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Charlotte Steeves
SIT Graduate Institute - Study Abroad

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Water Quality in Relation to Land-use of the upper 62.8 Kilometers of the Santa Maria River, Santa Fe, Veraguas Using Benthic Macroinvertebrates as Indicators

Spring 2016

Charlotte Steeves

SIT Panama: Tropical Ecology, Marine Ecosystems, and Biodiversity Conservation

I. Abstract

The Santa Maria River spans approximately 148 kilometers from its headwaters in the district of Santa Fe, Veraguas to its mouth at the Golfo de Parita, Herrera. The objective of this study was to determine the relation between land-use and site-specific water quality using benthic macroinvertebrates as indicators. To assess water quality of the upper portion of the Santa Maria River, benthic macroinvertebrates were collected at 10 points within the river from Santa Fe national park to the town of San Francisco, approximately 62.8 kilometers. This study examines how land-use near the banks of the Santa Maria River effect water quality, taking into consideration both point and non-point sources of pollution within the watershed. Sample areas encompassed a variety of land-uses throughout the watershed. Water quality was assessed at each sample site by measuring dissolved oxygen levels, pH, river flow, percent canopy cover, and water temperature. Benthic macroinvertebrates were collected using a 250-µm mesh D-Frame kicknet in 3 riffle habitats per site and identified and ranked based on pollution tolerance using the EPT index. The site-specific water quality was determined for each location and assessed based on the primary land-use within the immediate area around each river sample site. The water quality at each point was ranked as either very good, good, intermediate, or disturbed according to the EPT index and the benthic macroinvertebrates collected. Land-use and land-cover percentages of the surrounding area of the river were evaluated using geospatial data and direct observation. Generally, percent forest cover decreased with distance from Santa Fe and the area surrounding San Francisco was primarily cattle ranches and farms. It was observed that water quality decreased as distance from Santa Fe increased and as elevation decreased. The analysis of sample site water quality values ranked this portion of the Santa Maria River as good water quality overall, however, some of the sites further downstream near ranches and farms were ranked as disturbed. Therefore, this study supports evidence that the variety of water quality rankings of the upper portion of the Santa Maria River from Santa Fe to San Francisco are dependent on primary land-use of the area surrounding the river.

II. Acknowledgments

Many thanks to the members of the Santa Fe community, Veraguas, Panama who allowed me to access the Santa Maria River through their properties and who provided me with useful information about agricultural land-use of the surrounding area. Thank you to the staff of Hotel Santa Fe, for all of their support throughout my time in the area.

Also thank you to my research advisor, Viterbo Rodriguez, and academic director, Aly Dagang, for their knowledge and patience throughout my entire research process. Thank you to my guide Patricia Peña for her kindness, patience, and knowledge of the Santa Maria River, without which my project would have been impossible.

Last but not least, thank you to my Dad, Pete Steeves for helping me analyze my geospatial and watershed data. Thank you for providing the moral support that helped me every day of my Independent Study Project.

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III. Introduction and Literature Review

1. *Background information and justification for research*

Freshwater riverine networks are among the world's most biodiverse ecosystems, occupying approximately 0.8% of the earth's surface and housing just over 6% of all known species (Dudgeon et al 2006). The vast diversity of species within riverine habitats, along with the ecosystem services provided by rivers and streams, make freshwater ecosystems an overriding conservation priority (Brauman et al. 2007; Dungeon et al. 2006). Water quality refers to the chemical, physical, and biological characteristics of a body of water and the measurement of its condition related to the requirements of one or more biotic species or for human usage (Lombardo and Rodríguez 2008). Functionally intact freshwater ecosystems provide essential services to society, among them purification of human and industrial wastes, habitat for plants and animals, and nutrient cycling (Baron et al. 2003). The maintenance of good water quality in rivers and streams is essential to almost all life on earth, but riverine ecosystems are also one of the hardest habitats to manage due to their vulnerability in a changing landscape. Though water quality can be impacted by natural occurrences such as seasonal variation and weather, the majority of extreme impacts arise from anthropogenic factors such as polluted runoff and changes to land-use and land-cover (Meybeck 2006).

It is estimated that one of the largest global water quality threats is land-use change, especially in rapidly developing countries. Currently, tropical ecosystems are experiencing some of the most rapid development and changes to land-use and land-cover, though tropical water quality data is understudied and in many cases, undocumented (Uriarte et al. 2011; Wantzen et al. 2006). The lack of data surrounding tropical riverine ecosystems make them of upmost conservation priorities and it is crucial that more studies focus on documenting water quality to safeguard these freshwater resources and guide land-use decisions (Dungeon et al. 2006; Brauman et al. 2007). The vast diversity supported by tropical freshwater ecosystems stands in contrast to the limited knowledge surrounding their water quality. Furthermore, changes to land-use and land-cover heavily impact the morphology and function of a river network by introducing toxins, pollutants, and organic matter into its waters from various sources (Congalton et al. 2014). Thus, there is a pressing need for more studies to monitor annual fluctuations in water quality as land-use continues to change in the tropics (Arguello et al. 2010; Wantzen et al. 2006).

2. *Area of interest*

The Santa Maria River, approximately 148 kilometers from its headwaters in the district of Santa Fe, Veraguas to its mouth at the Golfo de Parita, Herrera, runs through the heart of Panamas cattle production region. The Santa Maria River is an important resource to the communities within the watershed who use its waters for bathing, drinking, and irrigation, though there is a lack of continuous data to monitor and compare annual water quality fluctuations of its waters (Venegas et al. 2012). As it snakes its way across the landscape towards the Pacific Ocean, it passes through a land-use gradient of mixed-use and rural areas, countless ranches, farms, and agricultural fields, all contributing polluted runoff into its waters. This region of Panama experiences a range in temperature of 23-28 degrees centigrade annually with average precipitation of 2,265mm per year, 90 percent of which falls during the months of June to December (Faustino et al. 2009).

Tropical riverine networks are especially vulnerable to the effects of land-use change as more land is cleared to make room for urban and agricultural development in rapidly developing tropical countries (Wantzen et al. 2006; Uriarte et al. 2011). It is estimated that one of the most significant land-cover changes tropical landscapes are experiencing is the conversion of riverine buffer zones to agricultural land (Lewis 2008). A watershed is an area of land which drains water, sediments, and dissolved ions into a common outlet. The Santa Maria River is located in the Santa Maria Watershed, which is heavily influenced by cattle culture and agricultural practice (Venegas et al. 2012). Much the land surrounding the Santa Maria River has been cleared for agricultural purposes, leading to a higher percentage of grassland and cropland areas where forests were once the dominant land-cover (Venegas et al. 2012). Excessive plowing and tillage of cropland has created a problem with erosion within the Santa Maria watershed (Venegas et al. 2012) as runoff from rainstorms carries the eroded soil, organic matter, and pesticides downslope into the river. Tropical soils are highly prone to erosion when forest cover is removed since tropical soils are older and weaker than those in temperate zones (Brauman et al. 2007). The increased discharge of pollutants from erosion and runoff into streams, rivers, and lakes leads to pollution of downstream waters and eutrophication, negatively impacting water quality (Uriarte et al. 2011).

