut decision criteria afforded by characteristics of the study river (e.g., pristine character in some places, clearly identifiable degradation in others). Ease-of-use was reported by all users to be very good. Accuracy was inferred subjectively to adequately reflect an ecological condition gradient apparent on the landscape. Further development of SVAP is highly recommended in the Maya Mountain Marine Area Transect, Belize, and the greater Latin American and Caribbean (LAC) region

INTRODUCTION

What is SVAP?

> *"The Stream Visual Assessment Protocol is intended to be a simple comprehensive assessment of stream condition that maximizes ease of use. It is suitable as a basic first approximation of stream condition. It can also be used to identify the need for more accurate assessment methods…" (NRCS 1998a, p. 22)*

The Stream Visual Assessment Protocol (SVAP) is a rapid assessment technique for evaluating the ecological condition of streams and small rivers (Bjorkland et al. 2001). As the name implies, SVAP relies on visual cues to qualitatively assess stream condition relative to "least-impacted" reference conditions. The protocol does not require expertise in aquatic science, and can be used successfully after a short training period. Written scoring criteria are used to rate multiple attributes of the in-stream/riparian environment on a condition scale from 1 (worst) to 10 (best). Scores from all attributes are averaged to calculate an "overall station score", which can be used to make inter-site comparisons and monitor stations over time (Bjorkland et al. 2001).

The original SVAP was developed by the Natural Resources Conservation Service (NRCS) of the United States Department of Agriculture (NRCS 1998a). Scientists at NRCS, the US Environmental Protection Agency (EPA), and the University of Georgia drew on existing visually-based assessment procedures (e.g., Georgia DNR 1996; USEPA 1997a, b; OHEPA 1999) to create the SVAP, which was then extensively field-tested throughout the United States and published in 1998 (Bjorkland et al. 2001)*. By the end of the development process, SVAP results correlated well with those from more scientifically rigorous assessment protocols (e.g., IBI-fish; Ohio QHEI).

SVAP was developed for maximum transferability. According to the NRCS (1998a, p. 22), the protocol "has been designed to utilize factors that are least sensitive to regional differences", and that "the protocol can be enhanced by tailoring the assessment elements to regional conditions". SVAP versions have been tested across the entire United States with good success. Field-testing has also been conducted in Puerto Rico, Jamaica and most recently in British Columbia, though no performance data have yet been reported (R. Bjorkland, University of Georgia, pers. comm.).

SVAP has become widely employed within the NRCS to develop and evaluate the effectiveness of conservation plans, set conservation priorities, and for education and outreach with riparian landowners (Bjorkland et al. 2001). In Belize, SVAP could be used for these and other purposes by a number of interest groups including:

1. Community volunteers for monitoring streams in their area;
2. Government officers for case-specific assessments (EIA's, etc.);
3. Conservation NGOs for coarse-level assessment and prioritization of streams in need of concentrated focus;
4. Private sector environmental officers for riparian management;
5. Environmental scientists for hypothesis generation.

So *"What is SVAP"*? In a sentence, SVAP is a visually-based assessment tool designed to provide a qualitative statement about stream health.

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* The complete NRCS SVAP document can be found on the web at http:\\www.ncg.nrcs.usda.gov\tech_notes.html

SVAP in the Maya Mountain Marine Area Transect

The Maya Mountain Marine Area Transect (MMMAT) is a large ridge-to-reef corridor in southern Belize composed of six watersheds that feed Port Honduras and the southern tip of the Belize barrier reef (Heyman and Kjerve 1999; Figure 4.1). According to Heyman et al. (1995), “Port Honduras represents the core of a naturally functioning, highly productive ecosystem where watersheds support coastal wetlands and thus support near shore fisheries production”. Watersheds and the rivers that integrate them are keystones of the MMMAT ecosystem.

One of the central goals of the Toledo Institute of Development and Environment (TIDE), a Belizean non-governmental organization, is conservation of the MMMAT. Recognizing the importance of river systems in connecting upland and coastal areas, TIDE has designated aquatic biological communities as a priority conservation target in need of immediate attention (TIDE 2000). Thus, maintenance of community types that exist in non-degraded areas is TIDE’s mandate, and in areas where communities have already changed because of degradation, TIDE must focus on restoring environmental conditions that can support healthy communities once again.

Successful maintenance of good stream conditions in the MMMAT requires monitoring and assessment techniques that can measure responses in stream conditions to natural and/or human pressures, and estimate stream condition across the transect. SVAP fulfills these requirements at “an introductory screening-level” (Bjorkland et al. 2001). As a screening-level tool, SVAP is best used to hypothesize responses to human pressures and estimate ecological condition. This is a significant step forward for river monitoring in MMMAT.

During the first six months of 2000 a modified SVAP was field-tested by a four-person field crew at 21 sites along the Monkey River and its major branches. The purpose of the research was to field-test an SVAP version appropriate for the greater MMMAT. The specific objectives were to investigate (a) the accuracy, (b) the precision, and (c) the ease-of-use of a modified SVAP.

Accuracy is a measure of how well the protocol estimates the real ecological condition of a given stream reach. The ideal way to measure accuracy would be to statistically compare SVAP scores to results from more scientifically rigorous assessment protocols. Unfortunately such protocols are only now being developed in Belize, leaving subjective means such as “professional judgment” or “observer opinion” as the next best alternatives. Precision is a measure of how similar scores are when independently assessed by multiple users at the same place. Usability refers to how easily the protocol can be applied by field personnel under normal field conditions.

This paper details the methods and results of field trials, discusses the outcomes, and presents performance data. Additionally, as an example of an application of the data, hypotheses are generated from SVAP results to address the question, “How does overall river condition change relative to dominant land-use types along the Monkey River?”

STUDY SITE

The Monkey River is the largest in the MMMAT with an estimated drainage area of 1,292 km^2 (Heyman et al. 1995) and an estimated total annual discharge of 2.0 x 10^9 m^3—a quantity approximately equal to the combined annual discharge of the remaining five MMMAT rivers (Heyman and Kjerve 1999). More than 80% of this discharge occurs in the rainy season from June to September (Heyman and Kjerve 1999). The trunk stream receives water and sediment from two major sub-catchments, the Bladen Branch and the Swasey Branch, before discharging into the Caribbean Sea as a 6th order stream. A third branch, the Trio, enters the Bladen in the lowlands. The Monkey River flows through the four major landforms found in southern Belize: (1) the Maya Mountain highlands; (2) karstic limestone relief; (3) rolling and undulating lowlands; and (4) coastal flatlands (Heyman et al. 1995).

In addition to being the largest drainage in the MMMAT, the Monkey River is also the most heavily influenced by human activities. Usher and Pulver (1994) estimated that 66% of land cultivated for bananas in Belize was located in the Monkey River watershed. Expansion of this industry has taken place since then. Activities associated with banana cultivation include agrochemical and fertilizer use, water pumping for irrigation, historic riparian mismanagement, and altered runoff associated with drainage ditches (Usher and Pulver 1994, Hernandez and Witter 1996). Commercial citrus plantations and a large mango farm (other potential contributors of agrochemicals and sediments via drains), and nine human settlements are also located in the watershed. Impacts from these settlements include intensive fishing and hunting, use of the river for domestic purposes (e.g., laundry, bathing), cattle farming, increased deforestation for slash and burn agriculture, and road building.

Aquatic science in the watershed has been limited to a general biodiversity report (Macrae et al. 1995), localized fish sampling (Greenfield and Thomerson 1997), and four years of hydrologic records (Rudolf Williams, National Hydrologic Service, pers. comm.).

Within the MMMAT, the Monkey River is an ideal setting for watershed assessment protocol development because: (1) the river and its tributaries traverse almost all geologic and physiographic types found in the transect; (2) the broadest range of ecological impacts and land-use types exist in this watershed; and (3) there is an immediate need for assessment and management as a result of the rapid expansion of industry and population.

METHODS

The original NRCS SVAP included 15 readily observable scoring elements that were selected for their ecological importance (Appendix A). After careful examination of these original scoring elements, it was obvious that some needed to be dropped or modified to be appropriate for Belize. Twelve elements were maintained, to which only minor changes were made (Table 4.1). Detailed descriptions of channel characteristics that may not have held for MMMAT streams (e.g., specific depths of visibility of objects under water; percentage of pool bottom obscured from visibility) were deleted. Elements judging human influences that are not present in MMMAT (e.g., dikes and levies) were also omitted, while other human influences (e.g., the presence of agricultural drains) were added. A complete copy of the revised scoring elements can be found in Appendix B. Because the scientific reasoning behind each element has been well described elsewhere (NRCS 1998a; Bjorkland et al. 2001), it is recommended that readers access these documents for a more complete discussion.

A thirteenth element, ‘fishing pressure’, was created and assessed at the end of the field season in response to an obvious pressure on the stream ecosystem. The fishing pressure element incorporates estimates of the frequency an area is fished and also the types of fishing gear used (Table 4.2). This information is collected through interviews with local residents, direct observation, or from recent prior experiences on the river reach being scored. This study relied primarily on direct observation and prior experience, though some informal interviews were conducted. All data shown in this report include scores from this new element.

Three Belizean field technicians were trained to use SVAP. The technicians lived in the Monkey River watershed for most of their lives and were very familiar with significant portions of the river prior to fieldwork. The training session consisted of an interactive discussion between the primary investigator and the technicians where each element score was described in detail and observed under different field scenarios. When all the technicians demonstrated an understanding of each element, practice assessments were performed at four sites, ranging from pristine to moderately altered. Scores were very consistent between observers after four full practice assessments.

From February to April 2000 the SVAP was applied by the same four observers (3 technicians and the primary investigator) at twenty-one sites, from mountains to sea, across a range of land-use types (Figure 4.2; Table 4.3). Lengths of the assessed stream reaches were thirty-nine times the estimated mean stream width. This length was determined by methods for an intensive quantitative channel assessment that was carried out as part of another study prior to scoring SVAP at each site. In future assessments of SVAP only, reach length will be 1 km. In this case, because SVAP was applied after quantitative channel assessment, all technicians were thoroughly familiar with local channel conditions prior to their use of SVAP. Each observer scored all thirteen elements at every site (except when optional elements were omitted) and calculated overall site scores by averaging results from all elements used.

Analysis. In the absence of more rigorous assessments or field data, a subjective approach was used to assess the accuracy of SVAP. Each field observer (n=4) ranked the condition of all sites in order from 1 (best) to 21 (worst) based on impressions gained during the field season about the overall level of impact obvious at sites from historic and recent land uses. Next, overall station scores from SVAP were used to similarly rank all stations for each observer. This process resulted in four rank determinations for each station from both methods (Subjective and SVAP). Mean values were calculated from these resulting in two mean ranks for each station. These rankings were plotted against one another and the Pearson product-moment correlation coefficient (an estimate of the statistical strength of the relationship between ranking methods) was calculated.

To measure precision, coefficients of variation from mean scores of all observations at each station were calculated. The coefficient of variation indicates the percentage that observations deviated from the mean value. Low coefficients of variation indicate good precision, with zero indicating perfect precision. Additionally, the overall station scores of each field technician were plotted against the same scores from the primary investigator, the benchmark observer in this case. For comparative purposes, each plot was fitted with a 1:1 line indicating a hypothetical perfect fit between observers. Correlation coefficients were then calculated.

To evaluate ease-of-use, the following questions (see NRCS 1998a) were answered by each observer:

- Does the SVAP score change in response to the condition gradient represented by the different sites?
- Are the individual element scores responding to key resource problems?
- Were users comfortable with all elements?

Affirmative answers to each of these questions indicate that the SVAP was working well (NRCS 1998a).

RESULTS

To reflect the condition gradient identified by SVAP, sites were arranged from highest to lowest overall score and individual element scores were displayed along this same gradient (Figure 4.3). Overall scores steadily declined across the gradient from 9.96 (BL06) to 4.96 (SW05) (out of 10), with a mean from all stations of 8.34. Nearly half the sites scored between 9-10, with a quarter between 7-9, and the remainder below 7.

Most element scores decreased in conjunction with decreasing overall scores. Mean values for element scores (in parentheses to the right in Figure 4.3) showed that the new element, fishing pressure, scored consistently low across sites, indicating constant, often intense fishing pressures at many sites. The pools scoring element had the next lowest mean value, indicating that pools were uncommon or absent habitat features at multiple stations. Most of the remaining elements had mean values in the 8-9 range with the exception of hydrologic alteration and barriers to fish movement which scored greater than 9. These two elements did the least to lower overall scores at the sample sites.

Accuracy. A very strong linear relationship existed between mean SVAP ranks and mean Subjective ranks (r=0.96; Figure 4.4). This indicates that the ‘best approximation’ of river condition by the field crew was closely matched by the results from the SVAP output. In terms of accuracy, this means that if the field crew perceived ecological condition accurately, then the SVAP was responding very well to the condition gradient present along the Monkey River.

Precision. Tests indicated that the SVAP was extremely precise (Table 4.4). Coefficients of variation ranged from 0-6.39 with an average for all stations of 2.89. At two sites (SW02 and SW03) scores for invertebrate habitat, pool quality, and in-stream fish cover differed between observers causing more variability. In general, coefficients of variation were low indicating very good agreement between the overall scores of observers at each site. There was near unanimous agreement at the highest-scoring sites, with more variation as mean overall scores decreased. By way of comparison, coefficients of variation attained from tests of the original NRCS version of the protocol ranged from 3.6-23.4 with a average of 10.53 (NRCS 1998a).

Breaking overall scores down on an observer-by-observer basis mirrored the conclusion of excellent precision. Correlations of scores from each observer with scores from the primary investigator (Figure 4.5) showed very strong linear relationships with correlation coefficients of 0.99, 0.97, and 0.98. The strength of these relationships indicates that there was very good agreement between the overall scores of trained observers and the primary investigator.

