Human Impact Mapping of the Mopan and Chiquibul Rivers within Guatemala and Belize

With Comments on Riparian Forest Ecology, Conservation and Restoration

by
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Abstract

On-going efforts to address environmental impacts within the Mopan River watershed involve government agencies, NGOs and communities within Guatemala and Belize. A human impact assessment of the major tributaries of this watershed was undertaken to identify the geographical extend of impact categories, resulting in the development of a set of twelve impact maps based on a field assessment approach developed by Esselman (2001). This study revealed that the upper Mopan River (all reaches above Los Encuentros or the convergence with the Chiquibul River) has been subjected to the greatest amount of stress from sedimentation, nutrient loading, habitat alteration, thermal alteration, toxins/contaminants and trophic alteration than indicated for the Chiquibul River or the lower Mopan River (all reaches below Los Encuentros to the river mouth at its confluence with the Macal River). The upper Mopan River upslope areas have been heavily deforested for agricultural expansion, greatly threatening future soil productivity and ultimately ecosystem functions and services within this area. The upper Mopan River also has the most reach area where riparian trees have completely removed or thinned. Many of these trees had been felled directly into the river, often obstructing flow. The steep-banked Chiquibul River had the most community access points but was the least impacted channel investigated within the Mopan River Watershed, followed by the lower Mopan River. These reaches supported less cattle grazing and more riparian forests (although many reaches have thin buffer areas) than the upper Mopan River. Importance of maintaining or re-establishing adequate-width riparian forests within this watershed system is essential to the protection of river reaches from a variety of stressors. This mapping effort is the first in a series of human impact assessment activities underway for the Greater Mopan/Belize River Catchment, a preliminary step in the rapid ecological assessment protocols planned for the entire watershed. The rapid ecological assessment will be conducted in order to target and support conservation, restoration and rehabilitation efforts that address the environmental issues of immediate concern within this important bi-national watershed system.

Introduction

The Greater Mopan/Belize River Catchment provides a prime example of a watershed under stress from extensive non-sustainable agricultural practices that have occurred within the region over the past three decades. This bi-national watershed reaches from the Peten District in Guatemala to the Caribbean Sea on the east cost of Belize. The Mopan River catchment (including the Chiquibul River sub-catchment) in Guatemala is home to 11% of the population of the Peten District and about 45% of the Belizean population lives within the Macal and Belize River catchments. On a regional scale, the Greater Mopan/Belize River catchment provides important linkages within the Meso-American Biological Corridor

1. This project was made possible through financial and technical support from Derric Chan of the Belize River Keeper Program, Rafael Manzanero of Friends of Nature (FON), Belize; Emilia Toralla of Melchor, Guatemala and the Watershed Research, Education, Conservation and Development Association (WRECDA), and the Mayors of Melchor and Dolores, Guatemala.
2. The Mobile Conservation Mapping Station (MCMS), Camelote Village, Belize and WRECDA
3. Natural Resources Management Program, University of Belize, Belmopan, Belize and WRECDA

system, serving as pathways for movement of flora and fauna. However this vital land bridge has been fragmented and is in need of immediate assessment, conservation, restoration, and rehabilitation to help conserve its bio-diversity and connectivity within the Central American Isthmus network of protected areas.

The ecological integrity of the Greater Mopan/Belize River Catchment, and the coastal zone ecosystems affected by the discharge of the Belize River, are threatened by increasing pressures from human activities. Deforestation, land degradation, habitat fragmentation and increasing pollution are occurring due to non-sustainable agriculture, livestock production and unplanned urban growth. Excessive fishing and hunting impose heavy impacts on aquatic and wildlife ecosystems. Drastic changes have occurred during the past three decades as many farmers moved into the area from the Pacific coast of Guatemala. Traditionally they use fire as a land-clearing tool for crop cultivation and pasture management, often clearing steep slopes, streams and riverbanks. If corridor connectivity, ecosystem functions and water quality are to be conserved, systematic assessment of the spatial scope and severity of ecosystem threats must be undertaken, and strategies implemented to ameliorate human impacts.

This paper describes the results of the Mopan and Chiquibul River human impact assessments (the main rivers of the Mopan River Watershed) conducted from March to July, 2003 to evaluate the extent of natural and impacted riparian forests and to identify the stressors imposed on the system. During this assessment, human impacts within the riparian corridor were mapped with a handheld GPS from boats, and mapped using ArcView GIS. Methods developed by Esselman (2001) were used to convert raw data on the locations of stress-sources into predictive maps about the severity and scope of specific aquatic ecosystem stresses. The stress maps for the watershed are presented below.

Site Description

The Greater Mopan/Belize River (GMBR) Catchment is located in the eastern portion of the Department of Peten District of Guatemala and central Belize, with about 40 percent of the river basin being concentrated in Guatemala and 60 percent in Belize (Figure 1). Several major rivers drain the GMBR watershed. These include the Mopan, Hulmul, Chiquibul, Salisipuedes, and possibly the Laguna Yaxha in Guatemala. The lower reaches of the Mopan River, Macal River, Roaring River, White Water Lagoon, Crooked Tree

Lagoons/Black Creek, and the main trunk of the watershed system, the Belize River all lie within Belize.

The soils of the Mopan River catchment, as for much of the Greater Mopan/Belize River basin, are relatively shallow soils and prone to erosion. During the rainy season, the Mopan River periodically carries heavy sediment and other pollutants to the Belize River. The main land use systems in the Mopan watershed are shifting cultivation and extensive cattle production. More than half of the area of the Mopan watershed has been converted to crops and pastures, with much of the land being over utilized. At least 20 villages and three towns lie within the Mopan River Catchment. These communities depend on the rivers within this catchment for their daily water needs and consequently have varying levels of impact upon the rivers and streams of the area.

