Report for The Nature Conservancy:
Integrating climate change into the TIDE freshwater programme
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1. Introduction

The freshwater ecosystems of the Maya Mountain Marine Corridor (MMMC) are suffering from multiple threats including, but not exclusively, climate change, agrochemicals, gravel mining, deforestation, dam construction and non-native fish species. Of the four largest and most impacted MMMC rivers, the Toledo Institute for Development and Environment (TIDE) is currently implementing monitoring and conservation measures within the Rio Grande (728km^2) and Monkey River (1292 km^2) watersheds. These aim to increase our understanding of how human activities are altering water quality, restore landscape connectivity through the participatory restoration of riparian forests and raise environmental awareness. In an ever changing local and global environment it is necessary that these activities are periodically assessed in order to determine their effectiveness and future suitability.

2. Objectives

1) Identify how climate change might impact MMMC rivers.
2) Review the activities undertaken through the freshwater programme over the past year.
3) Identify how the freshwater monitoring programme could evolve in order to detect the ecological and hydrological impacts of climate change.
4) Identify how communities can become more effective river stewards with the capacity to adapt to climate change.

3. Potential impacts of climate change on Toledo's watersheds

High resolution climate change scenarios for Mesoamerica up to 2020 and 2080 indicate the possibility of reduced precipitation and higher temperatures for Belize during the 21st century (Anderson *et al.* 2008). By the 2020s alone, average July temperatures could rise from 27°C to 29°C and considerably more by the 2080s (see figure 1 below). July, August and September average precipitation levels by the 2020s are expected to decrease in the northern sections of the Toledo district from 210mm to 180mm (see figure 2 below). Seasons are expected to shift and extreme weather events such as hurricanes may become more frequent and severe (IPCC 2001; Knutson *et al.* 2010). Coastal areas could experience up to 1-3m of sea-level rise by 2100, potentially increasing freshwater salinity, damaging wetland areas and flooding towns and villages (Dasgupta *et al.* 2007). These changes will shift the conditions to which Toledo's freshwater ecosystems have adapted to over recent millennia, consequently impacting their biodiversity and benefits to local communities.