Anthropogenic problems with water quality can arise from both point and non-point sources of pollution. A point-source of pollution can be directly observed entering a river and is easily identifiable (Bowden et al. 2015). An example of a point-source would be a pipe emptying pollutants directly into a river. Non-point sources of pollution to a river network come from a variety of pollutants, toxins, and organic matter which are carried downslope in runoff from rainfall events (Bowden et al. 2015). Therefore, non-point source pollution is heavily influenced by land-use (Uriarte et al. 2011). Non-point source pollution is harder to identify since it arises from a combination of different sources and can enter the river at different points based on amount of rainfall, slope, and elevation (Bowden et al. 2015). The majority of non-point source pollution entering the Santa Maria River will come from agricultural land-use, since the region is heavily influenced by agroindustry and cattle culture (Venegas et al. 2012).

Monitoring water quality involves finding a balance between limiting the amount of pollutants loading into the river annually without impacting the livelihood of the farmers and ranchers (Holden et al. 2004). However, without continuous annual monitoring, it is impossible to determine the functional and morphological changes occurring within a river network. The water quality of rivers and streams are being heavily and rapidly impacted in the tropics resulting in the loss of irreplaceable data that could help guide land-use planning and restoration projects (Wantzen 2006). Continuous studies of water quality in the Santa Maria River are especially important since the region is heavily influenced by agriculture and cattle ranching.

3. *The use of macroinvertebrates as water quality indicators*

One of the most widely used biological tests to determine site-specific water quality is the identification and determination of abundance of benthic macroinvertebrates. Macroinvertebrates, also known as bioindicators, are organisms living in aquatic environments under sediments and rocks, many of which are larval insects. Macroinvertebrates have long been used as indicators of riverine environmental conditions because of the wide range of tolerance to pollution among different taxa (Connoly et al. 2004). Their presence or absence, number and behavior are recognized as indicators of disorders in the physical and chemical conditions of the river network (Zeybek et al. 2014). Communities of macroinvertebrates may be impacted by natural events (flow, sedimentation rates) or anthropogenic (deforestation, organic discharges, erosion), which alter water quality (Lombardo and Rodríguez, et al. 2008).

Anthropogenic impacts, often arising from runoff carrying a high concentration of organic matter from fertilizers and manure, can degrade water quality by depleting dissolved oxygen (DO) levels in the water through eutrophication (Connoly et al. 2004). The level of DO in a river determines the community composition of macroinvertebrates, since some taxa cannot survive in areas where DO has been depleted (Connoly et al. 2004). Furthermore, agricultural runoff carrying pollutants and pesticides can degrade water quality by changing its p H and water chemistry to the point where that area of the river can no longer support certain macroinvertebrate taxa (Connoly et al. 2004). Thus, macroinvertebrates samples are assessed by looking at entire communities within a sample site, since community dynamics are heavily influenced by anthropogenic impacts to a river (Lombardo and Rodríguez, et al. 2008; Zeybek et al. 2014).

Macroinvertebrates are excellent indicators of water quality due to their stationality. They are stationary organisms, in many cases spend their larval life stage at the bottom of riverbeds and under rocks (Connoly et al. 2004). Therefore, they are site specific and can indicate water quality in a specific area. Macroinvertebrates are also frequently used as water quality indicators because they integrate changes over time. Changes to land-use and land-cover highly influence the morphological and functionality of a riverine network and thus the community dynamics of macroinvertebrates (Congalton et al. 2014; Mandaville 2002). Based on the annual comparison of macroinvertebrate taxa in the same site from year to year, it can be determined if the water quality has decreased or increased annually.

4. *Use of the EPT Index to determine site-specific water quality*

In Panama, the EPT (*Ephemeroptera, Plecoptera*, and *Trichoptera*) index is used to determine and classify site-specific water quality based on the ecological sensitivity and the percentage of the insect groups considered to be pollution-intolerant (Mandaville 2002). Macroinvertebrates are identified at the taxa level and are grouped into categories based on their tolerance to pollution. The three taxa which have the highest sensitivity to pollution and water quality change are *Ephemeroptera* (figure 1.1), *Plecoptera* (figure 1.2), and *Trichoptera* (figure 1.3). Site-specific water quality is assessed by determining the percentage of EPT taxa out of the entire sample captured at each site (Mandaville 2002). Thus, areas of good water quality will generally support a higher percentages of EPT species than areas where water quality has been degraded (Mandaville 2002). The index ranks water quality into 4 categories based on percentage of EPT taxa (table 1).

Table 1:
Classification of water quality according to the EPT index (Alvarez-Carrion & Parez-Rivera 2007; Carrera-Reyes & Fierro-Peralbo 2001).

EPT Index (%)	**Quality of water at site**
75-100	Very Good (no impact)
50 – 74	Good (low impact)
25-49	Regular (Moderate impact)
0-24	Bad (disturbed)

Figure 1.1
Ephemeroptera (Mayflies)

Figure 1.2
Plecoptera (Stoneflies)

Figure 1.3
Trichoptera (Caddisflies)