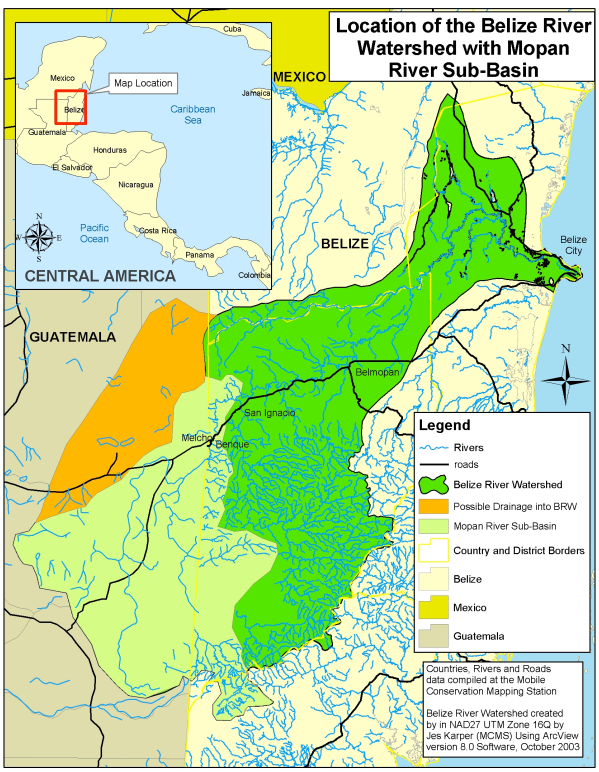


Figure 1. Map of the Greater Mopan/Belize River Catch-ment Basin showing the Mopan River Catchment (light green) and the Laguna Yaxha drainage (orange) area that may discharge into Laboring Creek.

Methods

Human impact point data was collected using Garmin 12XL, 12CX, and GPSMap176 handheld GPS units during four different float trips of the Mopan and Chiquibul Rivers using canoes and inflatable kayaks. The first trip was from January 25 to 26, 2003, running from la Polvora to Melchor. A second float went from Melchor to Branch Mouth in Belize where the Mopan and the Macal Rivers converge on March 27 to 29, 2003. A run was made from El Rosario on July 3, 2003 and ended at la Polvera on July 6, 2003. The final float was of the Chiquibul River from Nuevo Armenia to Los Encuentros, where the Chiquibul intersects the Mopan River, running from July 31 to August 3, 2003. A kayak was outfitted with a GPS unit housed in a dry case attached to an external antenna mounted on the bow. Companion boats included inflatable kayaks for steeper reaches characterized by cascades and rapids or canoes for lower grade reaches having higher amounts of wood.

Throughout the floats, all identifiable human activities were designated by a GPS point and by right bank or left bank (based on downstream orientation), classified within one of the stress-source categories given in Table 1 and described (Esselman, 2001). On completion of each float trip, the raw GPS data (waypoint names and coordinates) were entered into a Microsoft Excel spreadsheet, along with the descriptions. The dominant stress-sources for each kilometer of river was determined following procedures described by Esselman (2001). Color coded maps generated using ESRI ArcGIS® version 8.0 software.

Table 1. Classes of stress sources for human activities.

STRESS SOURCE CLASS	CODE	DESCRIPTION
No riparian buffer	NB	Bank where all of the riparian vegetation has been cleared
Thin riparian buffer	TB	Bank where less than a 66 foot wide strip of riparian forest of buffer remains
Pasture/ grazing	GRZ	Area where cattle, horses, sheep or other livestock graze but not necessarily having direct access to the water
Livestock access	CA	Bank where cattle have direct access to the water
Road access	RD	Site where a road reaches the water
Community Access	LA	Site where people access the river, laundry, fishing, bathing etc…
Water pump	PH	Site where water is extracted from the river for agricultural irrigation
In-stream gravel mining	GRV	Area of the river where active gravel mining is occurring
Channelization	CHN	Area where all or part of the active river channel has been diverted to a manmade channel
Logging	LG	Site where logging occurred recently within the Riparian Buffer

The stress-source of each one-kilometer of river reach was associated with the stress or stresses that it imposed on the aquatic system. Stresses included sedimentation, nutrient loading, toxins/contaminants, altered flow regime, thermal alteration, habitat alteration, direct trophic alteration, thermal alteration and habitat fragmentation. These stress sources and stress associations are based on accounts within the scientific literature and on professional judgment of researchers as outlined by Esselman (2001).

Each stress source was ranked according to the magnitude of its contribution to each stress (very high, high, medium, low, and none detected) and the irreversibility of given stress types (irreversible, reversible at a high cost, reversible at a moderate cost, reversible at little cost). Determinations of rankings for contribution and irreversibility were made based on professional judgment. Ranks were combined according to the rank scores derived from Table 2 (Esselman, 2001). Based on the factors in this table, numerical values are assigned to each source rank, with very high = 10, high = 7.5, medium = 5 and low = 2.5. These values were used to calculate "expected stress intensity" index scores for each one-kilometer river segment that was then used to create the “predicted stress” maps.

The river channels were divided into 1km reaches, beginning from the river mouth, using the “Measure” tool in ArcView®. Reaches were reset at major tributary confluences. Each segment was then labeled and served as the template for comparing source intensities. The 1km reach map was then overlain with the point source data map. The source rank scores associated with each source were added for each 1km reach and entered into a data table. For example, the sedimentation stress for a river reach where the buffer has been removed (10), cattle are grazing (5) and a road access point (5) would have a sediment stress value of 20. This same reach would have a nutrient loading stress of 10 due to the removed buffer (7.5) and grazing cattle (2.5). Thus each reach segment has a relative source intensity value representing all sources identified for that reach.

The value of the highest scoring segment for all categories combined was divided by four to establish category break points. Each of the four stress value ranges was assigned a color code whereby red is ‘*very high*’, yellow is ‘*high*’, bright green is ‘*medium*’ and light green is ‘*low*’. Those segments that have no stress sources were left colorless as ‘*none detected’*. Reach scores across stresses were combined to create a single map of overall stress intensities, showing those reaches that are expected to be experiencing the most intense combined stress in red (Figure 9). Also maps for each of the eight stress types (such as sedimentation, nutrient loading, habitat alteration) were compiled based on the same procedures described above (Figures 1 through 8).