Ease-of-use. The following questions were answered by each observer to draw conclusions about the usability of the SVAP. First, “Does the SVAP score change in response to the condition gradient represented by the different sites?” All observers felt that scores did change in response to a real condition gradient that existed along the course of the river. This is also reflected in the correlation of mean ranks (Figure 4.4). Second, “Are the individual element scores responding to key resource problems?” All observers felt that, for the most part, the SVAP was responding well to key resource problems. However, all observers unanimously agreed that fishing pressure was intense at many of the sites, further justifying its inclusion in the modified SVAP. Another potentially significant resource problem that was not addressed by the SVAP was bank erosion caused by powerboat wakes in the lower reaches of the river. This environmental factor is still under consideration for addition to the protocol in a later version. Lastly, “Were users comfortable with all elements?” Each observer answered a definitive “yes” to this question, commenting that the actual scoring elements and the written text accompanying each element were easy to understand and relatively unambiguous.

DISCUSSION

SVAP Performance

Overall, it was concluded from this field trial that the SVAP can be used in the field with excellent precision at a level of accuracy that approximated the subjective assessments of all observers. Unlike basic subjective assessment, SVAP allows users to identify specific physical aspects of a stream that may be negatively impacting stream condition. Assuming that observers in this study detected a real change in stream conditions, then results were consistent with the stated goals of the SVAP to be a basic first approximation of condition. Researchers should be encouraged by these results to further modify the protocol to reflect unique conditions of the region examined.

Precision values in this study were high relative to those found by the NRCS (1998a). There are several possible explanations for this. First, ‘pristine’ conditions were obvious at many of the sites in the Monkey River, making it easy to assign scores of 10 to many elements. In contrast, it is widely acknowledged in the United States that pristine conditions rarely exist after centuries of human modifications to rivers there (Benke 1990). Second, when conditions merited down-scoring for certain elements, it was usually quite obvious which elements were affected and how severely. Also, because observers had an opportunity to observe true reference conditions, degraded conditions were easier to recognize. Third, observers made their independent assessments after first becoming thoroughly familiar with the stream reach in question. Prior to scoring a site, each observer had a minimum of one day on location (spent measuring physical, chemical, and biological characteristics of the site) to form impressions. These factors clearly resulted in better agreement between scores.

While these results encourage continued use of SVAP in the MMMAT, several weak links in the protocol should be strengthened. First, data suggested that low elevation sites experiencing little to no local pressure (e.g., BL01, MR03, MR02, MR01) consistently scored lower than similar sites in middle to high elevation areas (e.g., BL06, BL05, BL04, TR03, SW09) (Table 4.3). When element scores for each of these sites were scrutinized (Figure 4.3), it was obvious that those relating to habitat complexity (invertebrate habitat and fish cover), and those judged by observing the river water (water appearance and nutrient enrichment) lowered overall scores the most. This begs the questions: (1) Do low elevation reaches naturally have less habitat complexity or is this caused by present or historic human activities?; and (2) Are low elevation reaches naturally more turbid and green with suspended and attached algae, or are these caused by transported upstream inputs? If answers to these questions indicate that low elevation stations *are* naturally less complex and more turbid and green, then scoring criteria should be modified to avoid penalizing a station for occurring in its most-natural or reference state. Because of the intensity of upstream sediment and nutrient loading (see Chapter 3), it seems more likely that water-based scoring criteria should remain the same, but not necessarily those relating to habitat complexity.

Accuracy estimates of the protocol will remain uncertain until scores can be validated with results from more rigorous stream assessment techniques. Rigorous assessment protocols have been developed at other locations in the region (see Michels 1998; Soto-Galera et al. 1999; Lyons et al. 1995). Successful application of similar protocols in the MMMAT will provide the comparative data necessary for full verification of this SVAP version. In the interim, comparisons of SVAP rankings with the subjective ranking suggested that the SVAP responded to some condition gradient perceived by an experienced work crew. The fact that the original protocol was well validated in the U.S. also supports this version's accuracy.

SVAP Application

Results from this study are promising enough to encourage expansion of the protocol both locally and regionally. A natural next step will be to apply SVAP on the remaining five rivers of the MMMAT. This work was already started on the Rio Grande by Andrew Kundtz (an undergraduate at Colorado College) as an independent study project for the School for International Training (Kundtz 2000). Kundtz applied SVAP incrementally to assess Rio Grande conditions along a longitudinal gradient from the uplands to the sea. Based on the work presented here, SVAP also seems well suited for testing beyond Belize in the Latin American and Caribbean region. Regional validation of the tool will allow for conservation assessment and prioritization of stream ecosystems at a very large spatial scale.

Research has shown that training improves the precision and accuracy of visually based stream assessment protocols (Hannaford et al. 1997). For this reason, a training course was developed by the NRCS to accompany the original SVAP in the United States. NRCS's multimedia *Introduction to Stream Assessment Course* (NRCS 1998b) provides an introduction to stream ecology, instruction on how to use the SVAP, field exercises, and technical information (Bjorkland et al. 2001). Adaptation of this training course to Belize could be easily accomplished to promote the tool and ensure consistency between application contexts.

SVAP results can be applied in many different ways depending on the objectives of the investigation. Scores are particularly well suited for comparison between stations or monitoring of specific sites over time. Scores can also be used by scientists to generate reasonable hypotheses about river conditions. These hypotheses can then be used to guide experimental design, research, and management programs.

A crucial research question for conservation of the MMMAT is, “How does river condition change relative to dominant land-use types along the Monkey River?”. Answers to this question can help organizations like TIDE focus planning efforts toward specific land-use types to promote the conservation of aquatic communities. SVAP scores can be used to explore this question.

Sites were divided into three categories based on their dominant surrounding land-use (bananas, milpa, and forested; Table 4.3). Sites grouped in the bananas category (BL02, SW06, SW05, SW04, SW01) were located in a local landscape dominated by banana agriculture. Sites grouped in the milpa category (BL03, SW03, SW02, MR01) were surrounded by slash-and-burn agriculture characteristic of subsistence farming in the area. Sites grouped in the in the forested category (BL06, BL05, BL04, SW09, TR03, BL01, SW08, SW07, TR02, TR01, MR03, MR02) were completely surrounded by forest, although some were subject to fishing pressures. It is important to note that in each dominant land-use category, there were usually other ‘sub-dominant’ land-uses that occurred. For example, at sites surrounded by banana agricultural fields, there were also residential areas, fishing pressure from residents, small patches of milpa, gravel mining, and other activities associated with the banana economy, or with the roads that passed near the plantations.

After verifying that the data met the assumptions of the test, and that there was no observer effect (e.g., when scores from observers differ significantly in a systematic way), site scores within each land-use category were averaged and compared using analysis of variance (ANOVA; Montgomery 1991). ANOVA is a mathematical test that allows for comparison of category means to determine if they are statistically different.

From the results of the ANOVA, it was concluded that at least two categories were significantly different ($F_{2,18}=26.59$; $p<0.0001$). Comparison of all pairs with a Tukey-Kramer test ($\alpha=0.10$) revealed that each category was significantly different from the next (Figure 4.6). The category with the highest mean overall score (best condition measurement) was forested, followed by milpa, then bananas. From these results it is hypothesized that banana agriculture has the greatest negative influence on river condition followed by milpa agriculture then forested lands.

Based on element scores with the greatest range of values (shown in Figure 4.7), it is predicted that:

- In banana agriculture areas, conditions are most affected by heavy fishing pressure from nearby communities, degraded channel conditions, compromised riparian zone, and a lower frequency of pool habitats (in order of influence on SVAP scores).
- In milpa agriculture, conditions are most affected by moderate to heavy fishing pressure from nearby communities, lower frequency of pool habitats, and compromised riparian zone.

- Conditions at some forested stations are negatively affected by moderate to heavy fishing pressure, while others have little to no degradation.

These hypotheses and predictions can now be tested in future studies and accepted or rejected as results dictate. Results can also be used by TIDE to initiate conservation action geared toward specific land uses.

CONCLUSIONS

Results of performance tests indicated that SVAP was well suited for application in the MMMAT. Condition ranks derived from SVAP were strongly correlated with those derived from simple subjective comparison made by users of the protocol, indicating that the tool accurately reflected observers' judgment of conditions. The precision of the tool was shown to be very high, perhaps because of relatively clear-cut decision criteria afforded by characteristics of the study river (e.g., pristine character in some places, clearly identifiable degradation in others). Ease-of-use was reported by all users to be very good.

Further quantitative validation of SVAP accuracy is highly recommended to verify that the protocol is doing a good job predicting the actual condition of river reaches. This will be best accomplished through comparison with rigorous assessment protocols. Based on validation of SVAP in the U.S. and on subjective evidence presented above, SVAP is tentatively considered to be accurate at an introductory screening-level. As recommended by NRCS (1998a), it is expected that SVAP can now be used in MMMAT to screen stream sites to identify problem areas in need of more intensive assessment and conservation focus. The protocol will also be useful as a comparative tool between sites or at the same site over time.

Further development of SVAP is highly recommended in the Maya Mountain Marine Area Transect, Belize, and the greater Latin American and Caribbean (LAC) region. Because the protocol has been designed to utilize factors that are least sensitive to regional differences, it is highly suitable for region-specific modification. A training program will help with the transfer and expansion process.

In summary, SVAP shows great promise as a useful and easy-to-learn assessment technique suited for a variety of interest groups. Once regionally adjusted and validated, it will be especially useful in developing countries lacking the resources, technology, and training necessary to carry out more scientifically rigorous assessments.

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LITERATURE CITED

Benke, A.C. 1990. A perspective on America's vanishing streams. Journal of the North American Benthological Society 9: 77-88.

Bjorkland, R., C.M. Pringle, B. Newton. 2001. A Stream Visual Assessment Protocol (SVAP) for riparian landowners. Environmental Monitoring and Assessment 68: 99-125.

Georgia Department of Natural Resources (GDNR). 1996. Standard operating procedures. Watershed Planning and Monitoring Program, Atlanta, GA, USA.

Greenfield, D.W. and J.E. Thomerson. 1997. Fishes of the Continental Waters of Belize. University Press of Florida, Gainesville, FL, USA.

Hannaford, M.J., M.T. Barbour, and V.H. Resh. 1997. Training reduces observer variability in visual-based assessments of stream habitat. Journal of the North American Benthological Society 14: 853-860.

Hernandez, C.E. and S.G. Witter. 1996. Evaluating and managing the environmental impact of banana production in Costa Rica: a systems approach. Ambio 25: 171-178.

Heyman, W.D. and B. Kjerve. 1999. Hydrological and oceanographic considerations for integrated coastal zone management in southern Belize. Environmental Management 24: 229-245.

Heyman, W., W. Maheia, S. Franklin, and L. Nicolait. 1995. Maya Mountain-Marine Area Transect: A Synthesis to Assist in Integrated Planning and Management (draft). Belize Center for Environmental Studies, Belize City, Belize.

Kundtz, A. 2000. Visual Techniques Used to Assess and Monitor the Health of Tropical Streams in the Toledo District of Belize: A Case Study of the Rio Grande River. Unpublished independent study, School for International Training, Brattleboro, VT, USA.

Lyons, J., S. Navarro-Perez, P.A. Cochran, E. Santana, and M. Guzman-Arroyo. 1995. Index of Biotic Integrity based on fish assemblages for the conservation of streams and rivers in West-Central Mexico. Conservation Biology 9: 569-584.

Macrae, E.M., J.C. Meerman, and T. Boomsma. 1995. Monkey River Special Development Area Biodiversity Study. Belize Tropical Forest Studies, Belmopan, Belize.

Michels, A. 1998. Use of diatoms (Bacillariophyceae) for water quality assessment in two tropical streams in Costa Rica. Revista de Biologia Tropical 46: 143-152.

Montgomery, D.C. 1997. Design and Analysis of Experiments. Wiley, New York, NY, USA.

Natural Resources Conservation Service (NRCS). 1998a. Stream Visual Assessment Protocol. National Water and Climate Center Technical Note 99-1. U.S. Department of Agriculture-Natural Resources Conservation Service, Washington, D.C., USA.

Natural Resources Conservation Service (NRCS). 1998b. Introduction to Stream Ecological Assessment Course. U.S. Department of Agriculture-Natural Resources Conservation Service, Washington, D.C., USA.

Ohio Environmental Protection Agency (OHEPA). 1989. Biological Criteria for the Protection of Aquatic Life: Volume III. Standardized Biological Field Sampling and Laboratory Methods for Assessing Fish and Invertebrate Communities. Columbus, Ohio.

Soto-Galera, E., J. Paulo-Maya, E. Lopez-Lopez, J.A. Serna-Hernandez, and J. Lyons. 1999. Change in fish fauna as indication of aquatic ecosystem condition in Rio Grande de Morelia-Lago de Cuitzeo Basin, Mexico. Environmental Management 24: 133-140.

Toledo Institute for Development and Environment (TIDE). 2000. Site Conservation Plan: Maya Mountain Marine Area Transect (draft). Toledo Institute for Development and Environment, Punta Gorda, Belize.

U.S. Environmental Protection Agency (USEPA). 1997a. Volunteer Stream Monitoring: A Methods Manual. Washington, D.C, USA.

U.S. Environmental Protection Agency (USEPA). 1997b. Field and Laboratory Methods for Macroinvertebrate and Habitat Assessment of Low Gradient, Nontidal Streams. Washington, D.C., USA.

Usher, W. and E. Pulver. 1994. Evaluation of Pesticide and Fertilizer Usage in Bananas and Potential Risks to the Environment. Natural Resource Management and Protection Project (NARMAP), Government of Belize, and United States Agency for International Development, Belmopan, Belize.

Table 4.1. Original SVAP scoring elements and those included in the MMMAT version of the protocol. The few changes that were made to the original protocol are listed in the third column.