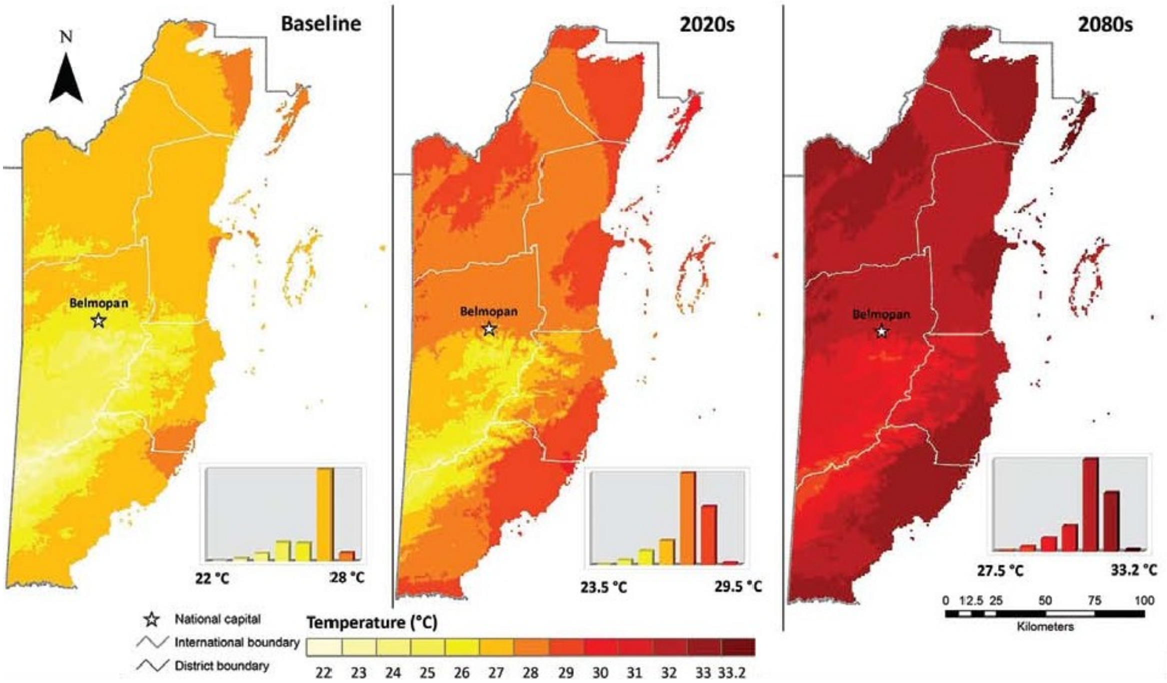


Figure 1: Average July temperature across Belize based on baseline conditions and Hadley H2 scenarios for the 2020s and 2080s. Note that Toledo's watersheds are likely to experience varying rates of temperature change into the future, with rivers to the north east of the Rio Grande suffering the most. (Source: Anderson et al. 2008).

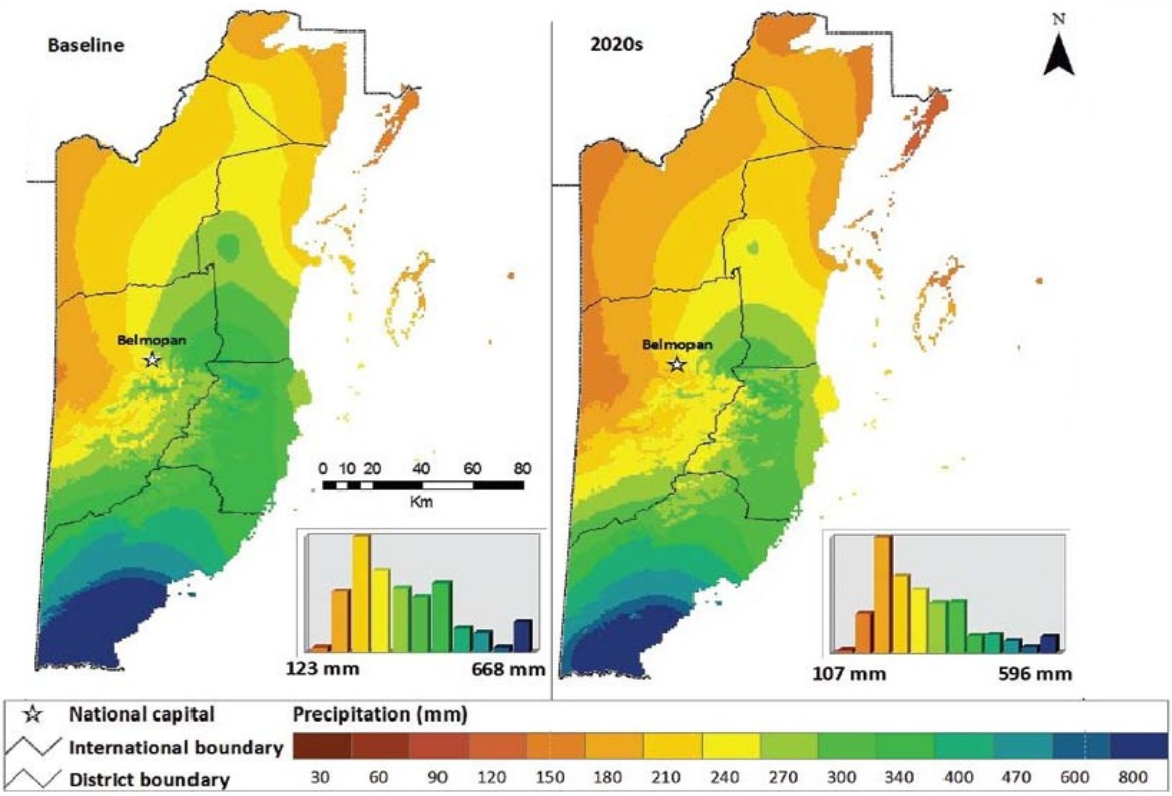


Figure 2: Accumulated precipitation for July, August and September across Belize based on baseline conditions and Hadley H2 scenarios for the 2020s. Note that Toledo's watersheds are likely to experience varying rates of precipitation change, with the MMMC watersheds suffering the most (Source: Anderson et al. 2008).