Three additional maps were made from the hot spot impact data. Using the Dot Density function in ArcView, frequencies of “No Buffer” and “Thin Buffer” recordings were plotted over the river to show the amount of riparian impact along the river. Those sites recorded as “Thin Buffer” are yellow and “No Buffer” points are displayed as red. Using this same procedure, a Cattle Grazing and Cattle River Access map shows those areas where cattle graze as yellow and where livestock have access to the river as brown. The "Community Use" map shows the location of villages, and separate colors for community access, road access, gravel or sand extraction from the river, logging within the riparian buffer, channelization of the river, and water pumping sites along the river reaches.

Table 2. Stresses, sources, ranking of contribution (Cont.) and irreversibility (Irrev.) source ranking and numerical rank score (based on personal experience and professional judgment given the lack of quantitative evaluation criteria) (modified from Esselman, 2001).

STRESS	SOURCE	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
	Livestock Grazing	L	H	Medium	5
	Livestock access	M	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
	Livestock Grazing	L	M	Low	2.5
	Livestock access	M	H	Medium	5
Toxins/ Contaminants	Drainage ditches	V	M	High	7.5
	Streamside agriculture	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	V	M	High	7.5
	Drainage ditches	L	M	Low	2.5
Direct Habitat Alteration	No riparian buffer	H	M	High	7.5
	Livestock access	M	M	Medium	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
	Fish trap	L	L	Low	2.5

Results

A total of 233 river kilometers were mapped, approximately 1720 data points collected and 12 final maps were generated. For purposes of comparison, the main channels of the Mopan River Watershed were divided into the 'upper' Mopan River (all reaches of the Mopan River above Los Encuentros, a total of 123 km of river), the Chiquibul River (all reaches of the Chiquibul down to its junction with the Mopan River at Los Encuentros, a total of 62 km of river) and the 'lower' Mopan River (from Los Encuentros to its junction with the Macal River near Santa Familia in Belize, a total of 48 km of river). The number of one-kilometer reaches within each of the three sections described for each stress were recorded by intensity category in Table 3.

Table 3. Number of I km river reaches within each intensity category (VH = very high, H = high, M = medium, L = low, NE = no effect noticed) for each stress category.

	SEDIMENTATION					**NUTRIENT LOADING**					**HABITAT ALTERATION**				
	VH	**H**	**M**	**L**	**NE**	**VH**	**H**	**M**	**L**	**NE**	**VH**	**H**	**M**	**L**	**NE**
Upper Mopan R.	18	31	26	47	1	18	39	20	44	2	7	23	35	55	3
Chiquibul River	0	0	13	45	4	0	0	16	40	5	0	0	9	42	11
Lower Mopan R.	0	2	15	28	3	0	4	15	26	3	0	0	10	30	8
	TROPHIC ALTERATION					**THERMAL ALTERATION**					**TOXINS AND CONTAMINANTS**				
	VH	**H**	**M**	**L**	**NE**	**VH**	**H**	**M**	**L**	**NE**	**VH**	**H**	**M**	**L**	**NE**
Upper Mopan R.	13	16	40	52	3	8	27	37	44	9	14	27	28	52	2
Chiquibul River	3	12	15	26	5	0	2	12	32	16	0	1	14	43	4
Lower Mopan R.	5	7	13	18	5	0	1	12	26	9	0	0	18	26	4
	ALTERED FLOW REGIME					**HABITAT FRAGMENTATION**					**OVERALL**				
	VH	**H**	**M**	**L**	**NE**	**VH**	**H**	**M**	**L**	**NE**	**VH**	**H**	**M**	**L**	**NE**
Upper Mopan R.	3	2	11	3	104	2	1	1	3	116	19	32	32	39	1
Chiquibul River	0	0	1	2	59	0	0	0	0	62	0	1	19	38	4
Lower Mopan R.	0	0	5	1	42	0	0	0	0	48	0	3	20	23	2

The "Overall Stress Map" reflects many of generalities that are shown in the individual stress maps (Figure 9). The upper Mopan River shows the most impact (Table 3). There were no high intensity reaches on the Chiquibul River and only three reaches that were classified as 'high' intensity on the lower Mopan River. The most impacted cluster of one-kilometer reaches within the upper Mopan River began about 1 km upstream of the Crucadero Bridge and extended downstream for about 18 kilometers. The second most impacted cluster of reaches was 6 km long and centered around La Polvera, with smaller impact clusters occurring upstream of the village for about 18 to 20 km. The third site was around the village of Pichelito and the forth was just upstream of and around El Rosario.

Sedimentation, nutrient loading, habitat alteration, toxins and contaminants and thermal alteration stress patterns all reflect the patterns indicated by the overall stress map for the upper Mopan River. The Chiquibul River had no "very high" or "high" ranked reaches for sedimentation, nutrient loading and habitat alteration (Table 3). High trophic stress conditions occurred downstream of Las Flores and around La Gracia and a high ranked reach for toxins and contaminants occurred downstream of La Gracia on the Chiquibul River. Thermal alteration was high at Las Flores and downstream of La Gracia. Along the lower Mopan, only two 1-kilometer segments were rated as “high” for sedimentation stress and four segments were high for nutrient loading. Thermal alteration was high only at Benque Viejo, Belize (Figure 5). No river segments were rated high or above for toxins and contaminants for the lower Mopan (Table 3). Trophic stress (related to fishing) showed high and very high reaches scattered throughout the main channels of the watershed, with the greatest number or critical reaches being located in the upper Mopan River (Figure 5). Habitat fragmentation was rated high for only a single 1-kilometer reach, located downstream of the bridge at La Crucadero, for the entire main channel system (Figure 8).