Original element	**Included?**	**Changes made**
Channel condition	Yes	• Removed comments about dikes and levies compromising flood plain functions (dikes and levies not present in MMMAT) • Added presence of drainage ditches as potentially compromising flood plain function
Hydrologic alteration	Yes	• None
Riparian zone	Yes	• None
Bank stability	Yes	• Removed comments about elevation of banks relative to active flood plain
Water appearance	Yes	• Removed criteria about specific depths of visibility of objects under water
Nutrient enrichment	Yes	• Removed comment about more algae growth during “warmer months”
Barrier to fish movement	Yes	• None
Instream fish cover	Yes	• None
Pools	Yes	• Removed criteria about percent pool bottom obscured due to depth
Insect/invertebrate habitat	Yes	• None
Canopy cover	No	N/A
Manure presence	Yes	• None
Salinity	No	N/A
Riffle embeddedness	Yes	• None
Macroinvertebrates observed	No	N/A

Table 4.2. Written scoring criteria for the new scoring element, fishing pressure. Fishing pressure is assessed by judging both the frequency of use by fishermen and the types of gears used by those fishermen.

Fishing pressure

No fishing pressure. No fishing taking place.	Low fishing pressure. Fished infrequently with spears and hand lines. No use of nets.	Moderate fishing pressure. Fished frequently with spears, hand lines, and/or cast nets. No use of gill nets.	Heavy fishing pressure. Frequent and intense use by many people. Gill nets used. Preferred game species absent.
10	7	3	1

Table 4.3. The twenty-one sites assessed with SVAP spanned a diversity of physical and human conditions. Stations with names starting with BL, SW, TR, and MR occurred on the Bladen, Swasey, and Trio branches, and Monkey River main-stem respectively. High elevation sites (riffle-pool dominated) were located in the Maya Mountains; middle elevation sites (riffle-run-pool dominated) occurred in the rolling lowlands; and low elevation sites (meandering flatwater) were found on the coastal plain. Stations where fishing was the dominant activity were locally surrounded by broadleaf forest. Intense fishing pressures were also usually present at stations surrounded by milpa and bananas. Measurements of percent buffer vegetated were visually estimated after observing the riparian zone along the entire station length.

Station Name	**Elevational Zone**	**Dominant Human Activities**	**Dominant Vegetation Type**	**% buffer**
BL01	Low	Forest	Broadleaf forest	100
BL02	Middle	Banana agriculture/residential	Early successional forest	60
BL03	Middle	Milpa	Early successional forest	65
BL04	High	Forest	Broadleaf forest	100
BL05	High	Forest	Broadleaf forest	100
BL06	High	Forest	Broadleaf forest	100
SW01	Low	Banana agriculture	Early successional forest/wild cane	75
SW02	Low	Milpa	Early successional forest/wild cane	80
SW03	Low	Milpa	Early successional forest/wild cane	96
SW04	Middle	Banana agriculture/residential	Early successional forest/wild cane	95
SW05	Middle	Banana agriculture	Wild cane	40
SW06	Middle	Banana agriculture/mining	Early successional forest/bananas	55
SW07	High	Fishing	Broadleaf forest	100
SW08	High	Fishing	Broadleaf forest	100
SW09	High	Forest	Broadleaf forest	100
TR01	Middle	Fishing	Broadleaf forest	100
TR02	Middle	Fishing	Broadleaf forest	100
TR03	High	Forest	Broadleaf forest	100
MR01	Low	Milpa	Early successional forest/milpa	100
MR02	Low	Fishing	Early successional forest/wild cane	100
MR03	Low	Fishing	Broadleaf forest	100

Table 4.4. Mean overall SVAP scores, standard deviations, and coefficients of variation for all sampled sites. Sites are arranged from highest mean score (top) to lowest.

Site	**No. Replicates**	**Mean SVAP Score (μ)**	**Standard deviation**	**Coefficient of variation**
BL06	4	9.96	0.08	0.84
SW09	4	9.83	0	0
BL04	4	9.83	0.12	1.20
TR03	4	9.79	0.32	3.22
BL05	4	9.77	0.04	0.43
SW08	4	9.38	0.08	0.89
SW07	4	9.29	0.08	0.90
BL01	4	9.06	0.04	0.46
TR02	4	9.00	0.39	4.34
TR01	4	9.00	0.39	4.34
MR01	4	8.86	0.16	1.78
MR03	4	8.70	0.19	2.15
MR02	4	8.34	0.14	1.63
BL03	4	8.02	0.38	4.75
SW01	4	7.48	0.30	4.02
SW06	4	7.46	0.31	4.13
SW03	4	6.86	0.40	5.87
SW02	4	6.85	0.44	6.39
SW04	4	6.56	0.13	1.90
BL02	4	6.18	0.36	5.88
SW05	4	4.96	0.28	5.57

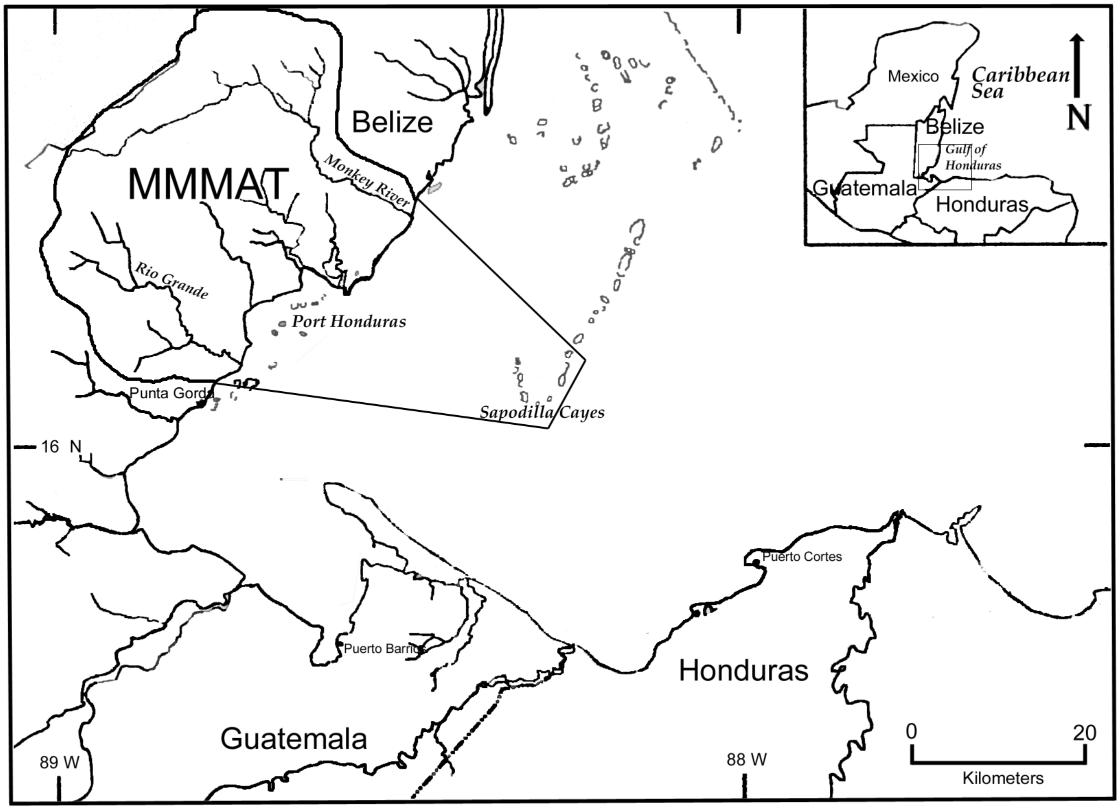

Figure 4.1. The Maya Mountain Marine Area Transect (outlined in figure) consists of six watersheds that feed the mangrove-lined Port Honduras and the southern tip of the barrier reef. The largest of these watersheds, the Monkey River is located at the northern extent of the transect.

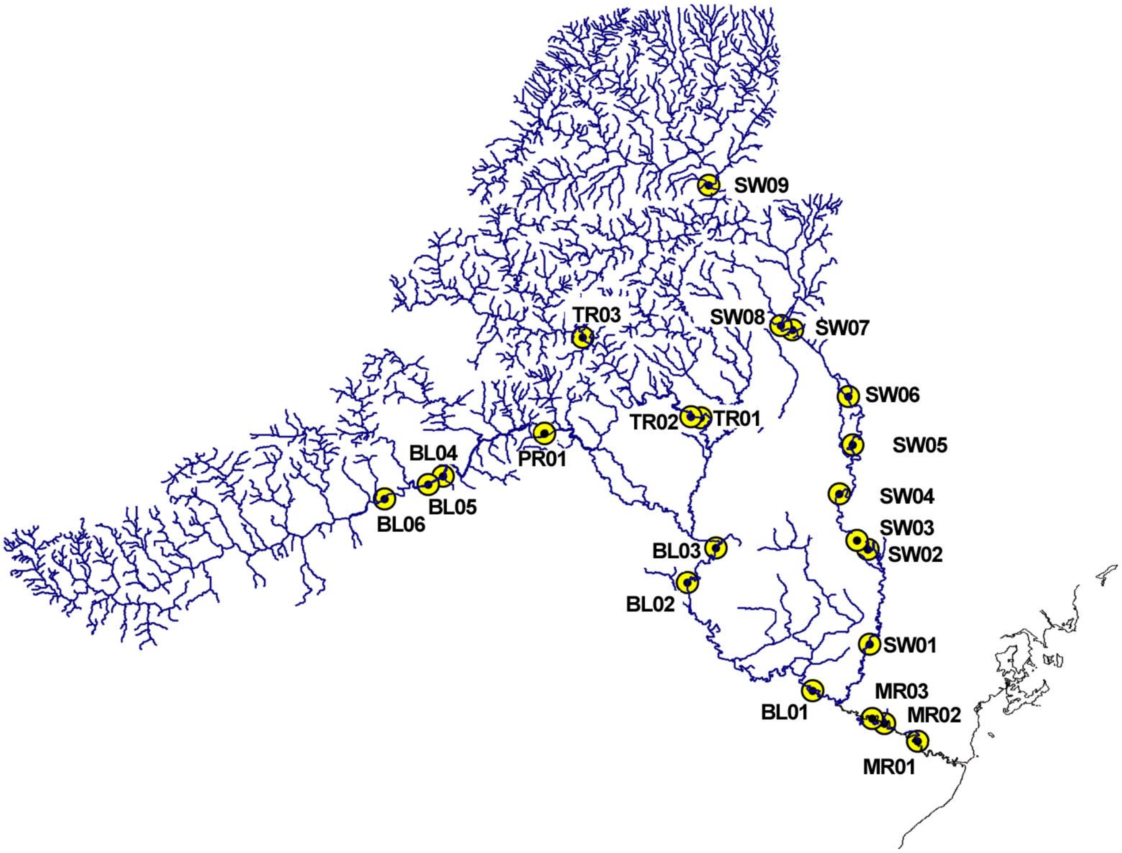

Figure 4.2. Twenty-one sites along the Monkey River were sampled by a team of four observers. Sampling sites were randomly selected from distinct physiographic regions on streams of 4th order or greater, resulting in relatively extensive coverage. The mouth of the river where it meets the Caribbean Sea is located in the bottom right hand corner of the figure. Roads are indicated in red.

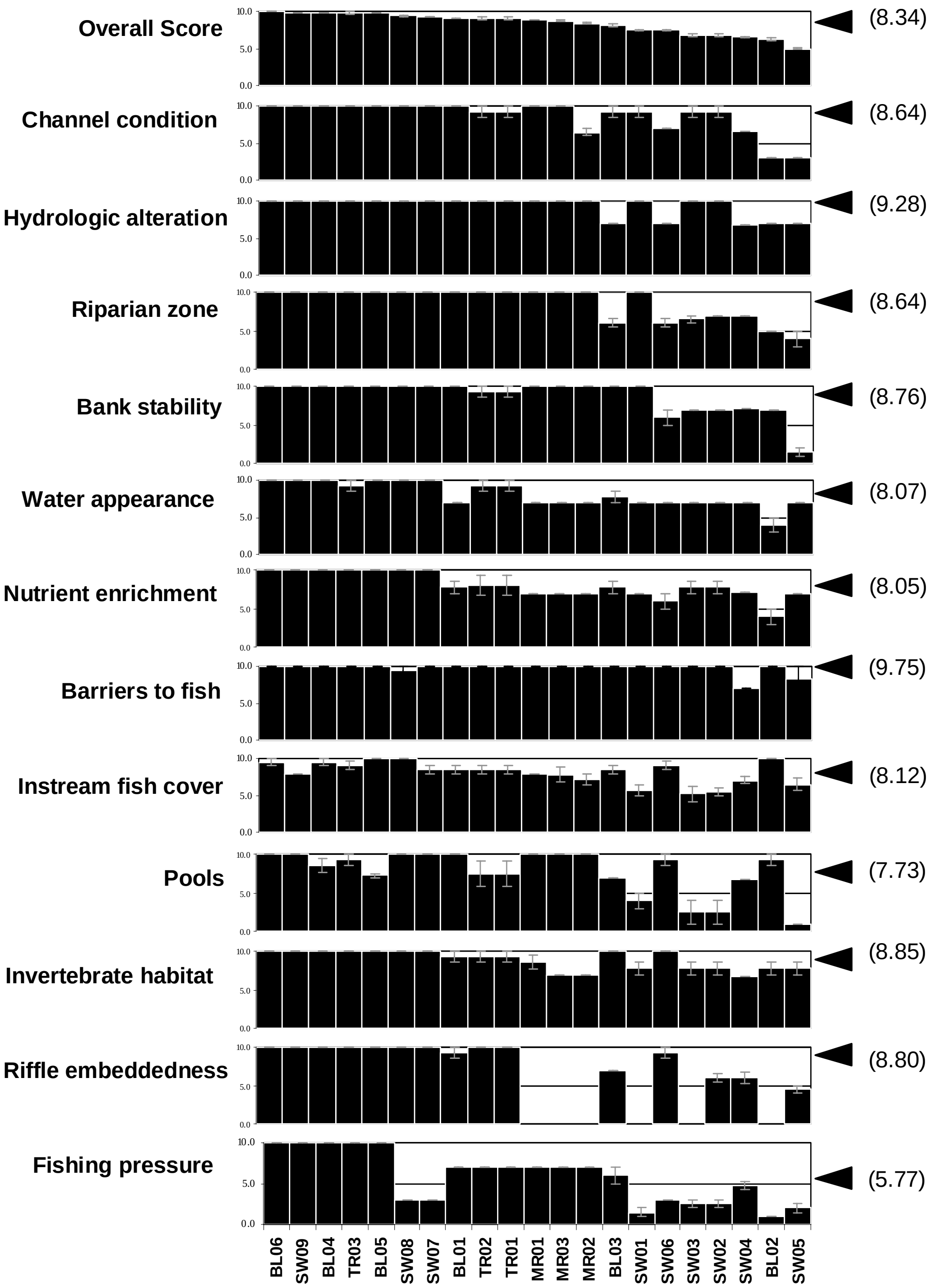

Figure 4.3. A site-by-site breakdown of overall scores (top) and element scores (± SE). Sites are arranged in rank order from highest (left) to lowest (right). Mean values for each element (across all sites) appears in parentheses to the right. Bars with zero values represent missing values (in cases of un-scored optional elements).