Direct impacts:

1. Altered flow regime due to either more precipitation or transpiration would:
   - reduce microhabitat availability
   - alter water temperature during low base flows
2. Raised water temperatures that would:
   - reduce habitat for cool water species including some macroinvertebrates
   - decrease dissolved oxygen
   - increase the possibility of microbial blooms
   - reduce rates of biodegradation
3. Increased sediment delivery that would:
   - reduce freshwater light availability
   - cause coral bleaching in marine ecosystems
4. Increased biomass
5. Salt-water intrusion in coastal areas

Indirect impacts:

1. Extirpation of freshwater and riparian species unable to tolerate the altered climate regime
2. Establishment of non-native species more adapted to the altered climate regime
3. Changing land-use due to population displacement from coastal areas
4. Increased likelihood of dam development
5. More severe/frequent hurricanes

These impacts may interact with any land-use pressures MMMC watersheds are experiencing, exacerbating or creating unsustainable social and ecological stresses.

4. Overview and effectiveness of TIDE's current freshwater programme

There are currently four main strands of TIDE's strategy to improve water quality within the Rio Grande and Monkey River watersheds: human impact mapping, physicochemical monitoring, community reforestation and education.

(a) Human impact mapping

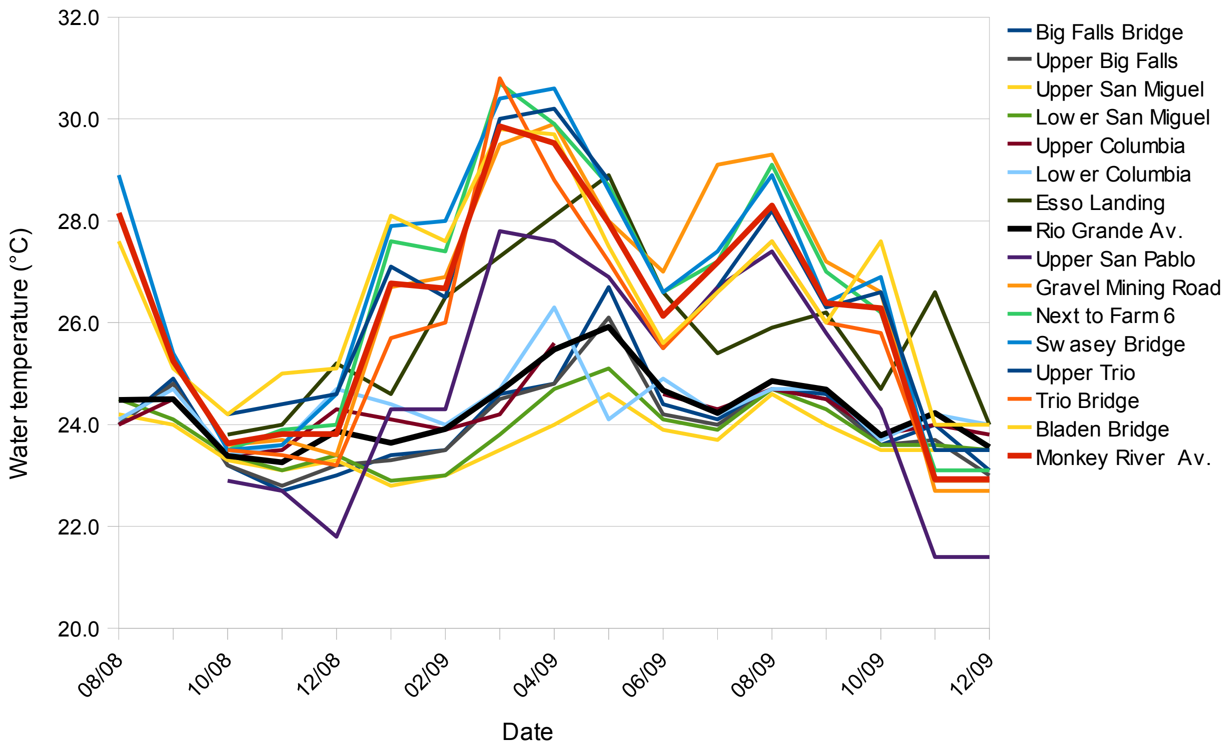
A human impact mapping exercise, using the methodology devised by Esselman (2001) was undertaken on the Rio Grande and its tributaries in April 2009. This was done with the assistance of students from the University of Belize and members from watershed communities to raise awareness of riparian zone stresses and river to reef connectivity. A total of 361 impact points were identified, primarily emanating from the deforestation of riparian zones for subsistence *milpa* farming and poaching from cattle ranching. Consequently, this information was used to identify the need for riparian reforestation on the Columbia and San Miguel tributaries.