A much higher frequency of “No Buffer” and “Thin Buffer” conditions occurred along the upper Mopan River as compared to the other main reaches, with deforested banks becoming more dominant from Pichelito to La Crucadero and the area around La Polvora being particularly impacted. Cattle grazing patterns were very similar, being associated with much of the riparian deforestation for pasture “development.” The Chiquibul River had more human access points than identified for either of the other main reaches. The reach of the upper Mopan River from Cedabenque to about five km downsteam of Crucadero had five large fish traps constructed across the main channel.

Discussion

The forest structure of a watershed is a complex component of the system, performing important functions necessary for maintaining effective integrity of the landscape, quality of the surface and subsurface waters and consequently flood plain, wetland and coastal zone systems receiving watershed discharge. Watershed forests exert controls on hydrologic patterns, geomorphology, sediment transport, habitat complexity and trophic ecology of streams and rivers. Upland forests are important mediators of microclimatic patterns and stream discharge due to evapotranspiration rates and also contribute species, water, detritus., dissolved organic matter and nutrients to riparian forests (Petersjohn and Correl 1984, Pinay and Decamps 1988, Tabacchi 1995). Consequently the spatial dynamics and biodiversity of riparian forests are affected by the geography and community composition of upland forests at the catchment scale (Wiens *et al*. 1985, Kentula 1997).