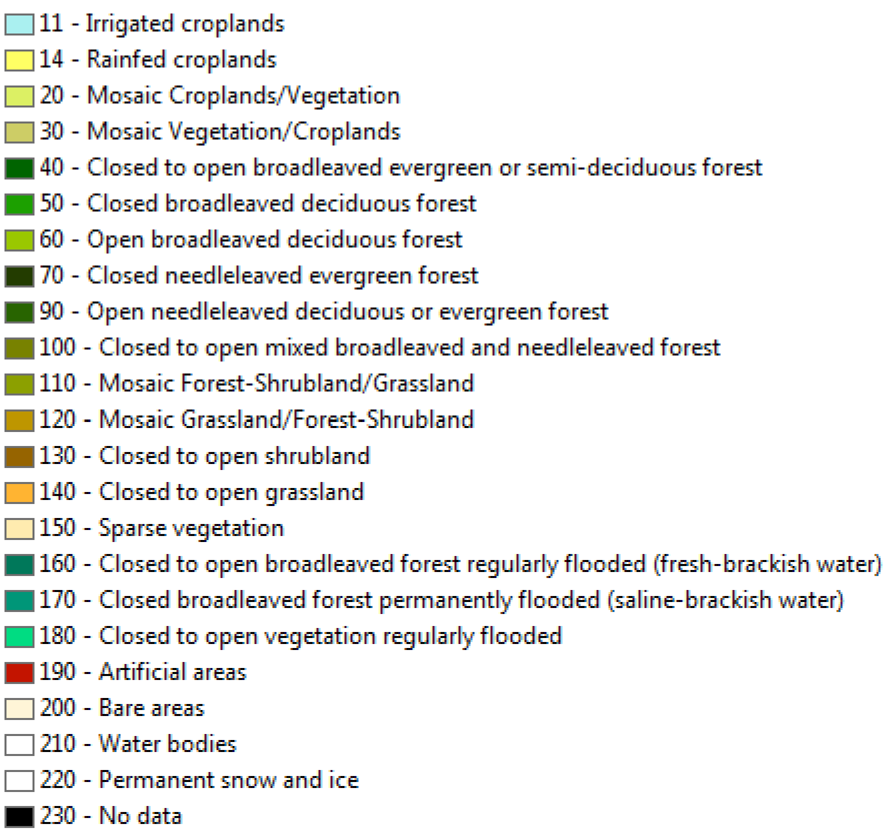
5. *Watershed boundaries and land-use summaries*

Mapping land-use and land-cover (LULC) has been done in many areas of the world with the use of satellite imagery to determine how changes to the landscape affect the environment (Reiss 2008). The Land Cover Classification System (LCCS) uses data from satellite imagery to categorize land into 22 internationally recognized cover classes defined by the Land Cover Classification System (Congalton et al. 2014). Depending on the size of an area, it can be broken down into one or more LULCs ranging from open evergreen forest to pasture land. An area of interest can be multiple LULC and can be broken down into percentages if it is a mixed-use area (Congalton et al. 2014).

LULC summaries can be viewed for an area of interest using the GLOBCover 2009 Land Cover dataset (Congalton et al. 2014). The GLOBCover 2009 Land Cover dataset is an efficient way to map and monitor global land-cover at various spatial scales using data from satellite imagery (Congalton et al. 2014). This database assesses percent of LULC within an area of interest and categorizes them by number under the classification system (Figure 2). The GLOBCover 2009 Land Cover dataset uses satellite imagery to determine primary land-use and land-cover. The GLOBCover 2009 Land Cover dataset allows user to view the land-cover summaries of an area of interest and to determine the percentage of each land-cover category within a watershed.

Drainage basins are areas of land within a watershed which will contribute runoff into smaller sections of a river network during rainfall events (Congalton et al. 2014). The GLOBCover 2009 Land Cover dataset can determine the LULC percentages for each drainage basin surrounding the river to determine how land-use within the drainage basin is impacting site-specific water quality (Congalton et al. 2014).

Figure 2:
Figure 2 shows the 22 cover classes recognized by the Land Cover Classification System (Congalton et al. 2014).



IV. Research Question

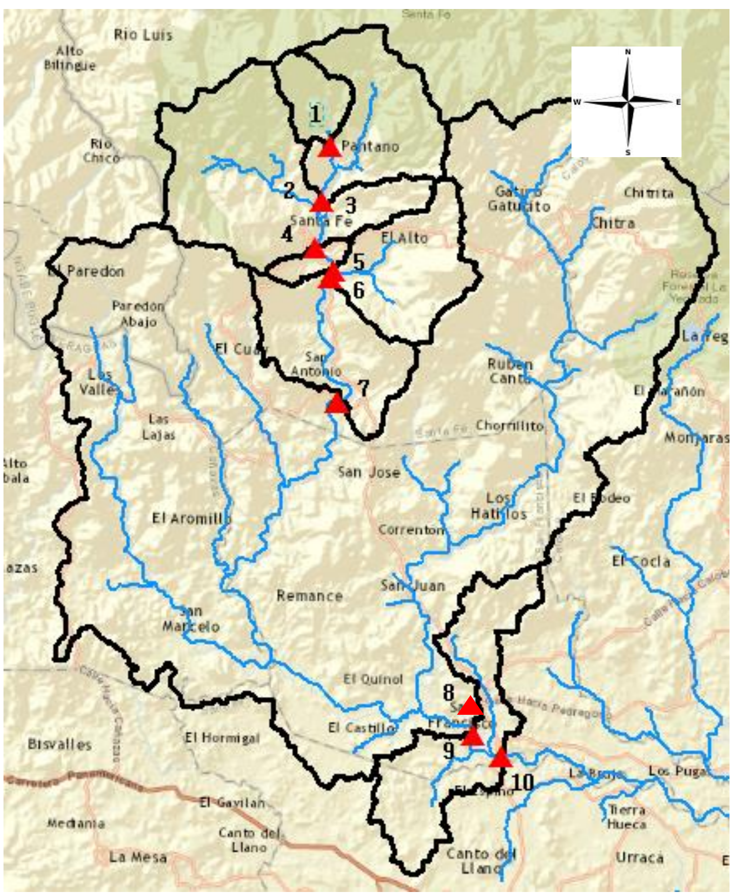
How does dominant land-use of the area surrounding the riverine landscape of the Santa Maria watershed affect the water quality of the Santa Maria River in Santa Fe, Panama?

V. Methods

1. Area of study

Samples were collected from 10 sites along the 60 km stretch of the Santa Maria River ranging from the buffer zone of Santa Fe national park to the city of San Francisco, Veraguas, Panama. The 10 points are located within a 807.5 km2 drainage basin (figure 3) which encompasses the area of land from Santa Fe to San Fransisco in which runoff will enter the Santa Maria River. The highest elevation where samples were collected was within the buffer zone of Santa Fe National Park at 421 meters above sea level. The lowest elevation where samples were collected was in San Francisco at 41 meters above sea level. The landscape of the area of study ranged from significant areas of forest cover to cropland, ranches and mixed-use rural areas. The furthest downstream point sampled was approximately 62.8 kilometers from the starting point in El Pantano, Santa Fe.

Figure 3:
Figure 3 shows a map of the drainage basins surrounding the 10 points surveyed along the Santa Maria River. Each of the 10 points are labeled along the Santa Maria River in red triangles to show the different sample locations and drainage basins (U.S. Geological Survey Earth Resources Observation and Science Center 1997).