In the future the human impact maps will be used for community presentations to raise understanding of TIDE's activities and the state of the watershed. The exercise also has relevance for assessing the effectiveness of reforestation activities, involving more communities and acting as a resource for decision-making within the MMMC. Furthermore, the identification of numerous land-slips on riparian areas farmed by the San Marcos community on the Rio Grande during the “Kern's” land-use mapping exercise, highlights the need to undertake human impact mapping in more populated areas as frequently as possible to ensure records and monitoring activities can respond to land-use changes.

(b) Physicochemical monitoring

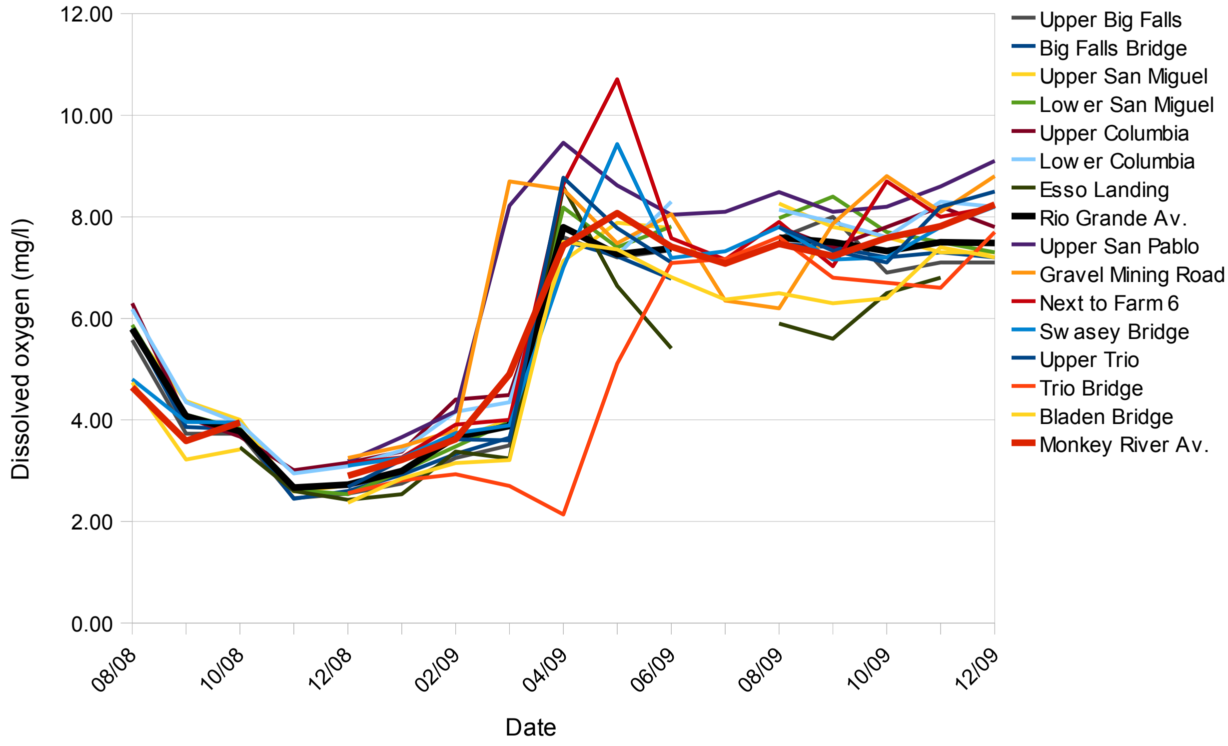
Data are currently being collected based on the indicators identified by the MMMC freshwater management plan (Carrie 2009a) that reflect the degree of ecological stress a particular river is experiencing. The parameters being monitored include water temperature, pH, dissolved oxygen, electrical connectivity and salinity. General qualitative observations of weather and flow conditions are also taken. To account for temporal and spatial variation, the data are collected on a monthly basis from a total of 14 sites across the Rio Grande and Monkey river watersheds using YSI 63 and 550 hand-held probes. The sites were chosen based on their accessibility and degree of human impact.