Figure 1

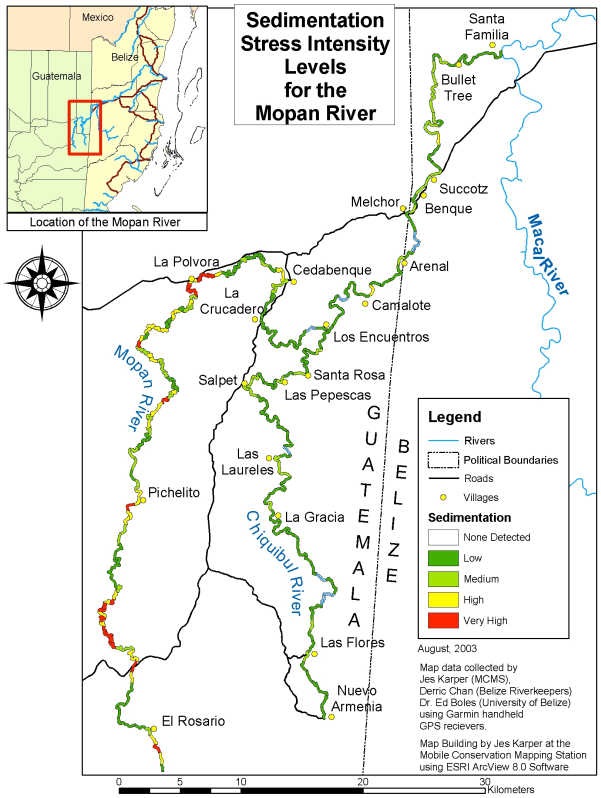


Figure 3

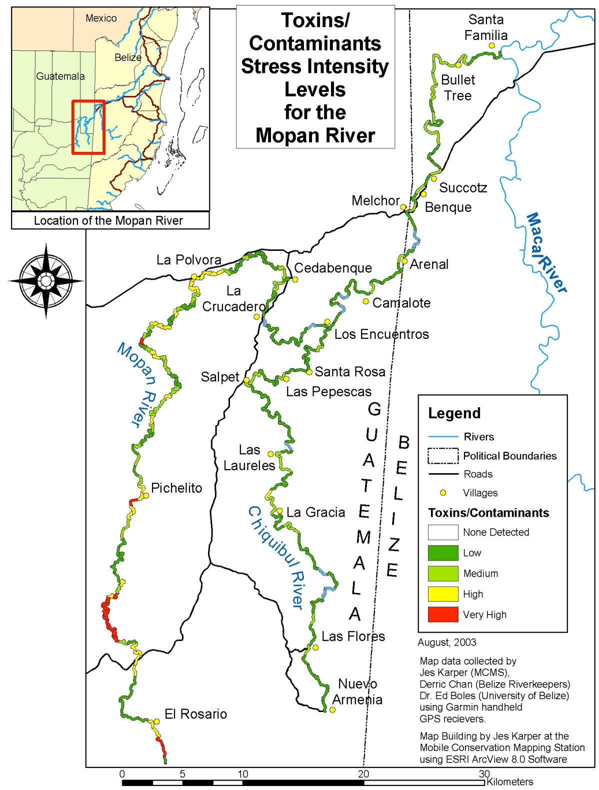


Figure 2

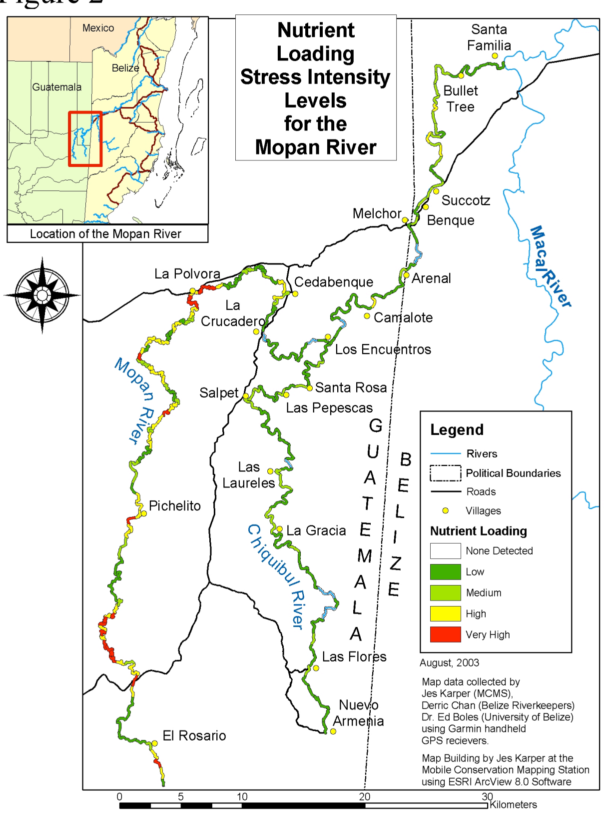
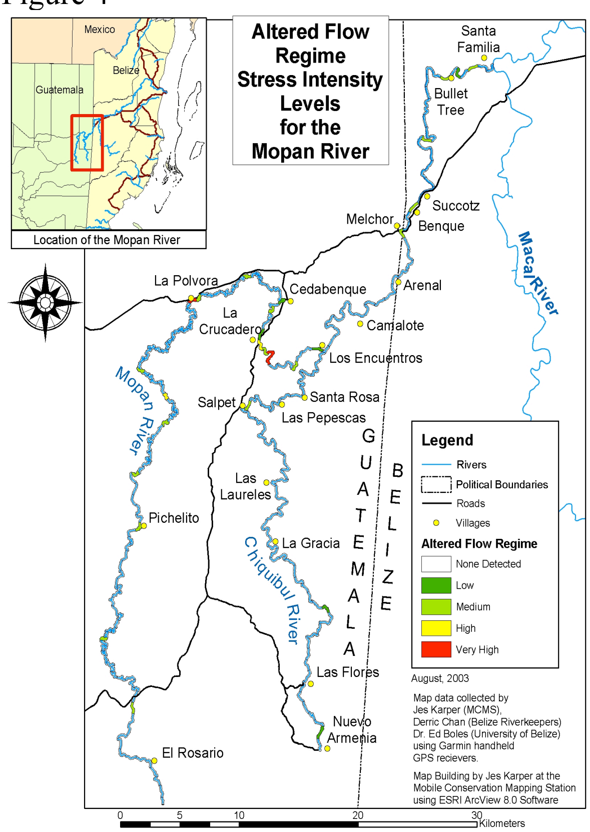


Figure 4



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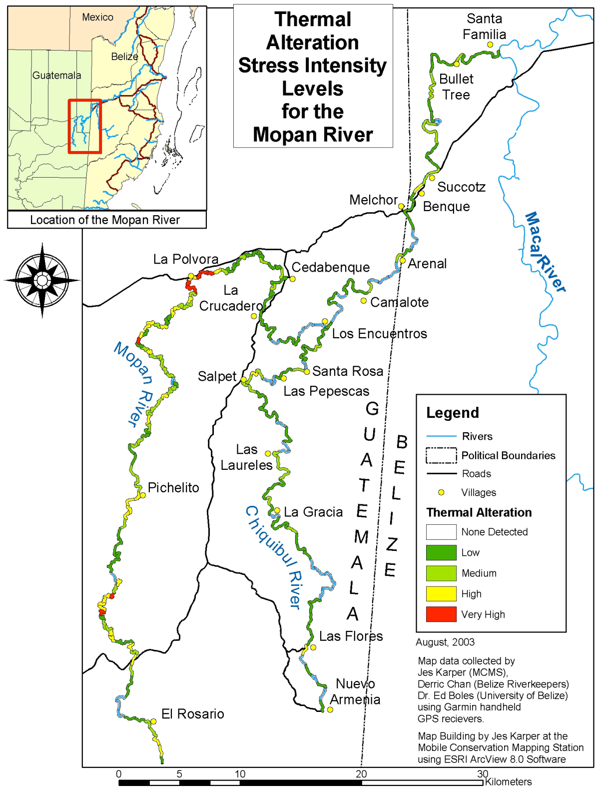

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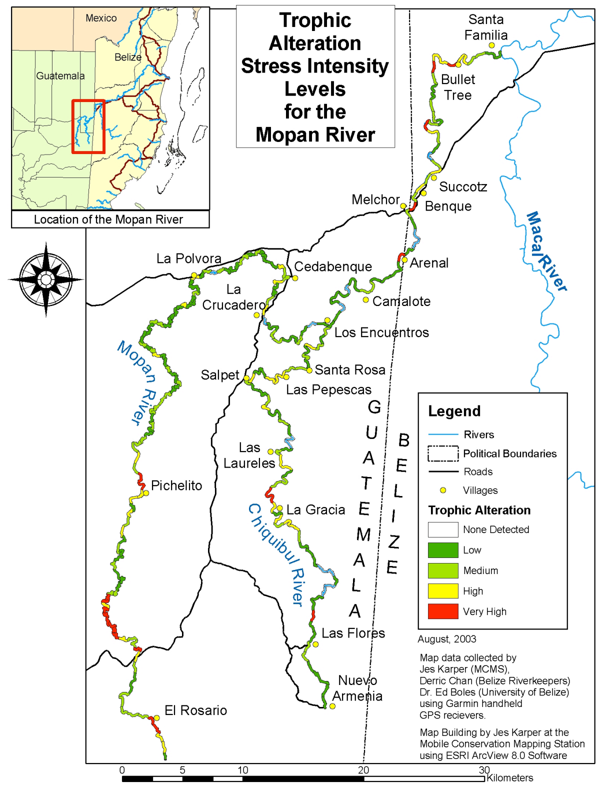
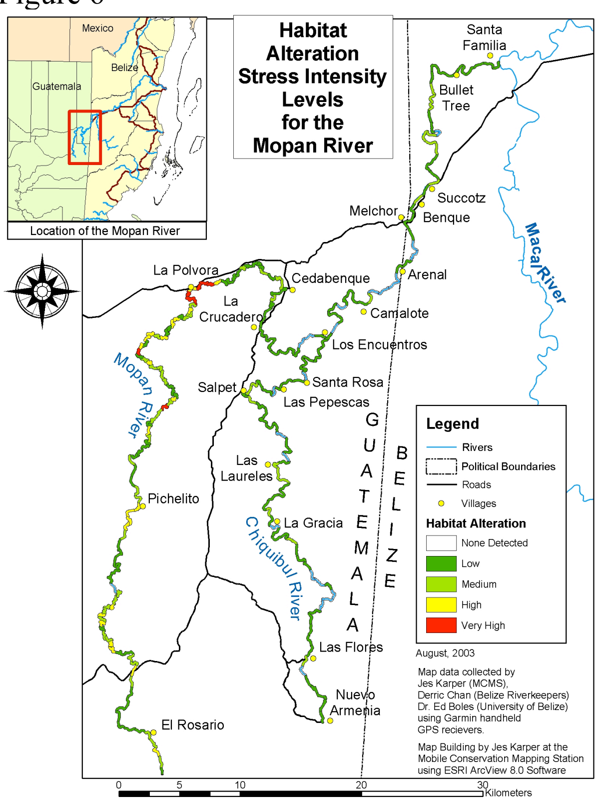