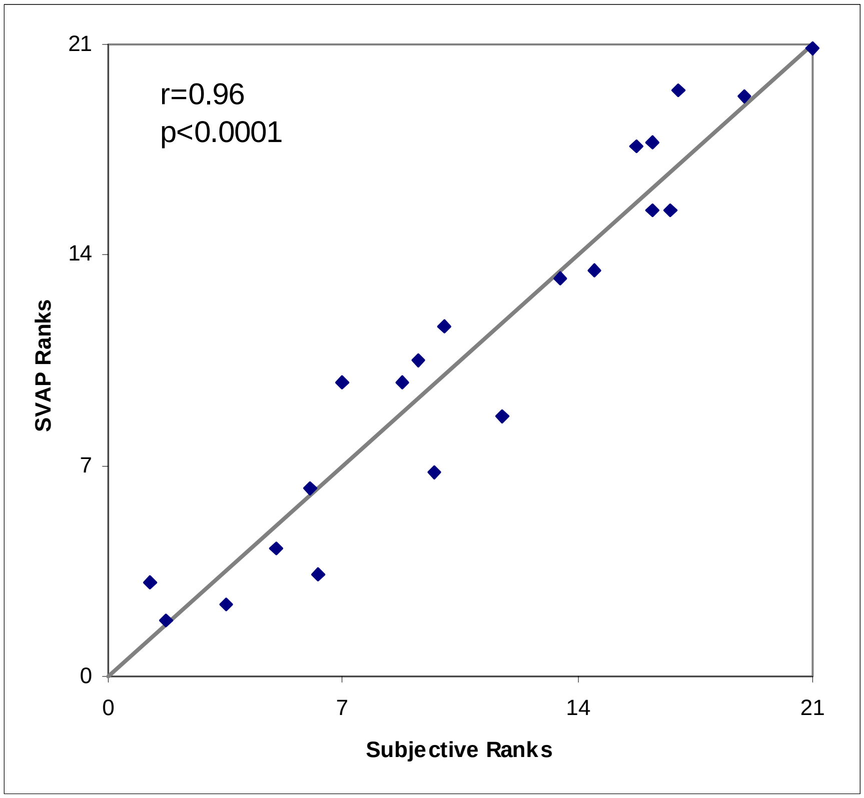

Figure 4.4. Scatter plot of mean ranks from four observers using two different methods (SVAP and Subjective). The diagonal line represents the perfect fit line. A correlation coefficient (r) of 0.96 indicates a very strong linear relationship between the ranks.

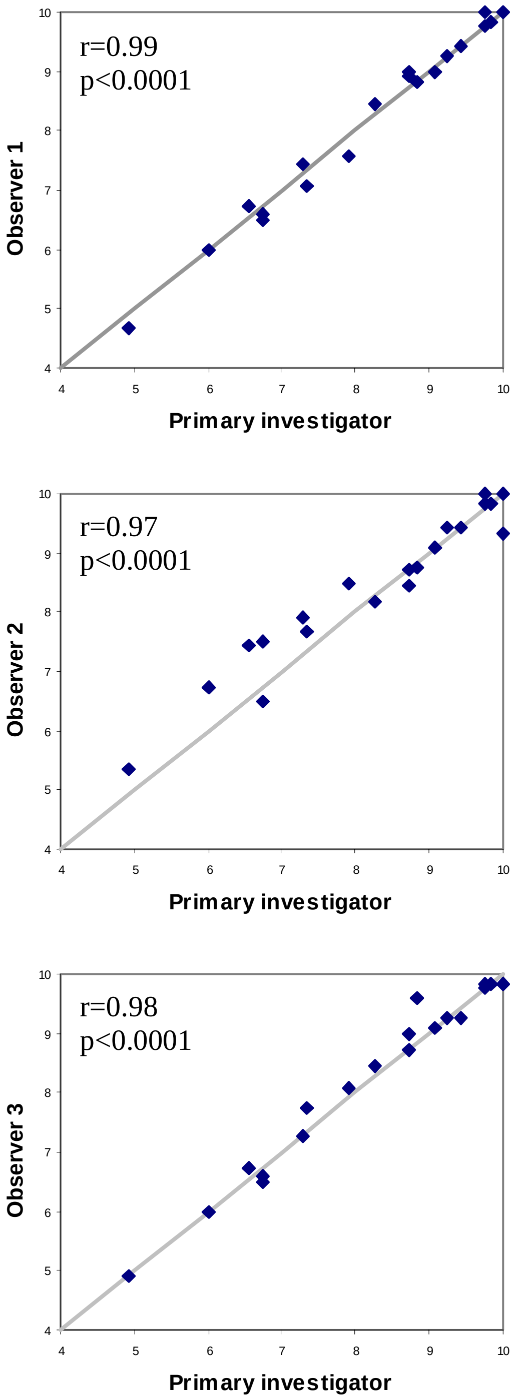

Figure 4.5. Scatter plots of overall scores for each observer versus those for the primary investigator. The diagonal line represents a hypothetical 1:1 perfect fit. In each case, the correlation coefficient (r) and the significance value (p) are given.

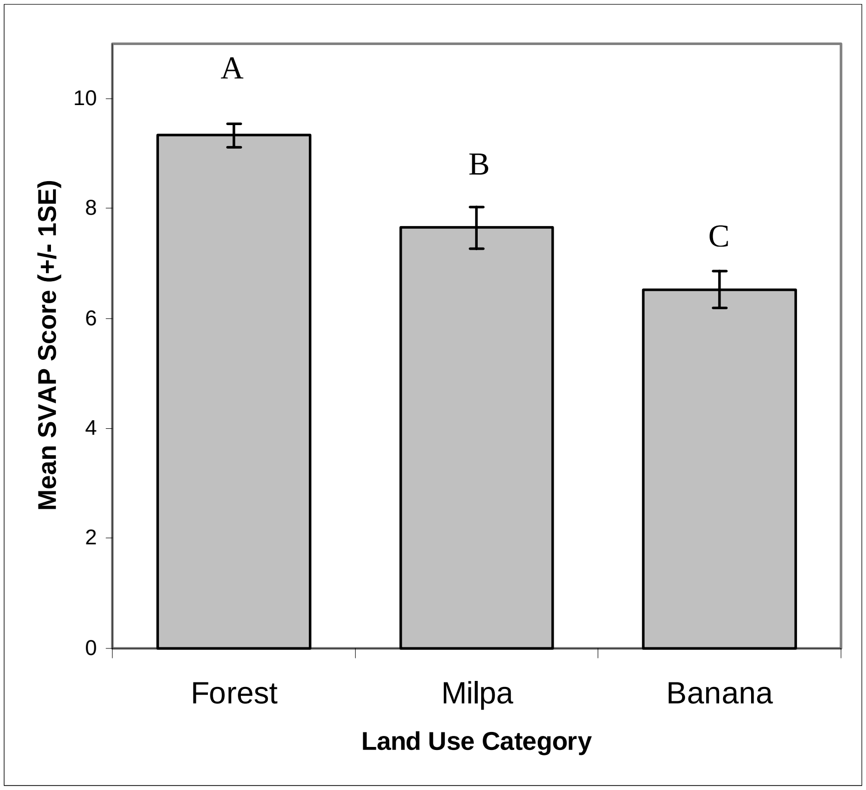

Figure 4.6. SVAP scores for three land-use categories used for hypothesis generation. ANOVA and subsequent Tukey-Kramer test revealed that each category was significantly different from the next at an alpha level of 0.10.

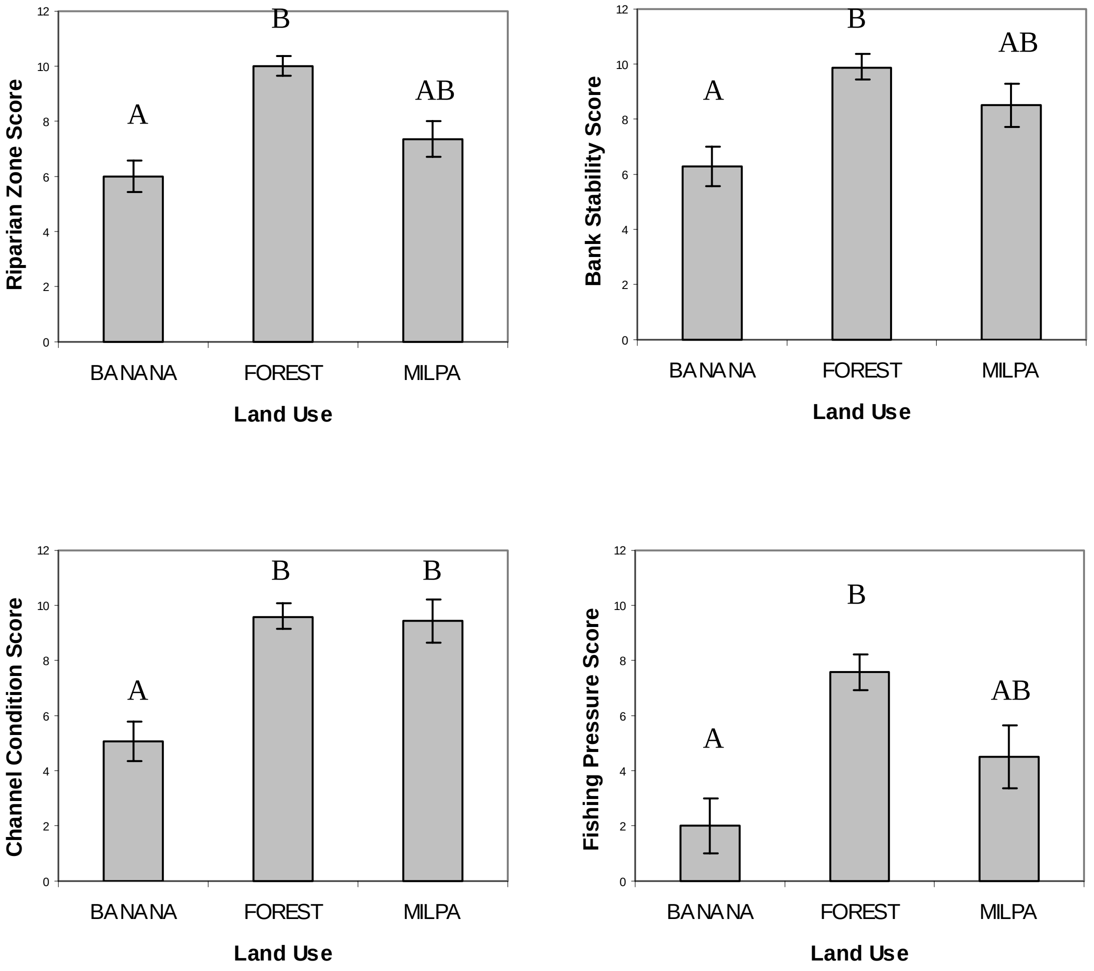

Figure 4.7. Four element scores with the greatest range of values. Landscapes dominated by banana agriculture consistently scored lowest, followed by milpa, then forest.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The Monkey River Baseline Study had three specific objectives: (1) to describe fish assemblages, river habitat, and water chemistry of the Monkey River; (2) to characterize and map impact “hotspots” along the river; and (3) to modify the Natural Resource Conservation Service stream visual assessment protocol (SVAP) to be MMMAT-appropriate.

The descriptive work on fish assemblages and physicochemistry (Chapter 2) was carried out at two scales: watershed and headwaters. At the watershed scale, the Monkey River fish assemblage showed continual addition of species downstream with few deletions. This was reflected in regression analysis, which showed increasing richness and diversity in a downstream direction. Multivariate analysis revealed three faunal groupings: one in the delta near the sea, one in coastal plains, and a third in the headwaters. Investigation of headwaters streams revealed a watershed divided along geologic lines. Evidence from water chemistry data showed that the granite/metasedimentary Swasey Branch waters carry elevated levels of phosphorus that may be driving high primary production of the aquatic angiosperm *Apinagia sp*. Trio Branch, also with granite/metasedimentary geology, had lower phosphorus levels but still supported *Apinagia* growth. In contrast, the extrusive volcanic/limestone Bladen Branch had very low levels of phosphorus and supported no macrophytes. Relationships between these geology-driven factors and headwater fish assemblage structure were sometimes overridden by strong relationships to other landscape and local-level factors. Fish assemblage structure was related to variables at both scales of analysis (landscape and local), but varied according to habitat type (pools, runs, and riffles) suggesting that different structuring forces are acting in each.