The graphs below show water temperature and dissolved oxygen content for all sites across the two watersheds for the period between August 08 and December 09, the other parameters have been excluded for the sake of briefness. For 2009, Monkey River had the highest average water temperature at 26.8°C while the Rio Grande was two degrees cooler at 24.6°C. In the Monkey River watershed, there is a clear seasonal pattern, peaking between the months of March and May, with a high of 30.8°C (Trio Bridge) and a low of 21.4°C (San Pablo village). The Rio Grande watershed shows considerably less variation with a high of 26.7°C (Big Falls Bridge) and a low of 22.9°C (Upper San Miguel). Factors controlling water temperature include weather, stream flow and riparian shading; Monkey River's higher average temperature might be due to its generally greater levels of channel modification and riparian deforestation than in the Rio Grande.



Graph 1: Water temperature readings for 14 sites across the Rio Grande and Monkey River watersheds between August 08 and December 09. The averages for each watershed are coloured black (RG) and red (MR).

Averages for dissolved oxygen through 2009 within both watersheds are fairly close, 6.36 mg/l for the Rio Grande and 5.34 mg/l for Monkey River. Readings for the Rio Grande range between 2.45 mg/l (Big Falls Bridge) and 8.58 mg/l (Esso Landing) and for Monkey River between 2.14 mg/l (Trio) and 10.71 mg/l (Swasey). The results show a clear temporal split, with two clusters of readings, one ranging between 2.45 mg/l and 6.30 mg/l from August 08 to March 09 and another between 5.41 mg/l and 10.71 mg/l from May 09 to December 09. The higher readings seem to correspond with the onset of the wet season although there are considerable differences between years for the months August to December. Dissolved oxygen is inversely related to water temperature and will rise with increased flow, so these results are likely to be associated with weather conditions. However, without any air temperature or stream flow data it is difficult to support this argument scientifically.



Graph 2: Dissolved oxygen (mg/l) readings for the 14 sites across the Rio Grande and Monkey River watersheds between August 08 and December 09. The averages for each watershed are coloured black (RG) and red (MR). Note the dramatic shift to higher dissolved oxygen levels around March.

With one year's data it is only possible to make some general statements on the water quality of the Rio Grande and Monkey River. A postgraduate student at the University of Lancaster in the UK will be analysing and interpreting the 2009 data in conjunction with the Ya'axche Conservation Trust (YCT) freshwater ecologist. This information will serve as a baseline to begin establishing the natural or desired state of these rivers, which will allow for some more substantive conclusions on trends, impacts or improvements (finer and coarser scales) within the MMMC. The key to the effectiveness of the physicochemical monitoring will be understanding the relationships between the various human pressures and the indicator variables. Furthermore, after the identification of additional agricultural pressures on the Rio Grande, it is recommended that monitoring is initiated at Jacinto Creek and San Marcos to cover the area between the Big Falls Bridge and Esso landing.

(c) Community reforestation projects

Two community led riparian reforestation projects have been implemented on the Rio Grande tributaries in San Pedro Columbia and San Miguel, building on the trust and capacity developed through a similar project in 2005. The reforestation targeted areas identified by the human impact mapping exercise as having high levels of stress intensity. Seedlings were established through nurseries in each village and maintained by hired community members who were guided by a team leader, who in both cases were pivotal in establishing awareness of riparian reforestation within the community. The added economic component of a stipend on the understanding that people need income provided an extra incentive for participants. Target local tree species included Bri-Bri (Inga), Mahogany (Sweitenia), Cedar (*Cedrela*), Fig (*Ficus*), Cotton Tree (*Ceiba*), Breadnut (*Artocarpus*), Avocado (*Persea*) and Moringa.