Figure 6



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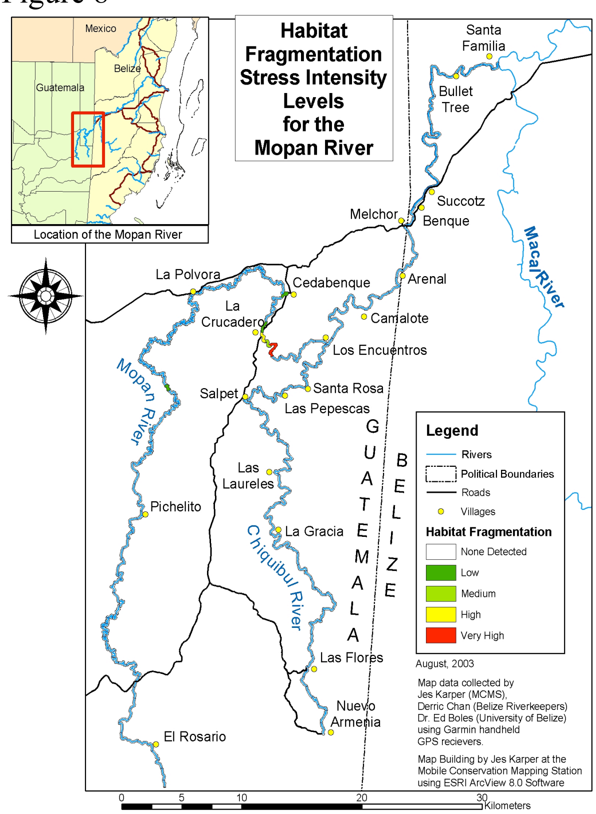