The work on impact mapping (Chapter 3) presented a new methodology to estimate the relative expected intensity of stresses to aquatic ecosystems on a reach-by-reach basis. The approach was intended to establish a logical framework for decision-making in the face of limited resources and information scarcity. Spatially-explicit, easily-collected information about stress sources was used to infer expected stress intensities drawing on criteria determined by The Nature Conservancy. End products of the impact mapping process were visually informative impact maps, and a prioritization of stress types at the basin-scale. It was tentatively concluded that sedimentation, trophic alteration, and nutrient loading (in that order) were the critical stresses to aquatic communities of the Monkey River, followed by direct habitat alteration, thermal alteration, toxins/contaminants, altered flow regime and habitat fragmentation (in decreasing order of importance).

Results from stream visual assessment protocol (SVAP) application in the Monkey River (Chapter 4) encourage further use and testing. SVAP is a visually based assessment tool designed by the Natural Resource Conservation Service (NRCS) to provide a qualitative statement about stream health. A slightly modified SVAP version was pilot-tested in the Monkey River to assess its performance in the Maya Mountain

Marine Area Transect. Results of performance tests indicated that SVAP was well suited for application in the MMMAT. Station ranks derived from SVAP were strongly correlated with those derived from simple subjective comparison made by users of the protocol, indicating that the tool accurately reflected observers' judgment of conditions. The precision of the tool was shown to be very high, perhaps because of relatively clear-cut decision criteria afforded by characteristics of the study river (e.g., pristine character in some places, clearly identifiable degradation). Ease-of-use was reported by all users to be very good.

One of the most significant accomplishments of this work is that there now exists a comprehensive "ecological snap shot" of an entire Central American river ecosystem during the early months of the year 2000. The scope of the data collection was left intentionally broad to facilitate future comparative work. The coming decades will steadily and negatively alter the condition of water resources in Belize. To facilitate future comparison, an account of the methods used in the baseline study are presented in Appendix C, GPS coordinates of all sites in Appendix D, and selected fish data from the study presented in Appendix E. The full data set from this work will be housed on compact discs at the Georgia Museum of Natural History (Athens, GA, USA), the library of The Nature Conservancy (Arlington, VA), at the Belize National Archives (Belmopan, Belize), and at the Toledo Institute for Development and Environment (Punta Gorda, Belize).

This study achieved its goal "to provide a foundation for a comprehensive system of river monitoring in the MMMAT". Future research should build on this foundation.

Recommended future research directions for each of the three components of this study are listed below.

Fish assemblages

1. Causal relationships between geology, water chemistry, and *Apinagia* growth should be established. Potential mechanisms for initial investigation include solution of bedrock and geothermally modified waters.
2. A detailed analysis of trophic structure should be performed in headwater streams after gaps in the literature on feeding ecology have been filled by analysis of gut contents of poorly described species (*Poecilia mexicana*, *Cichlasoma spilurum*, *Cichlasoma robertsoni*, *Heterandria bimaculata*, *Rhamdia laticauda*, *Rhamdia guatemalensis*, *Ophisternon aenigmaticum*, *Awaous banana*).
3. Patterns of landscape- and local-level influences on assemblage structure in coastal plain streams should be investigated in a way that incorporates human influences as local level variables.
4. Population status and range of the catadromous mullet *Joturus pichardi* in Belize merits study as this species may serve a potential indicator of future river fragmentation, and is also expected to become increasingly scarce in the region as population pressures increase.

Impact mapping

1. Studies should be developed to measure the real severity and extent of the three predicted critical stresses—sedimentation, trophic alteration, and nutrient loading. Biotic measures should be used when possible.
2. Future applications of the impact mapping technique should attempt to incorporate estimates of up- and downstream effects of various stress sources (e.g., outside of just the river segment where the stress source is located) to more accurately reflect diffuse impacts of certain stresses (e.g., downstream sediment transport from drainage ditches; headcutting from gravel mining).
3. Conservation workers and government environmental officers should begin to focus their attention on areas within the Monkey River where the most intense stresses are predicted to occur (e.g., Swasey middle reaches above Swasey Bridge; Swasey and Bladen bridge crossings, and Trio Farm area).
4. Impact mapping should be carried out on the remaining rivers of the MMMAT.

Stream visual assessment protocol

1. SVAP should be tested further in such a way that reduces potential bias caused by interactions among observers prior to scoring. If possible, future subjective ranking of stations should take place *prior* to SVAP scoring to avoid influences on perception of stream condition that may arise from the SVAP scoring process.
2. Quantitative validation of SVAP accuracy should replace subjective evaluation as more rigorous stream health assessment protocols are developed in the area.

3. The SVAP-generated hypothesis that banana agriculture has the greatest negative influence on river condition followed by milpa agriculture then forest should be tested biologically (using diatoms, macroinvertebrates, and/or fishes).
4. A training and testing program to facilitate protocol transfer should be developed to (a) train observers in use of the protocol, and (b) test that new observers are scoring elements consistent with more experienced observers or some predetermined benchmark.

As a final note, it is recommended that *basic* freshwater research continue in the MMMAT in conjunction with more applied techniques like SVAP and impact mapping. Basic research provides conservation workers with a firm understanding of the ecosystem components and processes that must be conserved to maintain ecological integrity or encourage sustainable development. Applied research can help predict and elucidate the complex relationships between human activities and the ecosystems in which they live. For conservation of ecosystem integrity to occur, both basic and applied information must be effectively distributed to a broad stakeholder base that ultimately will influence the fate of MMMAT ecosystems either through direct actions such as land-use practices, or through indirect actions such as creation and enforcement of environmental policy.

Conservation NGOs like the Toledo Institute for Development and Environment have a large role to play in disseminating information, educating the public, and building bridges between diverse and often conflicting stakeholder groups. Their efforts are only benefited by the understanding of local ecological systems provided by scientific inquiry.

APPENDIX A:

NATURAL RESOURCE CONSERVATION SERVICE (NRCS)

SVAP SCORING CRITERIA

Channel condition

Natural channel; no structures, dikes. No evidence of down-cutting or excessive lateral cutting.	Evidence of past channel alteration, but with significant recovery of channel and banks. Any dikes or levies are set back to provide access to an adequate flood plain.	Altered channel; <50% of the reach with riprap and/or channelization. Excess aggradation; braided channel. Dikes or levees restrict flood plain width.	Channel is actively down-cutting or widening. >50% of the reach with riprap or channelization. Dikes or levees prevent access to the flood plain.
10	7	3	1

Hydrologic alteration

Flooding every 1.5 to 2 years. No dams, no water withdrawals, no dikes or other structures limiting the stream's access to the flood plain. Channel is not incised.	Flooding occurs only once every 3 to 5 years; limited channel incision. Or Withdrawals, although present, do not affect available habitat for biota.	Flooding occurs only once every 6 to 10 years; channel deeply incised. Or Withdrawals significantly affect available low flow habitat for biota.	No flooding; channel deeply incised or structures prevent access to flood plain or dam operations prevent flood flows. Or Withdrawals have caused severe loss of low flow habitat. Or Flooding occurs on a 1-year rain event or less.
10	7	3	1

Riparian zone

Natural vegetation extends at least two active channel widths on each side.	Natural vegetation extends one active channel width on each side. Or If less than one width, covers entire flood plain.	Natural vegetation extends half of the active channel width on each side.	Natural vegetation extends a third of the active channel width on each side. Or Filtering function moderately compromised.	Natural vegetation less than a third of the active channel width on each side. Or Lack of regeneration. Or Filtering function severely compromised.
10	8	5	3	1

Bank stability

Banks are stable; banks are low (at elevation of active flood plain); 33% or more of eroding surface area of banks in outside bends is protected by roots that extend to the base-flow elevation.	Moderately stable; banks are low (at elevation of active flood plain); less than 33% of eroding surface area of banks in outside bends is protected by roots that extend to the base-flow elevation.	Moderately unstable; banks may be low, but typically are high (flooding occurs 1 year out of 5 or less frequently); outside bends are actively eroding (overhanging vegetation at top of bank, some mature trees falling into stream annually, some slope failures apparent).	Unstable; banks may be low, but typically are high; some straight reaches and inside edges of bends are actively eroding as well as outside bends (overhanging vegetation at top or bare bank, numerous mature trees falling into stream annually, numerous slope failures apparent).
10	7	3	1

Water appearance

Very clear, or clear but tea-colored; objects visible at depth 3 to 6 ft (less if slightly colored); no oil sheen on surface; no noticeable film on submerged objects or rocks.	Occasionally cloudy, especially after storm event, but clears rapidly; objects visible at depth 1.5 to 3 ft; may have slightly green color; no oil sheen on water surface.	Considerable cloudiness most of the time; objects visible to depth .5 to 1.5 ft; slow sections may appear pea-green; bottom rocks or submerged objects covered with heavy green or olive-green film. Or Moderate odor of ammonia or rotten eggs.	Very turbid or muddy appearance most of the time; objects visible to depth <0.5 ft; slow moving water may be bright-green; other obvious water pollutants; floating algal mats, surface scum, sheen or heavy coat of foam on surface. Or Strong odor of chemicals, oil sewage, other pollutants.
10	7	3	1

Nutrient enrichment

Clear water along entire reach; diverse aquatic plant community includes low quantities of many species of macrophytes; little algal growth present.	Fairly clear or slightly greenish water along entire reach; moderate algal growth on stream substrates.	Greenish water along entire reach; overabundance of lush green macrophytes; abundant algal growth, especially during warmer months.	Pea green, gray, or brown water along entire reach; dense stands of macrophytes clog stream; severe algal blooms create thick algal mats in stream.
10	7	3	1

Barriers to fish movement

No barriers	Seasonal water withdrawals inhibit movement within the reach	Drop structures, culverts, dams, or diversions (<1foot drop) within the reach	Drop structures, culverts, dams or diversions (>1 foot drop) within 3 miles of the reach	Drop structures, culverts, dams, or diversions (>1 foot drop) within the reach
10	8	5	3	1

Instream fish cover

>7 cover types available	6 to 7 cover types available	4 to 5 cover types available	2 to 3 cover types available	None to 1 cover type available
10	8	5	3	1

Cover types: Logs/large woody debris, deep pools, overhanging vegetation, boulders/cobble, riffles, undercut banks, thick root mats, dense macrophytes beds, isolated/backwater pools, other: ________________________.

Pools

Deep and shallow pools abundant; greater than 30% of the pool bottom is obscure due to depth, or the pools are at least 5 feet deep.	Pools present, but not abundant; from 10 to 30% of the pool bottom is obscure due to depth, or the pools are at least 3 feet deep.	Pools present, but shallow; from 5 to 10% of the pool bottom is obscure due to depth, or the pools are less than 3 feet deep.	Pools absent, or the entire bottom is discernable.
10	7	3	1

Insect/invertebrate habitat

At least 5 types of habitat available. Habitat is at a stage to allow full insect colonization (woody debris and logs not freshly fallen).	3 to 4 types of habitat. Some potential habitat exists, such as overhanging trees, which will provide habitat, but have not yet entered the stream.	1 to 2 types of habitat. The substrate is often disturbed, covered, or removed by high stream velocities and scour or by sediment deposition.	None to 1 type of habitat.
10	7	3	1

Canopy cover (if applicable)

Coldwater fishery

>75% of water surface shaded and upstream 2 to 3 miles generally well shaded.	>50% shaded in reach. Or >75% in reach but upstream 2 to 3 miles poorly shaded.	20 to 50% shaded.	<20% of water surface in reach shaded.
10	7	3	1

Warmwater fishery

25 to 90% of water surface shaded; mixture of conditions.	>90% shaded; full canopy; same shading condition throughout reach.	(intentionally blank)	<25% of water surface shaded in reach.
10	7	3	1

Manure presence (if applicable)

(Intentionally blank)	Evidence of livestock access to riparian zone.	Occasional manure in stream or waste storage structure located on the flood plain.	Extensive amount of manure on banks or in stream. Or Untreated human waste discharge pipes present.
	5	3	1

Salinity (if applicable)

(Intentionally blank)	Minimal wilting, bleaching, leaf burn, or stunting or aquatic vegetation; some salt-tolerant streamside vegetation.	Aquatic vegetation may show significant wilting, bleaching, leaf burn, or stunting; dominance of salt-tolerant streamside vegetation.	Severe wilting, bleaching, leaf burn, or stunting; presence of only slat-tolerant aquatic vegetation; most streamside vegetation salt tolerant.
	5	3	1

Riffle embeddedness (if applicable)

Gravel or cobble particles are <20% embedded.	Gravel or cobble particles are 20 to 30% embedded.	Gravel or cobble particles are 30 to 40 % embedded.	Gravel or cobble particles are >40% embedded.	Riffle is completely embedded.
10	8	5	3	1

Macroinvertebrates observed

Community dominated by Group I or intolerant species with good species diversity. Examples include caddisflies, mayflies, stoneflies, helgramites.	Community dominated by Group II or facultative species, such as damselflies, dragonflies, aquatic sowbugs, blackflies, crayfish.	Community dominated by Group III or tolerant species, such as midges, craneflies, horseflies, leeches, aquatic earthworms, tubificid worms.	Very reduced number or species or near absence of all macroinvertebrates.
15	6	2	-3