2. *Macroinvertebrate Sampling*

Macroinvertebrate samples were collected over a 2 week period during the dry season from the dates of April 14th, 2016 to April 23rd, 2016. Samples were collected within 10 different points along the 60 km stretch of the Santa Maria River from El Platano just outside Santa Fe National Park to the town of San Francisco, Veraguas. At each of the 10 sample points, macroinvertebrate samples were collected at riffle habitats (relatively shallow and rocky areas along the river bank where surface water flow is impeded by rocks jutting out of the river). At each site, samples were taken from 3 riffle areas to maximize the chances of capturing rare taxa as well as to keep sample habitat constant for each site. Macroinvertebrates were collected with a 250-μm mesh D-Frame kicknet (Plotikoff and Wiseman 2001). The net was held facing upstream and the substrate on the riverbed was kicked and disturbed, allowing for free macroinvertebrates to flow into the net to be captured. Samples were then sorted for any debris and stored in 75% ethanol-filled containers for later identification (Plotikoff and Wiseman 2001). The type of substrate at each riffle habitat was classified as either silt, sand, gravel, stone, or boulder.

Using a dissecting microscope, the macroinvertebrates were identified at the taxa (order) level using the *Guia de Insectos Acuaticos en el Parque Nacional Santa Fe* (De Garcia et al. 2014). The total number of individuals per site was counted and then the macroinvertebrates were separated by taxa. The EPT index was used to establish biological quality at each sampling station (Lombardo and Rodríguez, et al. 2008). The total number of samples collected at each site were added up and then the percentage of EPT was determined. Each percentage of EPT corresponds to a water quality ranking, thus each site was ranked according to the EPT index. Water quality was assessed at each of the 10 sites by determining the percent of EPT as well as the number of EPT taxa present in each sample and using the EPT index to determine each site-specific water quality.

3. Measuring Environmental Variability at Each Site

Each of the 10 sampling sites were chosen in order to encompass a gradient of land-use and human influences on water quality, as well as accessibility. All of the sites were no more than 1 kilometer from the road. At each site, the GPS coordinates and elevation in meters above sea level were determined using a Garmin GPSMAP 64s GPS. The distance between each survey point was determined by the GPS coordinates marked at each point. The date, time, and air temp were also noted in a field journal. All survey sites were investigated between the hours of 8:30 and 10:00 AM. Direct observations of land-use, such as proximity to farm, were noted as well as the dominant type of substrate (boulders, stones, gravels, sand) for each site.

The flow rate in meters cubed per second was also determined at each site. The length of the river in meters was measured and then the depths at 3 different locations across the river in meters was determined. Using the values from each of the three measurements, the average depth of the river was determined. Standing in the midpoint of the river, three flow tests per site were conducted. The time (seconds) for a plastic container to float downstream five meters was recorded and the average seconds from each of the three trials was determined (Helson 2012). Flow was calculated by multiplying the average depth (meters) by the area sampled (length of the river cross section by 5 meters). This value was in meters cubed, a volume of river cross section. This value was then divided by the average seconds to determine the flow rate at each site in meters cubed per second.

Canopy cover percentage was determined at each site using a densitometer (Argillo et al. 2007) by standing in the middle of the river cross section at each site. The Dissolved oxygen level percentage and the temperature of the water in degrees centigrade were measured using a DO meter at each site. The pH of the water at each site was also determined using a pH meter to determine how these variables differed from site to site and with proximity to farms or cropland. These measurements accounted for the natural and anthropogenic variations within the riverine network (Meybeck 2006).

4. Determining Land-use and Land-cover

At each site, direct observations of the primary land-use surrounding that part of the river were noted as well as well as the general conditions of the river (algae on rocks, if a dam was present, if there were cattle using the river to drink).The primary land-use was broken down into 4 main categories based on the direct observations; rural mixed-use, forested, cropland, and farmland (Helson 2012). Evidence of different types of human influence were noted for each sample location as well as the proximity of each influence to the river through visualization (Plotikoff and Wiseman 2001).
The percent land-cover categories within the area of interest around the Santa Maria River were examined using the GLOBCover 2009 Land Cover dataset (Congalton et al. 2014).The dataset showed percentage of LULC within the drainage basins surrounding each sample point, some of which showed a variety of different LULCs. The data from the land cover summaries was then analyzed to determine the primary land-use surrounding each point based on percentage and to relate the land-use to the water quality values indicated by the EPT index.

VI. Results

In the upper 60 kilometers of the Santa Maria River, a total of 983 macroinvertebrates were captured. Out of the total number of individuals, 725 were EPT taxa (73%). According to the EPT index, the 10 points sampled within the upper 60 km of the Santa Maria River ranked the overall water quality as good. The sites downstream closest to San Francisco were ranked as regular or bad quality (Table 2). 6 survey sites were ranked as very good water quality based on the EPT index. The environmental variables varied upon location (Table 3) as well and a general trend of decrease in water quality with distance from starting point was observed (Figure 4). The five furthest upstream points were 1, 2, 3, 4, and 5 which all correspond to very good water quality rankings based on EPT percentage (85%). The two middle points were 6 and 7, which had an average rank of good water quality based on EPT percentage (78%). The three points furthest downstream were 8, 9, and 10 which had an average rank of bad water quality based on EPT percentage (29%).

Table 2

Table 2 shows the varying water quality ranks and primary observed land-cover per location. The sites varied in elevation and distance from the national park in Santa Fe. The starting point furthest upstream in the Santa Maria River is shown highlighted in yellow. The furthest downstream point is shown highlighted in blue.