Figure 9

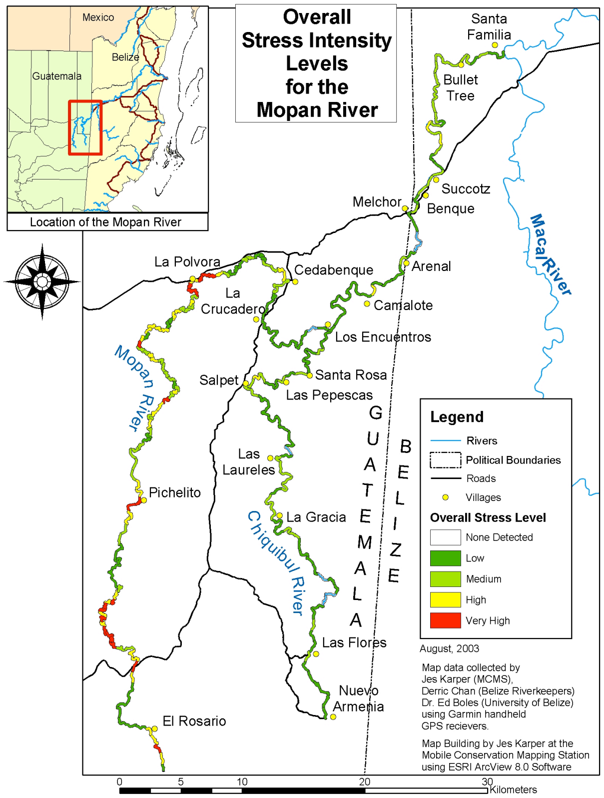


Figure 10

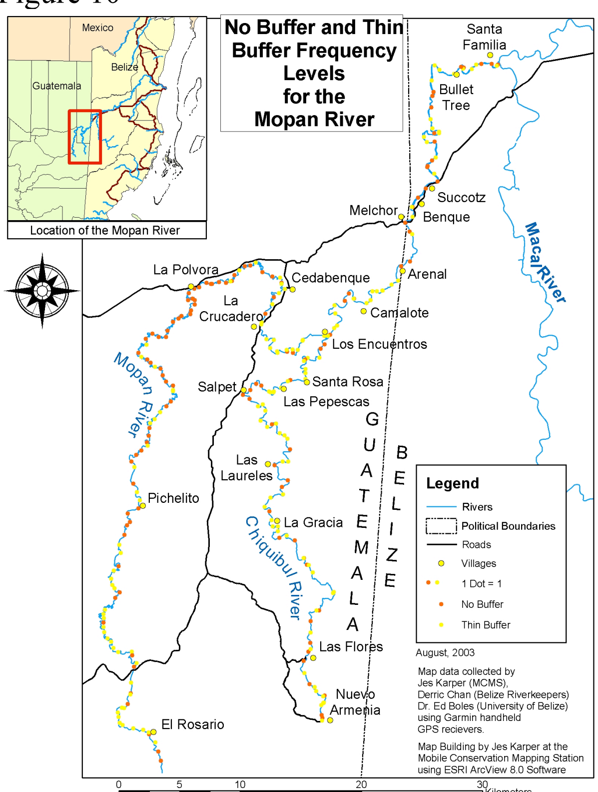


Figure 11

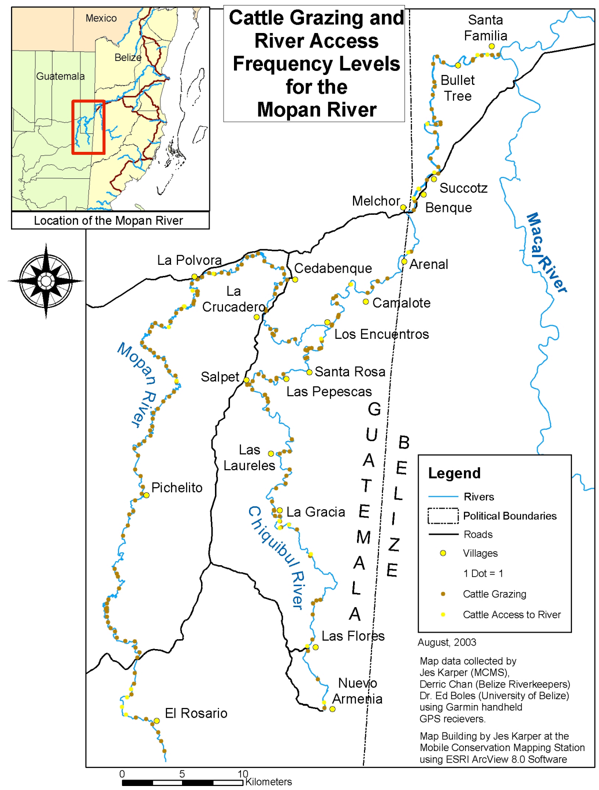
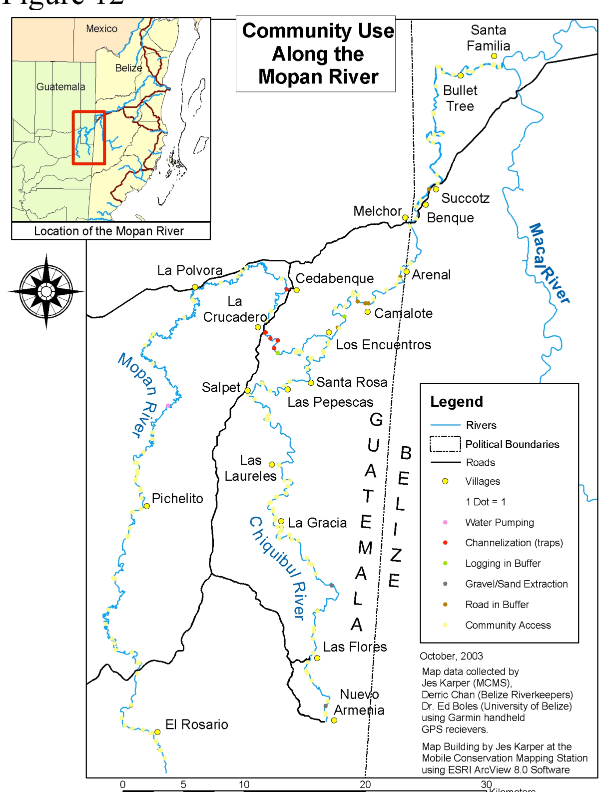


Figure 12



Riparian forests play an important role at the boundary between agricultural and flowing water ecosystems. Field studies have demonstrated that water quality at base flow conditions is related to the presence or absence of riparian forests. Sediment levels, turbidity, suspended solids and phosphorus levels within agricultural landscapes are reduced by the presence of riparian forests that function as sediment and nutrient filters (Karr and Schlosser 1978). Many studies have described processes whereby nutrients within agricultural surface runoff and subsurface flow are absorbed and assimilated through the microbial communities and plant roots within rich riparian soils (Lowrance *et al*. 1983, Peterjohn and Correll 1984, Jacobs and Gilliam 1985). Sediment stress intensity (Figure 1) and nutrient loading (Figure 2) were indicated throughout the rivers mapped in this study.

Vegetation overhanging streams and rivers reduce water temperature by shading, acting to increase the diversity of thermal habitats available to aquatic organisms (Brown and Krygier 1970). Thermal alteration has occurred in the Mopan and Chiquibul Rivers due to the excessive removal of riparian forests (Figure 5).

Streamside forests diversify habitat structure by contributing large woody debris to bank areas and aquatic systems that disrupt flow patterns during both floods and normal flow. Riparian trees that vegetate and thus stabilize islands help maintain divided channels, thereby increasing habitat complexity (Tabacchi *et al*. 1998). Trunks of living riparian trees disrupt the force of high flowing waters, reducing weathering and erosion effects of flowing waters on river banks. Riparian vegetation impose effects on high flow conditions by increasing channel and flood plain roughness. Large woody material and debris jams are important habitat for fishes and macroinvertebrates (Wallace *et al*. 1995). Woody snags also serve as points of detritus accumulation, temporarily storing large organic material and thus affecting energy flows, nutrient availability and biochemical processes within stream and river reaches (Bilby and Likens 1980, Smock et al. 1989, Raikow et al. 1995). Riparian forests have been recognized as important sources of not only energy and sediment, but organic matter for lotic and lentic systems (Hynes 1975, Naiman and Decamps 1997). Most of the particulate organic matter and much of the dissolved organic matter entering streams and rivers have been shown to originate from riparian communities in studies conducted in different areas of the world (Sedell *et al*. 1974, Winterborne 1976, Sidle 1986, King *et al*. 1987). Preservation and rehabilitation of these forests is essential to maintaining or even re-establishing watershed functions. Habitat alteration stress intensity for the study area is depicted in Figure 6 and is largely related to the widespread removal of riparian trees.

Riparian forests control aquatic communities by affecting the amount of solar radiation reaching the water (thus influencing water temperature), regulating nutrients, stabilizing river banks and contributing organic materials to the streams and rivers. Consequently, in the absence of baseline information, we can assume that the Mopan and, to a lesser extent, the Chiquibul Rivers have undergone significant changes in riverine ecology, with several reaches experiencing very high levels of trophic alteration related largely to the removal of riparian forests (Figure 7). Many of the trees have been felled directly into the river, creating an overabundance of woody debris that obstructs flow. Based on mapping efforts for the Mopan River Watershed main channels, the upper Mopan River (up to its sump just upstream of the El Rosario) is the most impacted of the channels investigated (Figure 9).