APPENDIX B

MODIFIED SVAP SCORING CRITERIA APPLIED IN BELIZE

Channel Condition

Natural channel; no structures, drainage ditches. No evidence of down-cutting or excessive lateral cutting.	Evidence of past channel alteration, but with significant recovery of channel and banks. Any drainage ditches are filling in and well vegetated.	Altered channel; <50% of the reach with riprap and/or channelization. Excess aggradation; braided channel. Drainage ditches inhibit floodplain functions.	Channel is actively down-cutting or widening. >50% of the reach with riprap or channelization. Multiple drainage ditches inhibit floodplain functions.
10	7	3	1

Hydrologic alteration

Flooding every 1.5 to 2 years. No dams, no water withdrawals, no dikes or other structures limiting the stream's access to the flood plain. Channel is not incised.	Flooding occurs only once every 3 to 5 years; limited channel incision. Or Withdrawals, although present, do not affect available habitat for biota.	Flooding occurs only once every 6 to 10 years; channel deeply incised. Or Withdrawals significantly affect available low flow habitat for biota.	No flooding; channel deeply incised or structures prevent access to flood plain, or dam operations prevent flood flows. Or Withdrawals have caused severe loss of low-flow habitat Or Flooding occurs on a 1-year rain event or less.
10	7	3	1

Riparian zone

Natural vegetation extends at least two active channel widths on each side.	Natural vegetation extends one active channel width on each side. Or If less than one width, covers entire floodplain.	Natural vegetation extends half of the active channel width on each side.	Natural vegetation extends a third of the active channel width on each side. Or Filtering function moderately compromised.	Natural vegetation less than a third of the active channel width on each side. Or Lack of regeneration. Or Filtering function severely compromised.
10	7	5	3	1

Bank stability

Banks are stable; banks are low; >33% of eroding surface in outside bends protected by roots that extend to base flow elevation.	Moderately stable; banks are low; <33% of eroding surface in outside bends is protected by roots that extend to base flow elevation.	Moderately unstable; banks may be low, but typically are high; outside bends are actively eroding (some mature trees falling into stream annually, some slope failures apparent).	Unstable; banks may be low, but typically are high; some straight reaches and inside edges of bends are actively eroding as well as outside bends (numerous mature trees falling into stream annually, numerous slope failures apparent).
10	7	3	1

Water appearance

Very clear, or clear but tea-colored; no oil sheen on surface; no noticeable film on submerged objects or rocks.	Occasionally cloudy, especially after storm event, but clears rapidly; may have slightly green color; no oil sheen on water surface.	Considerable cloudiness most of the time; slow sections may appear pea-green; bottom rocks or submerged objects covered with heavy green or olive-green film. Or Moderate odor of ammonia or rotten eggs.	Very turbid or muddy appearance most of the time; slow moving water may be bright green; floating algal mats, surface scum, sheen or heavy coat of foam on surface. Or Strong odor of chemicals, oil, sewage, other pollutants.
10	7	3	1

Nutrient enrichment

Clear water along entire reach; diverse aquatic plant community includes low quantities of many species of macrophytes; little algal growth present.	Fairly clear or slightly greenish water along entire reach; moderate algal growth on stream substrates.	Greenish water along entire reach; overabundance of lush green macrophytes; abundant algal growth, especially during warmer months.	Pea green, gray, or brown water along entire reach; dense stands of macrophytes clog stream; severe algal blooms create thick algal mats in stream.
10	7	3	1

Barriers to fish movement

No barriers.	Seasonal water withdrawals inhibit movement within the reach.	Drop structures, culverts, dams, or diversions (<1 foot drop) within the reach.	Drop structures, culverts, dams, or diversions (>1 foot drop) within 3 miles of reach.	Drop structures, culverts, dams, or diversions (>1 foot drop) within the reach.
10	7	5	3	1

In-stream fish cover

>7 cover types available.	6 to 7 types available.	4 to 5 types available.	2 to 3 cover types available.	None to 1 cover type available.
10	7	5	3	1

Cover types: logs/large woody debris, deep pools, overhanging vegetation, boulders/ cobble, riffles, undercut banks, thick root mats, dense macrophytes beds, isolated/backwater pools, other _______________

Pools

Deep and shallow pools abundant; the pools are at least 5 feet deep.	Pools present, but not abundant; the pools are at least 3 feet deep.	Pools present, but shallow; the pools are less than 3 feet deep.	Pools absent.
10	7	3	1

Insect/invertebrate habitat

At least 5 types of habitat available. Habitat is at a stage to allow full insect colonization (woody debris and logs not freshly fallen).	3 to 4 types of habitat. Some potential habitats exists, such as overhanging trees, which will provide habitat, but have not yet entered the stream.	1 to 2 types of habitat. The substrate is often disturbed, covered or removed by high stream velocities and scour or by sediment deposition.	None to 1 type of habitat.
10	7	3	1

Cover types: fine woody debris, submerged macrophytes, submerged logs, leaf packs, undercut banks, cobble, boulders, coarse gravel, other ______________

Fishing pressure

No fishing pressure. No fishing taking place.	Low fishing pressure. Fished infrequently with spears and hand lines. No use of nets.	Moderate fishing pressure. Fished frequently with spears, hand lines, and/or cast nets. No use of gill nets.	Heavy fishing pressure. Frequent and intense use by many people. Gill nets used. Preferred game species absent.
10	7	3	1

Riffle embeddedness (if applicable)

Gravel or cobble particles are <20% embedded.	Gravel or cobble particles are 20 to 30% embedded.	Gravel or cobble particles are 30 to 40% embedded.	Gravel or cobble particles are >40% embedded.	Riffle is completely embedded.
10	7	5	3	1

Manure presence

(Intentionally blank)	Evidence of livestock access to riparian zone.	Occasional manure in stream or waste storage structure located on the flood plain.	Extensive amount of manure on banks or in stream OR Untreated human water discharge pipes present.
10	7	3	1

APPENDIX C

FIELD METHODS FOR THE MONKEY RIVER BASELINE STUDY

Background

One of the great challenges of fieldwork in the Monkey River is the remoteness of much of the drainage. Headwater areas are accessible only by foot after 1-3 days hiking. All equipment employed in a monitoring program must be lightweight and portable enough to be carried, along with staples, by a four-person field team. The middle and lower reaches are accessible by canoe and kayak and thus offer slightly less of a problem to gear transportation. These constraints were considered in the study design and are reflected in the methods described below.

Site Selection

The Monkey River watershed was stratified into 6 physiographic regions based on geology, topography, and gradient (Table 1). Within each physiographic region, three stations were sampled with the exception of the Swasey mid-elevation region (R5) where six were sampled. More intensive sampling of Region 5 occurred in response to elevated impacts from development. Stations lengths were defined as 39 mean stream widths, within which 13 transects were evenly spaced (Simonson et al. 1993). Mean (wetted) stream width was visually estimated in the 2000 field study. It is recommended that future determination of MSW proceed by measuring the wetted width of five random transects along the sample reach and averaging them.

Study reaches were randomly selected by the following method:

1. River kilometers were measured and consecutively labeled (1, 2, 3, …etc.) using GIS.
2. Those river miles "eligible" for sampling were determined for each physiographic region and put in a hat for random selection. In order to be eligible for selection, a stream mile must have been of 4th order or higher (based on the Strahler ordering system), and be reasonably accessible ($\leq$3 days hiking). Streams of lower than 4th order were be targeted because they are not immediately threatened by development activities and adequate reference streams exist at the 4th order and higher.
3. After selecting 3 river kilometers for each physiographic region (except R5 where n=6) the latitude and longitude of the top of each was identified with GIS and recorded. These lat./long. designations were then located in the field using GPS.
4. From the designated top of a selected river kilometer, the field team moved downstream to the nearest riffle/pool junction and started sampling 10 m upstream from the bottom of that riffle. In low gradient areas, sampling started directly at the top of the river kilometer.

Table C.1. Proposed physiographic regions of the Monkey River watershed based on sub-basin, geology, topography, and stream gradient.

Region	Sub-basin	Geology	Topography	Gradient
R1	Bladen (headwaters)	Extrusive volcanic and limestone	Incised trellis drainage pattern	High-medium
R2	Trio (headwaters)	Metasediments, granite, volcanics	Incised dendritic drainage pattern	High-medium
R3	Swasey (headwaters)	Granite, metaseds., shales	Incised radial drainage pattern	High-medium
R4	Bladen (mid-elevation)	Recent sediments	Coastal plain	Medium-low
R5	Swasey (mid-elevation)	Recent sediments	Coastal plain	Medium-low
R6	Monkey R.	Recent sediments	Coastal plain	Low

Habitat Assessment and Water Chemistry

Each of 21 stations was sampled one time during dry season 2000. Stations were systematically assessed along a series of transects for physical habitat. At each station 13 transects were established, three mean stream widths apart. Five evenly spaced habitat points were sampled across each transect starting and ending at 10 cm from the water edge (Angermeier and Karr 1983). At each point, multiple habitat variables were evaluated (Table 2), and the type of habitat recorded (riffle, run, pool, backpool). Variables were averaged across each transect and then across the entire station for use in analysis.

At three transects intersecting representative mesohabitats (riffle, run, pool), Wolman Pebble Counts were performed (Wolman 1954). At each representative transect a field technician started at a randomly determined point on the bank (point was determined by throwing a pebble over the shoulder within the bankfull height and starting there). At that point, while averting their gaze, the technician will pick up the first particle touched by the tip of their index finger. The intermediate axis of this particle was measured using a metric ruler and its size recorded in mm. The field technician then took one step toward the opposite bank perpendicular to the direction of flow and repeat this procedure. When the bankfull stage on the opposite bank was reached, the investigator moved 5 meters downstream and sampled back toward the original bank until 100 particles were measured.

At one transect in each station, multiple physiochemical variables were measured. A Grant/YSI portable water quality lab was used to measure pH, dissolved oxygen, water and air temperature, conductivity, and turbidity. Water samples were also collected in the field to be analyzed for Total Nitrogen and Total Phosphorus using the persulfate digestion technique, and nitrates (NO_3^-) and soluble reactive phosphorus (SRP) using automated colorimetry (APHA 1993). To collect fresh samples, the sampling bottle (a 250 mL drinking water container) was prewashed in the lab, then rinsed 3 times in the field with river water prior to collecting the sample. The bottle was filled to the top at the top of the sample reach (to avoid contamination from crew activities) and capped underwater to eliminate all air. The sample was then placed in a dark cooler on ice for no more than 36 hours before it was frozen. Total suspended solids (TSS) were measured by filtering 1 L of water through a pre-weighed coffee filter, drying it, re-weighing it, and then calculating TSS (mg/L) from the difference between the two measures.

At one representative transect at each station, discharge was recorded using a Marsh-McBirney flow meter. Representative transects were chosen as evenly shaped, straight run habitats with no obstructions or fallen trees immediately upstream of the sample point. Twenty panels of a known width were were established across the wetted width of the stream channel. At the middle of each panel the depth was recorded and water velocity measured at 0.6 depth. The surface area and water velocity were multiplied to get the discharge at that panel, then all panels added together.

Table C.2. Physical habitat variables sampled at each station.

Measurement	Comments
Channel depth*	To nearest (x cm)
Substrate classification*	Using ½ phi values
Substrate embeddedness*	% embedded with sediment; visual or tactile estimate
Channel width	Wetted width (x.xx m) and bar width (if applicable)
Bank angle	Visual estimate of degree slope
Bank erosion	Percent of bank within a 10 m zone centered on the transect line that was bare soil
Bank full height	Measured to nearest (x.xx m)
Undercut distance	Distance of bank undercut (x.xx m)
Gradient	Degrees inclination easured between each transect using a clinometer
Fish cover features	% cover by overhanging vegetation, undercut banks, woody debris, and boulders assessed 5 m to either side of transect; each cover type placed into one of four cover classes (0=absent; 1=0-10%; 2=10-40%; 3=40-75%; 4=>75%)
Woody debris	Counts of large (>10 m), medium (5m<x<10m), and small (<5 m) wood debris greater that 0.30 m in diameter
Percent canopy cover	Canopy densiometer; 6 readings across channel at left bank, center-upstream, center-downstream, center-left, center-right, and right bank
Riparian forest condition	Bank stability, riparian land-use, vegetation type, percent of mandated 66’ buffer forested
Aquatic vegetation	Subjective estimate of % of station covered with aquatic vegetation, and the vegetation type
Stream discharge†	Measured by floating object *or* Marsh McBirney flow meter at 0.6 depth with at least 20 panels across the channel
Stream chemistry†	pH, temperature, conductivity, turbidity, TSS, water color, DO, nitrates, ammonium, phosphorus

*Measurements taken at every habitat point.
†Measurements taken at one transect per reach.

“Human influences” were estimated on both banks in a 10 m zone to either side of the transect line extending away from the stream. The presence or absence of 12 influence types was recorded, and if present, the proximity to the stream bank estimated (0=not present; 1=>10m from bank; 2=within 10 m; 3=on bank). Influence types included walls, buildings pavement, roads, pipes or ditches, landfills/trash, laundry/washing sites, commercial agriculture, milpa agriculture (slash and burn), pasture, logging operations, and mining activity.

Each station was photographically documented at four points: upstream and downstream from the downstream end of the reach, and upstream and downstream from the upstream end of the reach (Simonson et al. 1993). A detailed map was also drawn of each station showing the shape and aspect of the stream, major habitat features, and the location of transects.

Methods for Fish Sampling

Each station was stratified into major habitat types (riffle, run, pool, backpool) for assessment of fish assemblages. For each major habitat type, specific methods were used to collect fishes (Table 3). Fishes were identified to species using keys developed by Greenfield and Thomerson (1997). Uncertain identification and voucher specimens were preserved in 10% formalin. The main methods employed were visual assessment and electrofishing.

Table C.3. Habitat specific fish sampling methods for baseline assessment of the Monkey River.