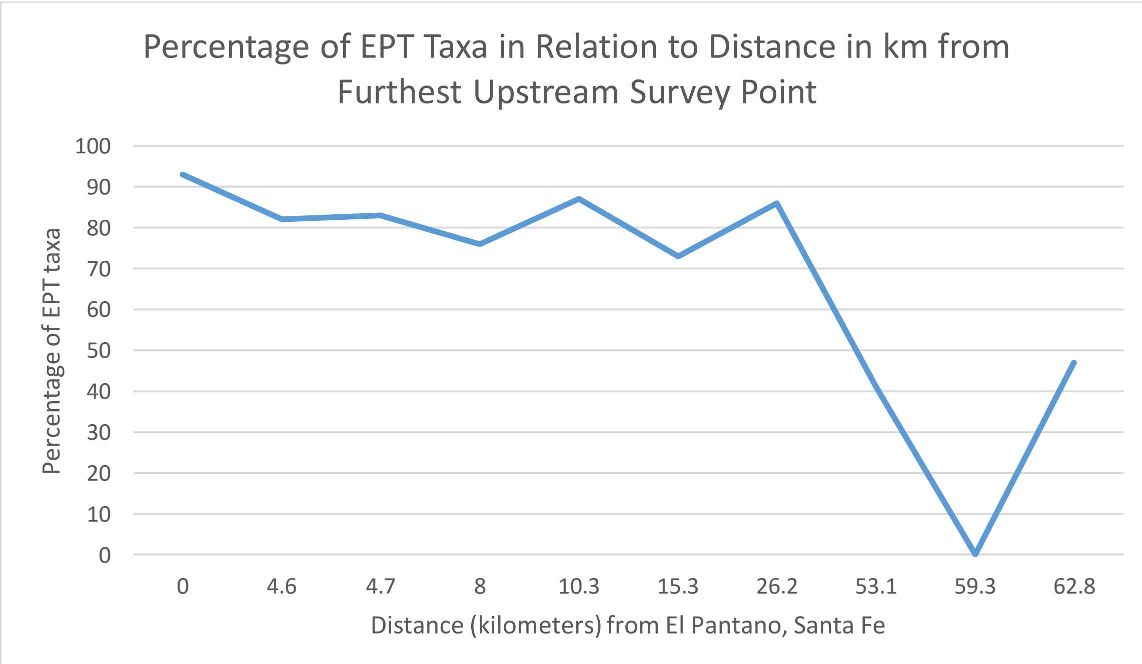
Location	Total # Macros	EPT %	Water quality rank	Elevation meters above sea level	Primary land-cover from direct observation	Distance from starting point (Kilometers)
1	183	93%	Very good	421	Forested	0
2	100	82%	Very good	282	Forested	4.6
3	116	83%	Very good	290	Forested	4.7
4	117	76%	Very good	289	Forested	8
5	193	87%	Very good	314	Forested	10.3
6	71	73%	Good	255	Mixed-use rural	15.3
7	60	86%	Very Good	194	Mixed-use rural	26.2
8	66	41%	Regular	41	Farmland	52.1
9	1	0%	Bad	55	Farmland	59.3
10	76	47%	Regular	58	Cropland	62.8

Table 3:

Table 3 shows the environmental variability between testing sites.

Site Number	Flow rate (meters cubed/sec)	Dissolved Oxygen (mg/l)	pH	% Canopy cover
1	4.42	21.6	8.6	22
2	3.81	21.4	9.1	12
3	5.6	20.3	8.6	7.2
4	7.2	21.5	9.1	2.3
5	8.7	19.7	8.3	22
6	8.7	19.7	8.3	22
7	20.7	20.6	8.1	14
8	16.3	17.2	8.2	4
9	3.9	16.7	8.1	22
10	6.6	18.3	8.2	2

Figure 4:
Figure 4 shows a trend in decreasing EPT percentage as distance from starting point increased. The starting point was El Platano, Santa Fe (point 1) and the furthest downstream survey point was taken approximately 62.8 kilometers in San Francisco (point 10). Point 1 is shown at a distance of 0 kilometers. Point 10 is shown at a distance of 62.8 kilometers from point 1.



1. Locations and survey notes of the 10 survey points

Point 1: Location 9 was the highest in elevation at 421 meters above sea level and was located in the buffer zone of Santa Fe national Park in El Pantano. It was the furthest upstream point surveyed along the Santa Maria River. This location was the closest survey site to the headwaters of the Santa Maria. There were no signs of eutrophication and the area was completely forest cover.

Point 2: Located in Santa Fe at elevation of 282 meters above sea level. The survey point was a 0.5km walk from the Santa Fe hotel. The observed land-use was mostly forest cover with a few scattered homes. The river had many boulders as well as areas of both rapids and smooth flows.

Points 3 and 4: Located about 5 km downstream of point 1 at 290 meters above sea level. The observed land-use was forest cover with some evidence of livestock and human usage. The rocks along the river bank were covered in algae.

Point 5: This point was located in an area of Santa Fe called La Altura at an elevation of 314 meters above sea level. It was located in a rural mixed-use area with a significant amount of forest cover. Many of the homes had livestock.

Point 6: This point was located in an area between Santa Fe and San Francisco called Los Corrales at an elevation of 255 meters above sea level. There was a human-built dam made of large rocks stretching about halfway across the river at the survey point. The area is frequently used for bathing. This location was a mixed-use rural area with significant forest cover and numerous riffle areas.

Point 7: This point was taken about midway between Santa Fe and San Francisco at an elevation of 194 meters above sea level. The area was mixed-use rural with significant forest cover and scattered homes and ranches.

Point 8: Samples taken from the San Francisco area where the Santa Maria River crosses the highway at an elevation of 41 meters above sea level. This area of the river was surrounded by cattle ranches on both banks of the river. There was a cow drinking from the river as well as an abundance of trash along the banks of the river. Algal growth on rocks was observed throughout the area. Land was primarily ranches and farms.

Point 9: This point was accessed through the property of a large chicken and cow farm in San Francisco about 4km downstream of point 4. The elevation was 55 meters above sea level. This area of the river is frequently used by humans and animals. The current was much stronger than the other previous locations and there were very few riffle habitats. The test site was located next to the water treatment plant for San Francisco.