The extent of cattle gazing and cattle access to the water throughout the major rivers of the watershed are shown in Figure 7. Cattlemen impose heavy impacts on rivers and streams through the clearing of upland and riparian forests for pastures. Cattle exert significant effects on riparian systems through the input of nitrogen rich fecal material, over-grazing of riparian vegetation, exposure of soil to erosion and trampling of habitat areas (Robertson and Rowling 2000, Rosario *et al*. 2002). Figures 1 and 2 show areas where high potential for sediment stress and nutrient loading occurs, most of these sites attributed to impacts from cattle. Compaction and pocking by livestock hooves can destroy soil structure within riparian zones (Robertson, 1997). Changes in plant biomass by land clearing and grazing can impose indirect effects on soil microbe communities through the modification of microclimates and organic matter, consequently impacting the nutrient transformation capacity of riparian forests. Livestock can affect the density of trees by impacting seedlings and saplings (Naiman and Decamps, 1997). Riparian forests improve within a few years when cattle are excluded, but recovery may require decades.

Main roads, village roads and farm service roads have been constructed throughout the study area. Roads are built parallel to the river along some reaches. A few roads reach to the edge of the water, such as at the confluence of the Mopan and Chiquibul Rivers (Figure 12). Surface erosion from gravel roads has been shown to contribute significant amounts of sediment to river systems (Reid and Dunne, 1984). Contribution of eroded sediments from road access areas was obvious at sites along the Mopan and Chiquibul Rivers.

Many stone and pole fish traps were constructed along the reaches of the upper Mopan River. Typically these large traps are built on an existing rapid within the river and span the entire channel of the river. The sides and throat of the trap are made from large poles that are reinforced along the sides by stacks of rocks. The throat of a trap faces downstream and, according to one account, when pesticides are added upstream of the trap, dead and dying fishes float to the surface and are funneled through the trap where they can be easily collected. Impacts include obstructing movement of fishes upstream during low flow conditions, fragmenting the river system, removing significant numbers of fishes from the local reaches (thus impacting the local trophic structure of riverine communities), and introducing pesticides directly into the water (particularly impacting aquatic insects and larval fishes). Much of the impact potential for “Toxins and Contaminant” stressors shown in Figure 3 are related to pesticide usage in corn and urban drainage ditches. Fish traps are shown in Figure 4 as “Altered Flow Regime” stressors, but they also represent “trophic alteration” stressors (Figure 7) as large quantities of fishes are removed from local reaches.

Villages along the main channels throughout the watershed are often built directly on the riverbanks where riparian forests have usually been largely or completely removed. Typically pigs run unpinned around villages and freely access the river. Drainage ditches funnel wastewaters laden with sewage, lechate from organic waste, animal waste and any other stormwater transported pollutants directly to the rivers. Downstream of many villages are backwater areas where solid wastes, mostly plastic, accumulate. Septic smells are encountered along some villages, indicating that waters may be polluted with sewage and potentially with cholera and other waterborne diseases. This same river water is used by communities for washing laundry, household needs and drinking purposes, creating high-risk conditions for disease outbreaks. Village distribution, roads, logging activities, gravel extraction and other activities related to villages are shown in Figure 12. Villages also contribute to the “Toxins and Contaminants” stressors shown in Figure 3.

Damage to upland and riparian forests and, consequently, disruption of ecosystem functions and services can have far reaching effects. Downstream communities throughout the watershed are negatively impacted by increased sediment loads, increased floodwater levels and reduced water quality. Ultimately these impacts will exert pressure on coastal zone systems. Excessive domestic and agricultural pollution and poor land use practices that increase sedimentation have been linked to coral reef degradation, deterioration of other marine ecosystems and a declining fisheries industry (Bryant *et al*. 1998).

Most of these problems listed above are very avoidable, assuming communities understand how to avoid them, are willing to develop their villages within the boundaries of ecological restraints and are given the technical and economic assistance needed to effectively address these issues. The main problems can be avoided by not clearing steep slopes, protecting the riparian forest, adopting more soil conservative agricultural efforts, practicing integrated pest management, building bioremediation systems to handle liquid organic wastes composting solid organic wastes, preventing solid wastes from entering the streams and rivers and practicing sustainable fishing and hunting. Where damage has already occurred, as in the upper Mopan River, reforestation of both steep slope and riparian areas is required to help repair local ecosystems and restore ecological services.

Ecological restoration, in some situations where interconnectivity is still established, may occur naturally once the cause of the stressor is identified and eliminated. Often restoration efforts pose much greater challenges. Generally the complexity of restoration efforts increase as the size of watersheds and magnitude of human activities increases, with overall impacts accumulating in a downstream direction. Restoration may involve such activities as reducing terrestrial erosion, increasing the width of riparian strips, excluding grazing livestock and stopping or properly treating waste discharge into flowing waters. In more severe impact situations, removal of introduced species, re-establishment of locally extinct native species, re-planting of riparian stock and removal of unnatural structures may be required (Wissmar and Beschta 1998). The ultimate objective of restoration activities is to create conditions that promote the natural geomorphic, hydrologic and biotic functions and processes of watershed ecosystems (Kauffman *et al*. 1997).

Bi-national efforts are underway to identify and mitigate causes and negative impacts of land degradation and pollution on ecosystem stability, functions and services in the Greater Mopan/Belize River watershed. The first steps in such a process is to compile a rapid ecological assessment (REA) of the system that can help better visualize the extent of impacts, factors imposing impacts and links between causes and effects in order to effectively prescribe solutions. The initial phase of an REA is to conduct a reach survey and human impact assessment (HIA) as presented in this report. This effort is currently being conducted for other major catchments and the Belize River Valley. Once initial efforts are completed, solution strategies will be prescribed and implemented. Besides riparian and steep slope preservation and reforestation, efforts may include installation of bioremediation filters made from available resources, improvement of pasture and crop productivity, instillation of waste management systems and promotion of good potable water treatment. Effective rehabilitation of a severely impacted watershed requires understanding the spatial extent and relationships of human induced impacts within a watershed.

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