Habitat Type	Method
Riffle	Daytime electrofishing to a 2 x 5 m seine (5 mm mesh)
Run	Headwaters: daytime electrofishing with handnets Coastal plain: nocturnal electrofishing with handnets and light
Pool	Visual assessment, hook and line, cast nets; some electrofishing in shallow pool habitats
Lentic back pools	Headwaters: daytime electrofishing with handnets; seines Coastal plain: nocturnal electrofishing with handnets and light, seines
Benthic pool habitat	Nocturnal trot line with chicken skin; shrimp; or dead fish bait

Visual assessment. All visual assessment of fishes in the Monkey River was done at headwaters stations only using mask, snorkel, fins, writing cuff, and a wetsuit. At each station, all available pool habitat was sampled by establishing transects across the channel (perpendicular to flow) at 15 m intervals. This transect spacing was determined so that the viewing lane of adjacent observers would not overlap. Before sampling began, maximum underwater visibility (x.xx m) was measured by observing the point where a #10 tin can painted with a black and white pattern disappeared underwater. Width of each transect was also estimated (x m). Underwater visibility and width were multiplied for a measure of the area surveyed.

All transects in an individual pool were surveyed simultaneously if possible (e.g., <5 transects) to minimize recount, and sampling proceeded from downstream to upstream to avoid clouding water at later survey points. Divers approached transects from the banks if possible so as not to chase fishes ahead. Every transect was surveyed for 10 minutes during which time the observer counted and recorded all species with pencil on an underwater writing cuff made of 6 inch PVC pipe. Common species were counted first followed by cryptic/nocturnal species that are harder to locate. Recount was avoided at all costs.

Electrofishing. Riffles, runs, littoral habitats inaccessible to divers were sampled using a Smith-Root battery-powered backpack electroshocker (on loan from UGA). Appropriate voltage and pulse settings were established prior to sampling (generally set within the ranges of 300-400V K-M 3-5). Sampling proceeded from downstream to upstream and was stratified by habitat type (riffle, run, pool, backpool). Once stunned, fishes were collected either with dip nets or a seine depending on current. Captured fishes were transferred to buckets until sampling was complete at which point they were counted, measured (mm standard length), examined for abnormalities (disease, deformities, fin erosion, lesions, tumors), and released. The area shocked was visually estimated within each habitat to allow for calculation of fish density.

Nocturnal Sampling. Nocturnal samples were taken in coastal plain run, backpool, and pool habitats at night because fishes take cover in deep waters during the day and more diverse samples could be gained at night. All sampling occurred during the moonless period of the night. The crew proceeded in an upstream direction holding an 8-D battery underwater light to help target habitats and fishes in the water column.

Team Organization

The majority of the sampling was conducted between February and April 2000. A two-week intensive training session was held during early February, during which all methods were trained, and technicians were tested for their fish identifications. Field work required the following excursion:

1. <u>Bladen Branch Headwaters</u> (R1) – 8 day foot excursion through Bladen Nature Reserve with four person field crew.
2. <u>Trio Branch Headwaters</u> (R2) – 6 day foot excursion from BFREE to Trio and back with four person field crew.
3. <u>Swasey Branch Headwaters</u> (R3) – 4 day trip from Red Bank Village to SW09 and 2 days at SW07 and SW08 with four person field crew and guide.

4. Bladen Branch Mid-Reaches (R4) and Monkey River Mainstem (R6) – 9 day canoe excursion from Trio Farm downstream to mouth with five person field crew.
5. Swasey Branch Mid-Reaches (R5) – 8 days of sampling in canoes from Red Bank to Monkey River Village.

No more than two days were required at each station. Several “sting missions” were made to collect freshwater samples in April so that the fresh samples could be collected and frozen within 36 hours of collection.

Literature Cited

Angermeier, P.L. and J.R. Karr. 1983. Fish communities along environmental gradients in a system of tropical streams. Environmental Biology of Fishes 9: 117-135.

American Public Health Association. 1985. Standard Methods for the Examination of Water and Wastewater. Port City Press, Baltimore, MD.

Greenfield, D.W. and J.E. Thomerson. 1997. Fishes of the Continental Waters of Belize. University Press of Florida, Gainesville, FL.

Simonson, T.D., J.K. Lyons, P.D. Kanehl. 1993. Guidelines for evaluating fish habitat in Wisconsin streams. Gen. Tech. Rep. NC-164. U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, St. Paul, MN.

Wolman, M.G. 1954. A method of sampling coarse river-bed material. Transactions of the American Geophysical Union 35: 951-956.

APPENDIX D

LATITUDE, LONGITUDE (UTM; NAD27 CENTRAL DATA), AND DATE SAMPLED FOR 21 STATIONS ASSESSED IN MONKEY RIVER BASELINE STUDY

Station	Date Sampled	Latitude	Longitude
BL1	22 MAR 00	332005	1814463
BL2	19 MAR 00	324226	1821518
BL3	20 MAR00	326001	1823797
BL4	24 FEB 00	309079	1828489
BL5	21 FEB 00	308139	1827905
BL6	23 FEB 00	305426	1827008
SW1	1 APR 00	335532	1817511
SW2	1 APR 00	335444	1823698
SW3	30 MAR 00	334753	1824291
SW4	3 MAR 00	333651	1827333
SW5	29 MAR 00	334497	1830527
SW6	28 MAR 00	334246	1833635
SW7	4 MAR 00	330741	1838018
SW8	4 MAR 00	330040	1838288
SW9	28 FEB 00	325563	1847425
TR1	11 FEB 00	325079	1832281
TR2	11 FEB 00	324477	1832311
TR3	13 FEB 00	317727	1837498
MR1	25 MAR 00	338518	1811142
MR2	23 MAR 00	336460	1812332
MR3	24 MAR 00	335710	1812637
BL1	22 MAR 00	332005	1814463

APPENDIX E
SELECTED FISH DATA

Table E.1. Numerical abundance and proportion of each collection (in parentheses) comprised by species taken in run habitats.

	BL04		BL05		BL06		SW08		SW09		TR03	
Astyanax aeneus	142	(0.45)	47	(0.29)	13	(0.22)	10	(0.11)	17	(0.11)	79	(0.30)
Awaous banana	…	…	…	…	…	…	1	(0.01)	1	(0.01)	…	…
Agonostomus monticola	33	(0.11)	…	…	…	…	…	…	1	(0.01)	3	(0.01)
Atherinella sp.	4	(0.01)	…	…	…	…	…	…	…	…	…	…
Belonesox belizanus	…	…	1	(0.01)	…	…	…	…	…	…	…	…
Brycon guatemalensis	14	(0.04)	…	…	5	(0.08)	…	…	…	…	1	(*)
Cichlasoma maculicauda	…	…	…	…	…	…	7	(0.08)	5	(0.03)	…	…
Cichlasoma robertsoni	…	…	…	…	…	…	1	(0.01)	3	(0.02)	…	…
Cichlasoma salvini	30	(0.10)	9	(0.06)	…	…	11	(0.12)	5	(0.03)	15	(0.06)
Cichlasoma spilurum	53	(0.17)	46	(0.29)	20	(0.33)	31	(0.34)	33	(0.22)	76	(0.29)
Gobiomorus dormitor	…	…	…	…	1	(0.02)	…	…	2	(0.01)	1	(*)
Gambusia luma	…	…	13	(0.08)	…	…	1	(0.01)	…	…	…	…
Heterandria bimaculata	…	…	25	(0.16)	8	(0.13)	…	…	6	(0.04)	…	…
Hyphessobrycon compressus	…	…	…	…	…	…	1	(0.01)	…	…	…	…
Ophisternon aenigmaticum	1	(*)	1	(0.01)	…	…	1	(0.01)	3	(0.02)	…	…
Poecilia mexicana	35	(0.11)	10	(0.06)	…	…	15	(0.16)	72	(0.48)	75	(0.28)
Rhamdia laticauda	2	(0.01)	2	(0.01)	5	(0.08)	12	(0.13)	…	…	2	(0.01)
Xiphophorus helleri	…	…	6	(0.04)	8	(0.13)	…	…	1	(0.01)	13	(0.05)
TOTALS	314		160		60		91		149		265	

*Less than 0.01.

Table E.2. Numerical abundance and proportion of each collection (in parentheses) comprised by species taken in riffle habitats.

	BL04		BL05		BL06		PR01		SW07		SW08		SW09		TR03	
Astyanax aeneus ………	56	(0.65)	73	(0.54)	11	(0.26)	47	(0.40)	31	(0.49)	37	(0.74)	…	…	49	(0.60
Awaous banana …………	…	…	…	…	…	…	…	…	1	(0.02)	…	…	…	…	…	…
Agonostomus monticola …	21	(0.24)	2	(0.01)	24	(0.57)	64	(0.54)	7	(0.11)	2	(0.04)	7	(0.47)	10	(0.12)
Atherinella sp. ……………	…	…	1	(0.01)	…	…	1	(0.01)	…	…	…	…	…	…	…	…
Brycon guatemalensis …	2	(0.02)	…	…	6	(0.14)	2	(0.02)	5	(0.08)	…	…	1	(0.07)	1	(0.01)
Cichlasoma maculicauda	…	…	…	…	…	…	…	…	2	(0.03)	4	(0.08)	…	…	…	…
Cichlasoma salvini ………	1	(0.01)	12	(0.09)	…	…	2	(0.02)	1	(0.02)	2	(0.04)	…	…	5	(0.06)
Cichlasoma spilurum ……	3	(0.03)	20	(0.15)	…	…	1	(0.01)	…	…	…	…	…	…	5	(0.06)
Gobiomorus dormitor ……	…	…	…	…	…	…	…	…	1	(0.02)	…	…	…	…	…	…
Heterandria bimaculata …	…	…	3	(0.02)	…	…	…	…	…	…	…	…	…	…	…	…
Joturus pichardi …………	…	…	…	…	…	…	…	…	…	…	…	…	7	(0.47)	…	…
Ophisternon aenigmaticum	1	(0.01)	3	(0.02)	…	…	…	…	2	(0.03)	…	…	…	…	…	…
Poecilia mexicana ………	1	(0.01)	5	(0.04)	1	(0.02)	…	…	13	(0.21)	3	(0.06)	…	…	5	(0.06)
Rhamdia laticauda ………	1	(0.01)	14	(0.10)	…	…	1	(0.01)	…	…	2	(0.04)	…	…	6	(0.07)
Xiphophorus helleri ……	…	…	1	(0.01)	…	…	…	…	…	…	…	…	…	…	…	…
TOTALS …………	86		134		42		118		63		50		15		81	86

*Less than 0.01.

Table E.3. Mean numerical abundance (across transects) and standard deviation (in parentheses) of species taken in headwater pool habitats by underwater visual assessment.

	BL04	BL05	BL06	PR01	SW07	SW08	SW09	TR03
N ……………….	2	4	4	8	8	7	4	14
Awaous banana ……………..	0.50 (0.71)	1.50 (1.91)	… …	… …	… …	… …	… …	… …
Agonostomus monticola ……	… …	0.25 (0.50)	8.00 (9.63)	7.25 (6.56)	0.38 (0.74)	0.86 (1.86)	11.00 (12.81)	2.71 (7.65)
Atherinella sp. ………………..	16.00 (2.83)	7.75 (14.84)	10.00 (11.80)	3.63 (6.46)	0.88 (0.99)	12.57 (14.30)	… …	… …
Belonesox belizanus ………..	0.50 (0.71)	0.25 (0.50)	… …	… …	… …	… …	… …	… …
Brycon guatemalensis ………	… …	57.75 (50.20)	2.50 (3.00)	18.50 (19.32)	… …	4.71 (7.63)	8.50 (17.00)	0.29 (1.07)
Cichlasoma maculicauda …..	… …	17.00 (34.00)	… …	9.75 (9.35)	3.38 (5.58)	12.29 (9.32)	10.00 (9.59)	8.50 (10.68)
Cichlasoma meeki …………..	… …	… …	… …	3.63 (7.33)	… …	2.14 (5.67)	… …	0.07 (*)
Cichlasoma robertsoni ……..	… …	… …	… …	6.25 (8.83)	1.88 (3.48)	2.14 (5.24)	… …	0.36 (0.71)
Cichlasoma salvini ………….	1.00 (1.41)	… …	… …	7.88 (6.13)	… …	0.86 (1.86)	… …	2.07 (2.82)
Cichlasoma spilurum ………..	52.50 (3.54)	28.00 (30.24)	44.75 (29.78)	39.00 (28.70)	23.38 (15.79)	27.29 (12.11)	1.50 (1.73)	89.86 (21.01)
Gobiomorus dormitor ……….	… …	… …	… …	0.13 (0.35)	… …	… …	… …	… …
Gambusia luma ……………..	4.00 (2.83)	… …	0.75 (1.50)	2.50 (3.59)	… …	… …	… …	… …
Heterandria bimaculata ……..	4.50 (2.12)	… …	2.00 (1.63)	0.38 (0.74)	… …	1.86 (4.49)	10.00 (9.76)	0.29 (1.41)
Hyphessobrycon compressus	… …	… …	… …	… …	3.13 (6.64)	37.14 (17.42)	… …	… …
Joturus pichardi ……………..	… …	… …	… …	… …	… …	… …	2.75 (3.20)	… …
Pomadasys crocro ………….	… …	… …	… …	… …	… …	2.43 (3.99)	4.25 (7.23)	… …
Poecilia mexicana …………..	48.50 (34.65)	58.25 (34.26)	17.25 (8.54)	30.25 (27.05)	47.88 (35.63)	32.86 (22.78)	7.25 (11.98)	30.79 (36.60)
Petenia splendida …………..	… …	… …	… …	0.38 (0.74)	… …	0.14 (0.38)	… …	… …
Rhamdia laticauda ………….	… …	0.25 (0.50)	3.25 (3.30)	0.50 (1.41)	0.25 (0.71)	… …	… …	0.57 (0.74)
Xiphophorus helleri …………	1.50 (2.12)	1.25 (1.89)	2.00 (2.31)	… …	0.13 (0.35)	0.14 (0.38)	… …	2.07 (2.88)
TOTALS …………………..	129.00	172.25	90.50	130.00	81.25	137.43	55.25	137.57

*Less than 0.01.