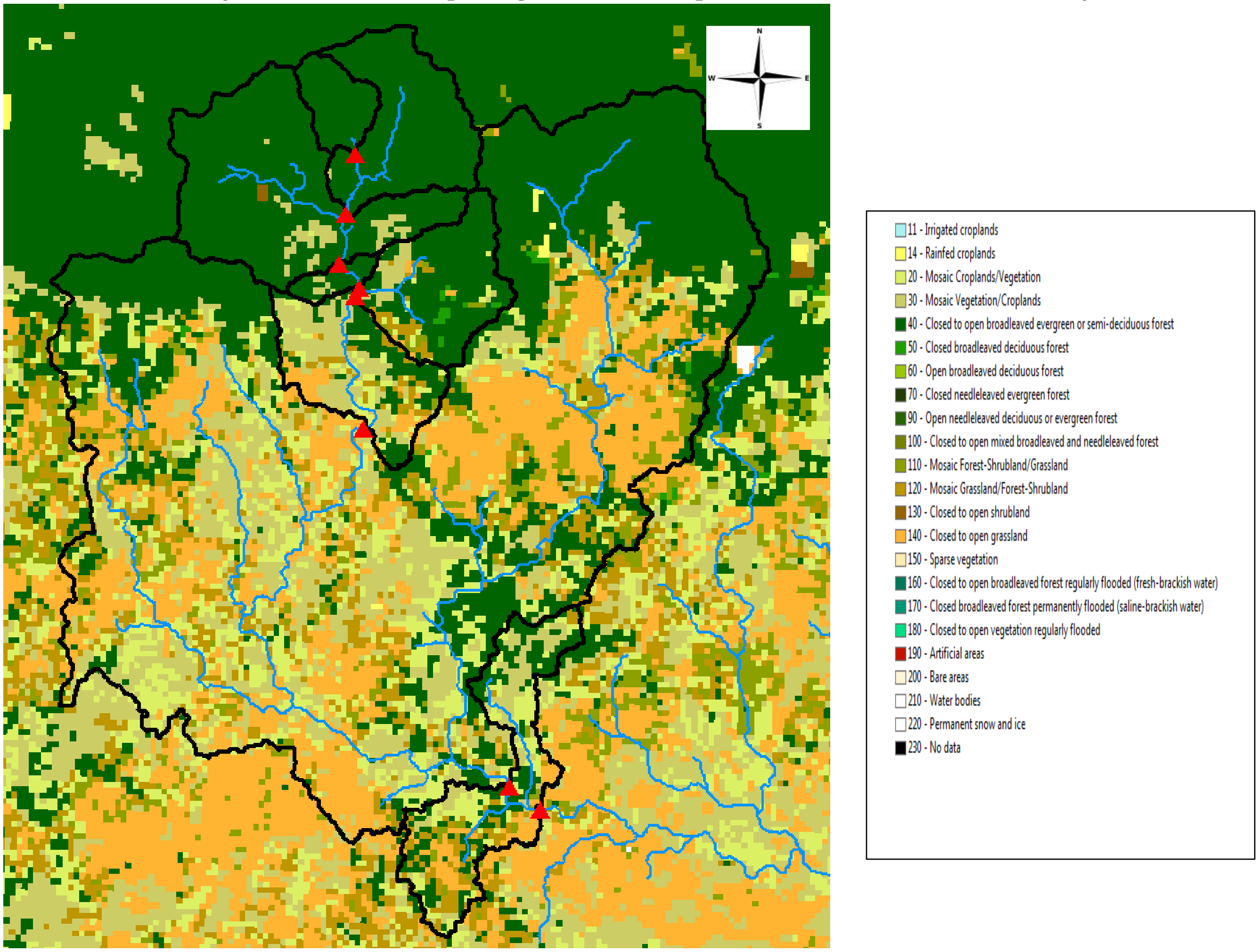
Point 10: This point was the furthest away from Santa Fe, approximately 62.8 km downstream from el Pantano. The elevation was 58 meters above sea level. The survey location was about a 2km walk through an area of land which had been cleared for rice crop. There was also evidence of cattle ranching. The stones along the banks of the river were covered in algae.

2. *Land-use and land-cover percentages per site*

The 10 sample points surveyed along the Santa Maria River were broken down into 6 different land cover classes (Table 4). The land-use at each of the 10 points were broken down by percentage and assigned a value based on the land-cover class key (Figure 5). The represented land cover classes found within the 62.8 km stretch of the Santa Maria River from Santa Fe to San Francisco are variations of mosaic cropland (LU20 and LU30), closed-open broadleaf evergreen forest (LU40), and variations of shrub land/grassland (LU110, LU120, LU140). Out of the 60 km stretch of the river sampled, the average percentage of forest cover was 79.4%, the average percentage of cropland was 10.7% and the average percentage of grassland/shrub land was 11%. The land-cover percentages show 6 different land-cover classes for the area studied. Forest cover decreases from 100% in El Pantano, Santa Fe to 43% at the three survey points in San Francisco.

Figure 5:

Figure 5 shows the delineated watersheds surrounding the 62.8 kilometer stretch of the Santa Maria River surveyed. Each colored pixel grid cell corresponds to the land-cover class key.



European Space Agency. (2009.) Land cover, Central and South America (GlobCover 2009).

Table 4:
This table shows the percentage of land-use (LU) at each point as determined by the values assigned by the land cover class key.

Point	Percent Land Use (LU)					
	LU20 cropland	LU30 cropland	LU40 forest cover	LU110 grassland/shrub land	LU120 grassland/shrub land	LU140 grassland/shrub land
1	0%	0%	100%	0%	0%	0%
2	0%	0.2%	99.8%	0%	0%	0%
3	0%	0%	100%	0%	0%	0%
4	0%	3%	97%	0%	0%	0%
5	0%	3%	96%	0%	1%	0%
6	0%	5%	92%	0%	3%	1%
7	3%	11%	80%	1%	3%	2%
8	1%	16%	44%	5%	6%	17%
9	11%	16%	42%	4%	8%	18%
10	12%	15%	43%	5%	8%	18%

The three survey sites in San Francisco were points 7, 8, and 9 with an average of 43% forest cover. The areas with the highest percentage of forest cover were points 1, 2, 3, 4 and 5 which were all located in the Santa Fe area. All of these points have an average of 98% forest cover. The points located between Santa Fe and San Francisco were points 6 and 7, with an average of 86% forest cover. Out of the 62.8 km of the Santa Maria tested, the highest average percentage of forest cover was within the elevation range of 282 to 421 meters above sea level. The lowest percentage of forest cover (43%) was observed between the elevations of 41-58 meters above sea level (Figure 6).

Figure 6:
Figure 6 shows a trend of decreasing forest cover as elevation decreased. The highest percentage of forest cover among the 10 survey points was observed between the elevations of 282 to 421 meters above sea level with a forest cover percentage of 98%. The lowest percentage of forest cover among the 10 survey points was observed between the elevations of 41 to 58 meters above sea level with a forest cover average of 43%.