In Columbia, the team leader was not chosen but rather contacted TIDE asking if we could assist with further reforestation activities. This was because a pilot project carried out in 2005 enabled the community to become more aware of the benefits of maintaining the riparian zone and they therefore sought to expand their involvement in efforts to improve water quality in the locality. A total of 3000 trees were planted and the project was completed two months before the target end-date, see figure 1 below for photographs. The community leader also suggested growing some fruit trees and flowering plants in the nursery for the village primary school. This was successfully followed up enabling 115 children between the ages of 8 and 12 to plant 60 fruit trees and 100 flowering plants around the school grounds to provide for shading, food and aesthetic needs. In San Miguel no projects had previously been undertaken, so effort was made to identify a willing leader who then found community members to participate. This project was slightly more challenging than in Columbia due to its greater educational demands, requiring some awareness and motivational building, however at present almost all of the 2000 seedlings have been planted. Both communities intend to continue producing seedlings from the nurseries for further reforestation efforts.

Figure 1: The nursery and riparian reforestation at Columbia (Daly 2010).

Overall, roughly 50% of all degraded riparian zones in both villages have been restored providing habitat, shade and bank stabilization improvements in the long-term. It is too soon to make any conclusions on its ecological effectiveness now, but in the future the collection of some biological data from these and other areas would be necessary to verify this.

(d) Education

Educational activities were recently extended into the Monkey river watershed through presentations in Trio, Bladen and Bella Vista to a total of 120 students. Content focused on an introduction to the principles of freshwater ecology, river to reef connectivity, impacts of land-use practices and ways to alleviate or prevent these. After these the teachers were particularly interested in adopting some of this information into their school's curriculum and suggested that TIDE share this information with other staff. While it is difficult to gauge the initial success of these activities, environmental awareness is a major pillar in sustainability and will prove valuable for future cooperation with communities. Additionally, significant potential exists to include more opportunities for raising understanding of climate change and its impacts.

5. Adaptation to climate change through integrated watershed management

(a) Monitoring

With the potential impacts mentioned in section 3, the monitoring programme will have to continually adapt if it is to detect changes within the Rio Grande and Monkey River watersheds. Currently, there are three potential hydrological or ecological components for expanded data collection activities: flow regime, freshwater biotic communities and riparian biotic communities.

(i) Flow regime

The amount of water within a river system and its residence time effects nutrient and ion concentrations and influences the availability of microhabitats. Stream flow is directly related to the quantity of water transferring from a watershed into a river and is determined by measuring the volume of water passing a particular point over a fixed time period (Carr & Neary 2006). Weather events control stream flow, so it will fluctuate depending on precipitation and temperature levels. These daily, seasonal or annual fluctuations will influence the amount of suspended and dissolved material in a river and determine the rate this is delivered downstream or to marine systems. If climate change is anticipated to alter the frequency and severity of wet and dry periods, understanding how stream flow is changing will prove important if management activities are to alleviate its impacts. To measure flow in the field, TIDE would use the same flowmeter as YCT (Valeport Flowmeter: BFM001/002**)** to ensure comparability of results throughout the MMMC. Additionally, precipitation and climate data collected by Hydromet could be obtained for each watershed in order to understand their hydrological responses. This could be analysed on a yearly basis to give a cumulative frequency distribution, which would enable us to detect changes in river flow over time and act as an indicator of watershed health due to its relationship to various land-uses.

Objective: Obtain equipment, begin monitoring flow within the Rio Grande and Monkey River watersheds and analyse data after one year.
Outcome: Reliable dataset and an understanding of the relationship between rainfall and flow in each watershed.

(ii) Freshwater biotic communities

Benthic macroinvertebrates are an important component of freshwater ecosystem functioning, controlling algae abundance through grazing and acting as a food sources for organisms at higher trophic levels. Individual macroinvertebrate species and community structure can be very good indicators of local ecological conditions due to their limited migration patterns and varying responses to stress. In Belize, research is currently underway through YCT to develop a biological monitoring protocol that includes macroinvertebrates as well as phytobenthos (Carrie 2009b). This will likely prove to be a valuable future tool for monitoring freshwater ecosystem response to land-use and climate changes. It could also aid in the understanding of the relationships between stream flow and changes in marcoinvertebrate populations. To ensure continuity throughout the MMMC and the monitoring of climate change impacts TIDE could adopt these methods for the Rio Grande and Monkey River. Biological training will be available through the YCT project but resources will be required to dedicate staff time, acquire equipment and establish monitoring sites; there is also the possibility of training community stakeholders.

Objective: Implement macroinvertebrate and phytobenthos monitoring at high impacts sites within the Rio Grande and Monkey River watersheds.
Outcome: Ability to accurately detect freshwater ecosystem degradation resulting from land-based activities and climate change.