Table E.4. Numerical abundance and proportion of collections (in parentheses) of species taken in all habitats by electroshocking.

	BL01	BL02	BL03	BL04	BL05	BL06	MR01	MR02	MR03
Astyanax aeneus	35 (0.17)	54 (0.17)	47 (0.30)	216 (0.49)	120 (0.40	37 (0.24)	10 (0.07)	28 (0.14)	12 (0.08)
Awaous banana	2 (0.01)	… …	4 (0.03)	1 (*)	1 (*)	1 (0.01)	1 (0.01)	… …	1 (0.01)
Anchoviella belizensis	… …	… …	… …	… …	… …	… …	1 (0.01)	… …	… …
Achirus declivus	1 (*)	… …	… …	… …	… …	… …	… …	… …	… …
Agonostomus monticola	… …	… …	4 (0.03)	54 (0.12)	2 (0.01)	24 (0.16)	… …	… …	… …
Ariopsis assimilis	… …	… …	… …	… …	… …	… …	3 (0.02)	1 (0.01)	1 (0.01)
Atherinella sp.	31 (0.15)	27 (0.08)	8 (0.05)	4 (0.01)	1 (*)	1 (0.01)	5 (0.04)	8 (0.04)	3 (0.02)
Belonesox belizanus	2 (0.01)	10 (0.03)	6 (0.04)	1 (*)	1 (*)	1 (0.01)	1 (0.01)	2 (0.01)	6 (0.04)
Brycon guatemalensis	4 (0.02)	… …	… …	16 (0.04)	1 (*)	11 (0.07)	1 (0.01)	2 (0.01)	8 (0.05)
Centropomus ensiferus	… …	… …	… …	… …	… …	… …	… …	2 (0.01)	3 (0.02)
Cichlasoma maculicauda	12 (0.06)	6 (0.02)	1 (0.01)	… …	1 (*)	1 (0.01)	19 (0.14)	18 (0.09)	25 (0.17)
Cichlasoma meeki	… …	10 (0.03)	6 (0.04)	… …	… …	… …	… …	… …	… …
Centropomus parallelus	… …	… …	… …	… …	… …	… …	… …	3 (0.02)	… …
Cichlasoma robertsoni	1 (*)	11 (0.03)	5 (0.03)	1 (*)	1 (*)	1 (0.01)	… …	10 (0.05)	5 (0.03)
Ciclasoma salvini	16 (0.08)	29 (0.09)	12 (0.08)	33 (0.07)	21 (0.07)	… …	2 (0.01)	10 (0.05)	2 (0.01)
Cytharichthes spilopterus	… …	… …	… …	… …	… …	… …	1 (0.01)	… …	… …
Cichlasoma spilurum	5 (0.02)	22 (0.07)	8 (0.05)	58 (0.13)	66 (0.22)	26 (0.17)	1 (0.01)	1 (0.01)	2 (0.01)
Cichlasoma urophthalmus	… …	… …	… …	… …	… …	… …	… …	1 (0.01)	8 (0.05)
Eleotris amblyopsis	… …	… …	… …	… …	… …	… …	… …	1 (0.01)	1 (0.01)
Eucinostomus melanopterus	13 (0.06)	1 (*)	… …	… …	… …	… …	42 (0.31)	28 (0.14)	22 (0.15)
Eugerres plumieri	… …	… …	… …	… …	… …	… …	2 (0.01)	… …	7 (0.05)
Gobiomorus dormitor	9 (0.04)	1 (*)	2 (0.01)	… …	… …	1 (0.01)	11 (0.08)	5 (0.03)	2 (0.01)
Gambusia luma	10 (0.05)	18 (0.06)	12 (0.08)	3 (0.01)	13 (0.04)	6 (0.04)	6 (0.04)	5 (0.03)	4 (0.03)
Heterandria bimaculata	… …	1 (*))		4 (0.01)	28 (0.09)	16 (0.10)	… …	… …	… …
Hyphessobrycon compressus	10 (0.05)	53 (0.16)	4 (0.03)	… …	… …	… …	… …	5 (0.03)	2 (0.01)
Lutjanus griseus	… …	… …	… …	… …	… …	… …	1 (0.01)	1 (0.01)	1 (0.01)
Lutjanus jocu	… …	… …	… …	… …	… …	… …	… …	1 (0.01)	4 (0.03)
Megalops atlanticus	… …	… …	… …	… …	… …	… …	2 (0.01)	… …	… …
Microphis brachyurus	1 (*)	… …	… …	… …	… …	… …	… …	… …	… …
Ophisternon aenigmaticum	3 (0.01)	7 (0.02)	4 (0.03)	5 (0.01)	4 (0.01)	… …	4 (0.03)	1 (0.01)	1 (0.01)
Pomadasys crocro	4 (0.02)	… …	… …	1 (*)	1 (*)	… …	… …	… …	1 (0.01)
Peocilia mexicana	44 (0.21)	67 (0.21)	32 (0.20)	43 (0.10)	15 (0.05)	8 (0.05)	14 (0.10)	62 (0.31)	19 (0.13)
Petenia splendida	… …	1 (*)	… …	… …	… …	… …	… …	1 (0.01)	… …
Rhamdia guatemalensis	… …	… …	… …	… …	… …	… …	… …	… …	1 (0.01)
Rhamdia laticauda	… …	… …	2 (0.01)	3 (0.01)	16 (0.05)	12 (0.08)	… …	… …	… …
Strongylura timucu	… …	… …	… …	… …	… …	… …	7 (0.05)	1 (0.01)	3 (0.02)
Xiphophorus helleri	2 (0.01)	4 (0.01)	2 (0.01)	1 (*)	7 (0.02)	8 (0.05)	… …	… …	7 (0.05)
TOTALS	205	322	159	444	299	154	134	198	151

*Less than 0.01.

Table E.4 (cont.).

	PR01	SW01	SW02	SW03	SW04	SW05	SW06	SW07
Astyanax aeneus	101 (0.29)	14 (0.07)	36 (0.12	37 (0.17)	88 (0.11)	71 (0.15)	44 (0.10)	38 (0.32)
Awaous banana	2 (0.01)	1 (*)	1 (*)	2 (0.01)	1 (*)	1 (*)	4 (0.01)	1 (0.01)
Anchoviella belizensis	… …	… …	… …	… …	… …	… …	… …	… …
Achirus declivus	… …	… …	… …	… …	… …	… …	… …	… …
Agonostomus monticola	64 (0.18)	… …	… …	… …	… …	9 (0.02)	3 (0.01)	7 (0.06)
Ariopsis assimilis	… …	… …	… …	… …	… …	… …	… …	… …
Atherinella sp.	1 (*)	1 (*)	9 (0.03)	5 (0.02)	131 (0.16)	31 (0.07)	27 (0.06)	1 (0.01)
Belonesox belizanus		3 (0.01)	5 (0.02)	2 (0.01)	12 (0.01)	4 (0.01)	3 (0.01)	1 (0.01)
Brycon guatemalensis	2 (0.01)	7 (0.03)	… …	7 (0.03)	… …	… …	… …	5 (0.04)
Centropomus ensiferus	… …	… …	1 (*)	… …	… …	… …	… …	… …
Cichlasoma maculicauda	4 (0.01)	14 (0.07)	3 (0.01)	9 (0.04)	24 (0.03)	11 (0.02)	6 (0.01)	2 (0.02)
Cichlasoma meeki	1 (*)	4 (0.02)	… …	4 (0.02)	40 (0.05)	8 (0.02)	29 (0.06)	… …
Centropomus parallelus	… …	… …	… …	… …	… …	… …	… …	… …
Cichlasoma robertsoni	1 (*)	6 (0.03)	13 (0.04)	7 (0.03)	24 (0.03)	7 (0.01)	11 (0.02)	1 (0.01)
Ciclasoma salvini	29 (0.08)	12 (0.06)	13 (0.04)	13 (0.06)	18 (0.02)	27 (0.06)	41 (0.09)	1 (0.01)
Cytharichthes spilopterus	… …	… …	… …	… …	… …	… …	… …	… …
Cichlasoma spilurum	51 (0.15)	… …	7 (0.02)	3 (0.01)	8 (0.01)	40 (0.09)	65 (0.14)	12 (0.10)
Cichlasoma urophthalmus	… …	… …	… …	… …	… …	… …	… …	… …
Eleotris amblyopsis	… …	… …	… …	… …	… …	… …	… …	… …
Eucinostomus melanopterus	… …	2 (0.01)	… …	1 (*)	… …	… …	… …	… …
Eugerres plumieri	… …	… …	… …	… …	… …	… …	… …	… …
Gobiomorus dormitor	1 (*)	3 (0.01)	2 (0.01)	… …	3 (*)	… …	4 (0.01)	1 (0.01)
Gambusia luma	27 (0.08)	… …	… …	2 (0.01)	5 (0.01)	6 (0.01)	7 (0.02)	1 (0.01)
Heterandria bimaculata	1 (*)	… …	1 (*)	… …	… …	… …	… …	1 (0.01)
Hyphessobrycon compressus	… …	… …	1 (*)	6 (0.03)	143 (0.17)	5 (0.01)	6 (0.01)	4 (0.03)
Joturus pichardi	… …	… …	… …	… …	… …	… …	… …	… …
Lutjanus jocu	… …	… …	… …	… …	… …	… …	… …	… …
Megalops atlanticus	… …	… …	… …	… …	… …	… …	… …	… …
Microphis brachyurus	… …	… …	… …	… …	… …	… …	… …	… …
Ophisternon aenigmaticum	4 (0.01)	7 (0.03)	3 (0.01)	3 (0.01)	7 (0.01)	9 (0.02)	13 (0.03)	5 (0.04)
Pomadasys crocro	… …	1 (*)	1 (*)	2 (0.01)	1 (*)	… …	… …	… …
Peocilia mexicana	11 (0.03)	122 (0.60)	198 (0.66)	95 (0.44)	294 (0.36)	220 (0.47)	178 (0.39)	34 (0.29)
Petenia splendida	1 (*)	… …	… …	… …	6 (0.01)	… …	2 (*)	… …
Rhamdia guatemalensis	... ...	3 (0.01)	1 (*)	9 (0.04)	5 (0.01)	3 (0.01)	3 (0.01)	... ...
Rhamdia laticauda	21 (0.06)	1 (*)	4 (0.01)	10 (0.05)	6 (0.01)	14 (0.03)	3 (0.01)	2 (0.02)
Strongylura timucu	… …	… …	… …	… …	… …	… …	… …	… …
Xiphophorus helleri	28 (0.08)	2 (0.01)	3 (0.01)	1 (*)	4 (*)	1 (*)	3 (0.01)	2 (0.02)
Xiphophorus maculatus	… …	… …	… …	… …	1 (*)	… …	… …	… …
TOTALS	350	203	302	218	821	467	452	119

*Less than 0.01.

Table E.4 (cont.).

	SW08		SW09		TR03	
Astyanax aeneus	47	(0.32)	17	(0.10)	128	(0.36)
Awaous banana	1	(0.01)	1	(0.01)	…	…
Anchoviella belizensis	…	…	…	…	…	…
Achirus declivus	…	…	…	…	…	…
Agonostomus monticola	2	(0.01)	8	(0.05)	13	(0.04)
Ariopsis assimilis	…	…	…	…	…	…
Atherinella sp.	1	(0.01)	…	…	…	…
Belonesox belizanus	1	(0.01)	…	…	…	…
Brycon guatemalensis	1	(0.01)	1	(0.01)	12	(0.03)
Centropomus ensiferus	…	…	…	…	…	…
Cichlasoma maculicauda	11	(0.07)	5	(0.03)	1	(*)
Cichlasoma meeki	1	(0.01)	…	…	1	(*)
Centropomus parallelus	…	…	…	…	…	…
Cichlasoma robertsoni	1	(0.01)	3	(0.02)	1	(*)
Ciclasoma salvini	13	(0.09)	5	(0.03)	20	(0.06)
Cytharichthes spilopterus	…	…	…	…	…	…
Cichlasoma spilurum	31	(0.21)	33	(0.20)	81	(0.23)
Cichlasoma urophthalmus	…	…	…	…	…	…
Eleotris amblyopsis	…	…	…	…	…	…
Eucinostomus melanopterus	…	…	…	…	…	…
Eugerres plumieri	…	…	…	…	…	…
Gobiomorus dormitor	…	…	2	(0.01)	1	(*)
Gambusia luma	1	(0.01)	1	(0.01)	…	…
Heterandria bimaculata	1	(0.01)	6	(0.04)	1	(*)
Hyphessobrycon compressus	1	(0.01)			…	…
Joturus pichardi	…	…	7	(0.04)	…	…
Lutjanus jocu	…	…	…	…	…	…
Megalops atlanticus	…	…	…	…	…	…
Microphis brachyurus	…	…	…	…	…	…
Ophisternon aenigmaticum	1	(0.01)	3	(0.02)	…	…
Pomadasys crocro	1	(0.01)	1	(0.01)	…	…
Peocilia mexicana	18	(0.12)	72	(0.43)	80	(0.22)
Petenia splendida	1	(0.01)	…	…	…	…
Rhamdia guatemalensis			…	…	…	…
Rhamdia laticauda	14	(0.09)	…	…	8	(0.02)
Strongylura timucu	…	…	…	…	…	…
Xiphophorus helleri	1	(0.01)	1	(0.01)	13	(0.04)
Xiphophorus maculatus	…	…	…	…	…	…
TOTALS	149		166		360	

*Less than 0.01.