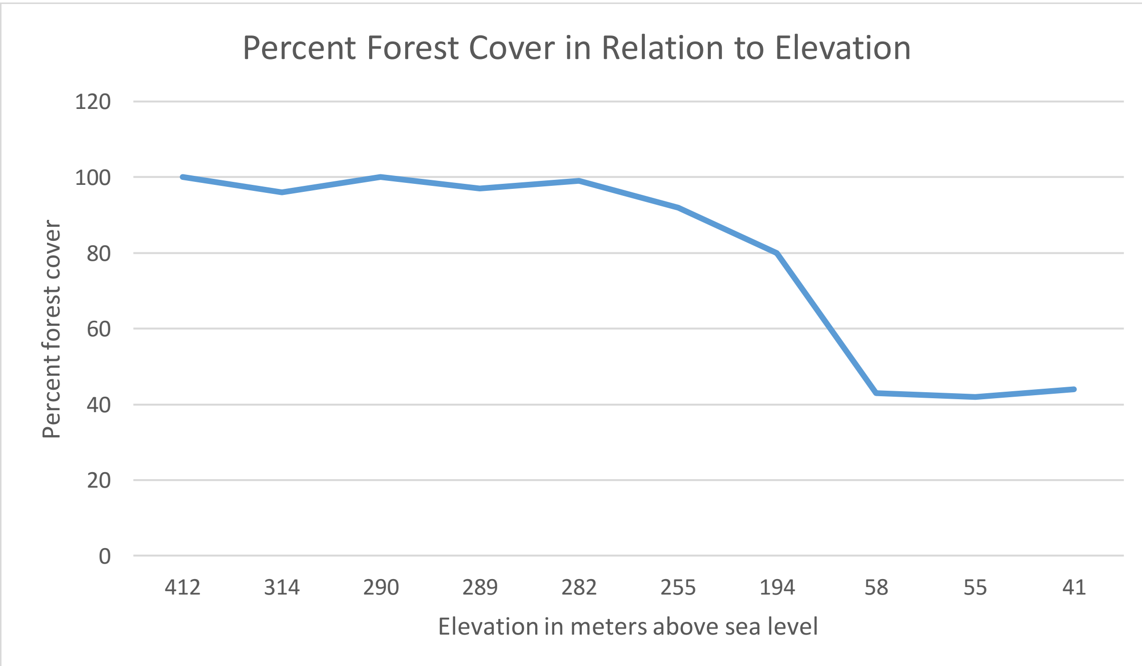
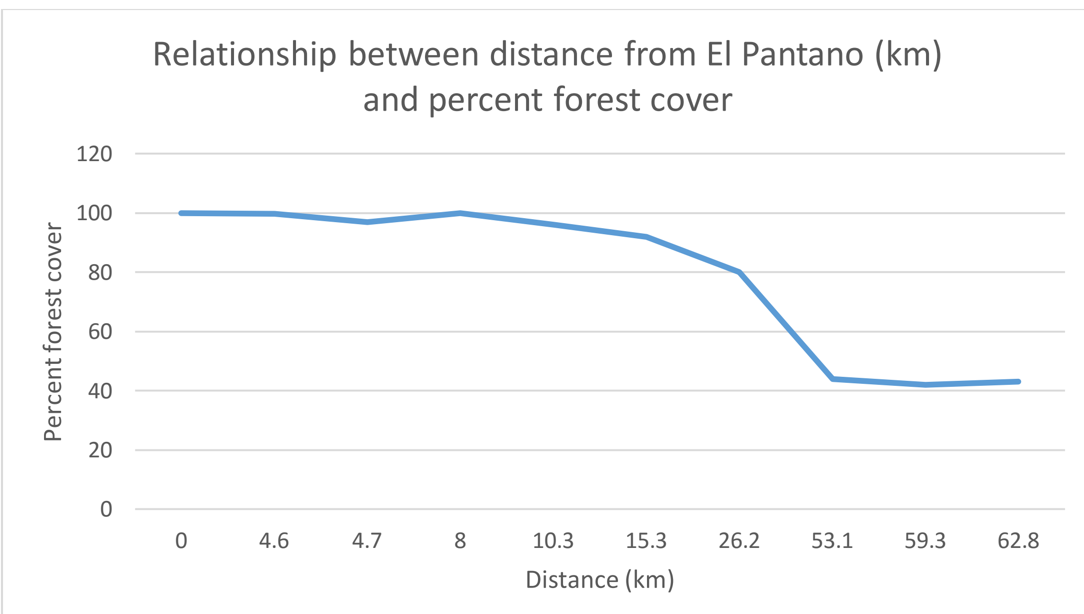
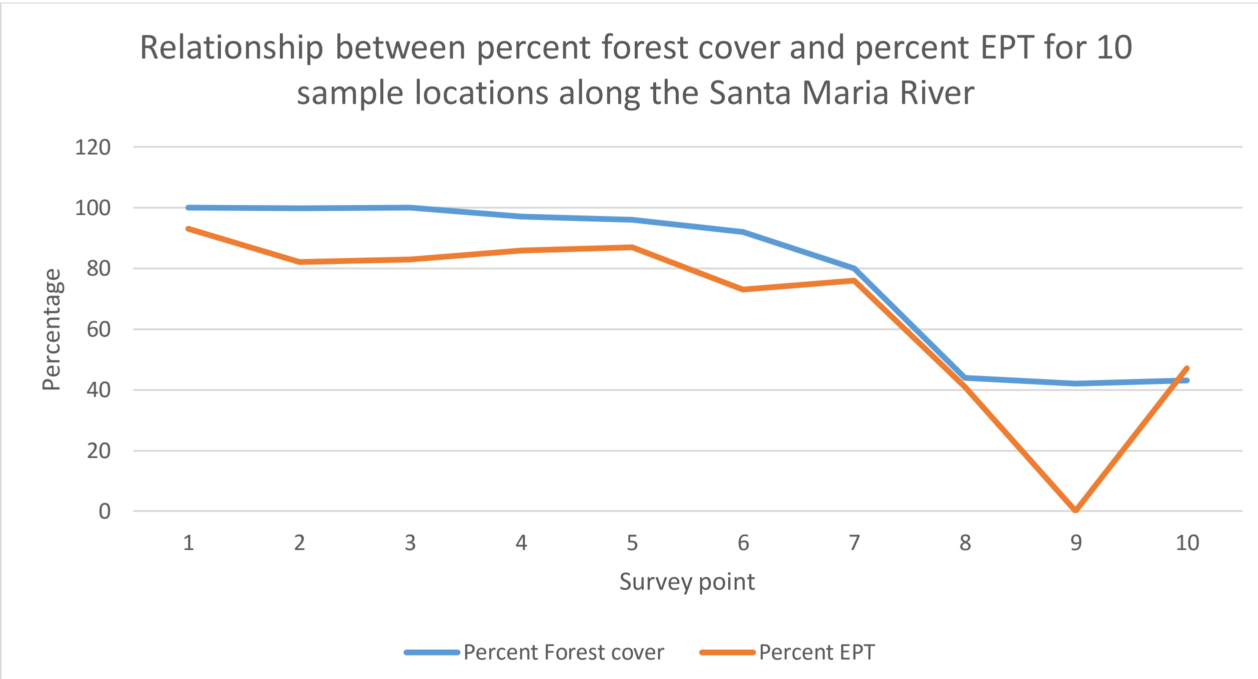


Figure 7: Figure 7 shows the relationship between distance from starting point and percent forest cover. The first survey point is indicated at a distance of 0 kilometers.