(iii) Riparian biotic communities

As a transition zone between land and freshwater, riparian zones perform a variety of physical and biological functions that are crucial for the regulation of the freshwater environment. With their longitudinal pattern they provide corridors across watersheds that control the flow of water, nutrients, sediment and species. They are composed of a high diversity of woody vegetation from shrubs providing habitat for small mammals to trees offering nesting and perching sites for birds. Riparian biotic communities are shaped by numerous factors including flood frequency/intensity and variations in stream flow, which are in turn controlled by weather events. Even small future changes in flow regime resulting from climate change may induce detectable changes in vegetation structure (Nilsson & Svedmark 2002). Additionally, bird communities are known to be sensitive to disturbances in riparian habitat resulting from human activities (Croonquist & Brooks 1993).

Species diversity is considered an important index of riparian integrity (Innis *et al.* 1999); however, there are currently no assessment methods for Mesoamerican rivers. Establishing some biodiversity baselines through the Rio Grande and Monkey River watersheds would start to provide information for comparison with future changes. The initial focus could be on plant, tree and bird diversity and when integrated with stream flow and human impact mapping observations it would enable us to link cause and effect. This could prove particularly useful in areas with high levels of channel modification due to gravel mining.

Objective: Establish bird and vegetation transects in both low and high impact riparian zones within the Rio Grande and Monkey River watersheds.
Outcome: Baseline report on the relationship between biodiversity and riparian condition.

(b) Management

The effective management of freshwater resources around the world is widely accepted to come from the understanding of the interrelatedness between people, terrestrial ecosystems and rivers (Folke 2003). Some general themes of integrated watershed management - connectivity, community participation and riparian integrity - already exist in TIDE's water quality work; however, it is not an explicit guiding principle that guides freshwater conservation and development activities. The future sustainable management of MMMC watersheds will be highly dependent on the knowledge, cooperation and adaptive capacity of river communities. After all, it is the people living and working within these watersheds that will ultimately make the land-management decisions that have the potential to improve or degrade freshwater ecosystems under climate change. Decentralized management institutions at multiple scales (i.e. village/watershed/district) have been found to be a necessary characteristic of successful freshwater resource management (Carpenter & Biggs 2009). One option for MMMC watersheds would be the creation of groups within each village to take the lead in managing their watersheds and respond to future changes.

(i) Watershed stewardship groups

YCT is currently implementing a programme to establish watershed stewardship groups (WSG) within Medina Bank and Big Falls to encourage people to participate in freshwater management activities. These are intended to function as models for other communities to adopt, so if they are successful TIDE could assist with their further establishment through the Rio Grande and Monkey River watersheds. Community stakeholders (farmers, teachers, women, students, leaders, etc.) could be engaged through “our freshwater future” discussion groups or workshops within each village. This would allow people to begin thinking about the opportunities and challenges climate change might present and to build on previous efforts to raise levels of ecological understanding. This process would aid in the formation of the WSG's, allowing people to consider how their actions impact rivers and make decisions on how freshwater conservation projects could fit into their land-use practices. As river stewards they would play an important role within the community in raising awareness, monitoring river condition and influencing people to act sustainably. Communities within each watershed could then link their activities together through a larger-scale group that would consist of representatives from each WSG and local environmental NGO's (e.g. TIDE, YCT), allowing for the exchange of knowledge and information. There would have to be an effort to involve stakeholders from business interests including Hydro-Maya on the Rio Grande and the Banana Growers Association on Monkey River, if water quality measures are to be integrated into their operations. TIDE could take the lead to ensure the establishment of these groups but thereafter the respective communities should have the will and knowledge to self-organise.

Objective: Conduct a stakeholder and scenario analysis for the Rio Grande and Monkey River watersheds to engage communities and establish WSG's.
Outcome: Increased understanding and awareness of climate change/impacts of land-use; community making decisions relating to river conservation, transfer of knowledge between communities and capacity to respond to future challenges.

(ii) Riparian reforestation and agroforestry

As temperature increases and precipitation decreases, intact riparian forests will continue to perform their crucial roles through bank stabilization, water retention and microclimate regulation. So current rates of community reforestation will have to be maintained and increased in order to conserve at least the 66ft legal setback. As mentioned above, the riparian areas close to San Marcos on the Rio Grande have been identified as suffering from a high degree of deforestation due to *milpa* farming and have subsequently begun to severely erode. This area should now be a priority area for reforestation however, the San Marcos community is highly dependent on this section of floodplain for its fertile soils on which to grow maize. The cultivation of this land is therefore a necessity for the maintenance of food security within the community and any efforts at reforestation alone are likely to experience significant resistance. Agroforestry, the combined use of shade trees and agricultural crops, represents a viable option for habitat enhancement/riparian restoration and livelihood development. They have been found to increase forest connectivity, which will be important for species migrating between protected areas due to shifting climate conditions. Furthermore, diversified agricultural production that allows communities to generate a higher income has been found to reduce their dependence on forest resources, potentially having benefits for TPPL (Masozera & Alavalapati 2004). The availability of a range of crop species would reduce the community's vulnerability to maize crop failures that may result from climate variability. YCT are developing model farms that could be used to demonstrate agroforestry techniques, while workshops and continued support from the terrestrial biologist would be required to maintain and build capacity within communities. If TIDE is to measure the success of projects such as these it will be necessary to monitor the relevant physicochemical or biological indicators at the corresponding section of river.

Objective: Implement an agroforestry and riparian reforestation project along the Rio Grande with the San Marcos community.
Outcome: Bank stabilization, habitat restoration, agricultural diversification, landscape connectivity, resilience to crop failures and reduced flooding risk.

(iii) Education/awareness

Understanding and awareness within local communities of unsustainable land-management practices and their consequences for freshwater and marine ecosystems within the MMMC is growing through both TIDE's and YCT's efforts. The discussion groups and the WSG's mentioned above would serve an important role in generating an understanding of rivers and can be combined with the distribution of some easy to understand reading materials. YCT are currently developing a document on agricultural best-practices for farmers within the Golden Stream watershed and a poster/short film on river to reef connectivity. TIDE could add to this through materials or workshops that are dedicated to explaining what climate change is and how it may affect people's use of rivers.

Objective: Develop climate change workshop content and implement in six villages (three in each watershed) plus leaflet/poster materials for distribution amongst community members within the Rio Grande and Monkey River watersheds.
Outcome: Increased understanding of climate change, its freshwater impacts and options for adaptation.

6. Conclusions

High resolution climate scenarios for Belize up to 2020 and 2080 indicate the possibility of reduced precipitation and higher temperatures, particularly during the wet season. These changes will shift the conditions to which Toledo's freshwater ecosystems have adapted to over recent millennia, consequently impacting their biodiversity and benefits to local communities. TIDE's freshwater programme is currently focusing on monitoring physicochemical indicators, participatory riparian reforestation and education. The past year's activities have three main achievements: 1) the completion of a human impact mapping exercise that involved UB students and community members and successfully identified the sources and locations of riparian stresses within the Rio Grande watershed for restoration activities; 2) the establishment of a reliable water quality dataset for the Rio Grande and Monkey River watersheds, which will now serve as a baseline to determine the natural state of these rivers allowing us to make future conclusions on the level of human influence over freshwater ecosystems within the MMMC; 3) community reforestation projects on the Columbia and San Miguel tributaries that restored 50% of degraded riparian areas, building on the knowledge and trust established through a previous project in the area and allowing villagers to participate in environmental management. However, due to the emerging threats that climate change now poses to Toledo's rivers, it is necessary that the freshwater programme develops and adapts in order to detect future change and enable communities to respond appropriately. More specifically it is proposed that TIDE begins monitoring flow regime, freshwater biotic communities and riparian biotic communities. These extra components will serve as indicators, allowing us to assess the impacts of climate change and determine the appropriate management responses. The formation of watershed stewardship groups consisting of community stakeholders, following YCT's activities in the Golden Stream, would allow communities to consider the opportunities and challenges of climate change and enable them to make decisions concerning the management of the rivers they use. The expansion of reforestation and an agroforestry project within the San Marcos community would aim to restore degraded riparian zones on the Rio Grande and increase landscape connectivity at the same time as developing alternative livelihoods that are resilient to the impacts of climate change. Further educational activities would include the development of climate change workshops and materials that will aid in the understanding of its impacts on people, rivers and food security.

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