On the graph, the percent forest cover is shown from starting point 1 (0 kilometers) to point 10 (62.8 kilometers). The three survey points with the highest average of EPT percentage were sites 1, 5, and 7 with an average of 88.6%. Points 1, 5, and 7 have an average percent forest cover of 90.6%. The three survey points with the lowest average EPT percentage were sites 8, 9, and 10 with an average of 29.3%. These three points have an average forest cover of 43%. The percentage of forest cover and EPT percent for each of the 10 survey points are shown plotted together in figure 10.

Figure 8: Figure 8 plots the relationship between percent EPT and percentage of forest cover per site.



VII. Discussion

1. Water quality ranking and land-use proximity

The results of this study ranked the overall water quality of the upper 62.8 kilometers of the Santa Maria River from El Platano, Santa Fe to San Francisco as good based on the EPT percentages found at 10 different sample sites. The water quality results varied based on elevation and distance from the point furthest upstream in El Platano. The results of this study infer that the water quality of the upper 62.8 kilometers of the Santa Maria River is affected by land-use and land-cover. The survey areas with the highest percent of forested land corresponded with the highest values of the EPT percent and very good water quality rank. The middle areas tested correspond with intermediate water quality rank and an increase in percentage of land used for crops. The survey sites with the highest percentage of land used for crops and the lowest percentage of forest cover also correspond to the lowest EPT percentages and the poorest water quality rankings.

El Pantano, high up in the buffer zone of Santa Fe National Park, is surrounded by broad-leaf evergreen forest covering 100% of the land surrounding point 1. As the river flows downstream, it passes through areas of land which have been converted to cropland for agricultural use and grassland for cattle ranching. The percentage of forest cover decreases steadily as the Santa Maria River flows down towards San Francisco (figure 5, table 4). The high percentage of forest cover observed in Santa Fe could be explained by the proximity to Santa Fe National Park. Santa Fe was also higher up in the mountains where the elevation and climate might not be as suitable for crop production. Much of the land surrounding San Francisco was observed to be heavily impacted by the agroindustry, as many areas had been converted into grassland and cropland. The San Francisco area was approximately 300 meters lower an elevation than El Pantano and the land was observed to be flatter and more suitable for farming. Figures 6 and 7 indicate that percent forest cover decreased as elevation decreased and as distance from El Pantano increased.

The first 5 survey points were all between 96-100% LU40 which is classified as broad-leaf evergreen forest according to the land-cover key. These 5 sites were also directly observed to be located in areas with significant forest cover. Survey points 6 and 7 were between 80-92% LU40. Site 7, located 26.2 kilometers from El Pantano, was considered 11% LU30, 3% LU20 (both of which are different variations of cropland), 3% LU123 and 2% LU140 (both of which are considered variations of grassland and shrub-land areas). Points 8, 9, and 10, showed the highest percentage of cropland LULC and the lowest percent of broad-leaf evergreen forest LULC.

There was a general trend of decreasing forest cover based on the land-cover summaries surrounding each sample point which correlated with a decrease in EPT percentage and water quality ranking (figure 10). The first five points, located within 11 kilometers downstream of El Pantano, all showed an average of 98% forest cover. All of these sample points were ranked to be of very good water quality based on the EPT index. The two middle points (6 and 7) had an average EPT percentage of 79%, which corresponds to good water quality based on the EPT index. Points 6 and 7 also had an average of 86% forest cover. The three points furthest downstream (8, 9, and 10) had an average EPT percentage of 29%, which is ranked as bad water quality based on the EPT index. These three points, located in San Francisco, showed an average of 43% forest cover based on the land cover summaries. The graph drops down to 0 at point 6, since there were no EPT taxa found at this survey site.

Figure 10 also supports evidence of a direct relationship between percent forest cover and percent EPT. The graph plots the relationship between EPT percentage and percent forest cover for each of the 10 sites. It can be observed that both percentages follow similar trends on the graph. Areas of r high forest cover percentages correspond with high EPT percentages. Figure 10 supports evidence that forest cover had an effect on the water quality rankings of the Santa Maria River as determined by EPT percentages. Therefore, it can be concluded that as forest cover percentage decreased, so did water quality ranking in the upper 62.8 kilometers of the Santa Maria River.

A study assessing water quality of the Santa Maria River was conducted in April of 2003 and supports evidence that water quality decreases with proximity to degraded land-cover (Lombardo and Rodríguez 2008). The study focused on the mid-lower part of the Santa Maria River, with all survey points south of San Francisco. This study used macroinvertebrates to assess water quality but used a different index to rank the overall quality of this 50 kilometer stretch of the Santa Maria River. The overall water quality was found to be classified as disturbed, which corresponds to poor water quality rank (Lombardo and Rodríguez 2008). The study surveyed 13 points, determining that water quality decreased as distance from starting point increased. The study determined a gradient of water qualities, the poorest being in areas highly influenced by the agroindustry. The results of the 2003 study on the Santa Maria River support evidence that land-use affects water quality. The majority of the survey points ranked as disturbed corresponded to areas of land-use which were primarily agricultural. This study concluded that the poor water quality rankings might be related to the presence of agricultural land-use in the region surrounding the 13 sample sites.

Another study to support evidence that land-use affects water quality was conducted in Puerto Rico in 2011. The objective of the study was to evaluate the influence of land-use on tropical rivers (Uriarte et al. 2011). The study assessed percent LULC within the watersheds to determine primary land-use and land-cover. The results of the study concluded that disturbed areas had lower DO levels and poorer water quality values, which were determined through chemical analysis rather than biological (Uriarte et al. 2011). This study compared spatial variation with LULC variation between test sites. It was concluded that percent land-use and land-cover was the primary influence on water quality rather than spatial variation (Uriarte et al. 2011). The results of the Land-use study in Puerto Rico indicated that land-use rather than spatial variation was the primary factor affecting water quality. The results of this study suggest that land-use can have a greater effect on water quality than spatial variability and therefore, it is a possible factor contributing to the trends observed in the Santa Maria River.

2. Environmental variability

The environmental variables such as river flow at each site, pH, dissolved oxygen, and canopy cover varied between sites. The pH range seemed to be independent of land-use since the recorded values did not show a trend based on distance from testing site. The flow rate was also independent of land-use since this is a natural variation which changes depending on slope, width of river, and rainfall. The variable which changed the most depending on location was dissolved oxygen level. The highest dissolved oxygen level was observed at point 1, which was also the furthest upstream point. The highest 5 dissolved oxygen levels were within the first 11 kilometers downstream from point 1. The lowest 3 values were recorded at the three points furthest downstream, with the lowest value recorded at site 9. Site 9 was located on the property of a chicken and cow farm in an area which is frequently used for bathing. The proximity of this location to the farm might have contributed to the low dissolved oxygen level. This site was also in one of the areas with the lowest percentage of forest cover and the highest percentage of cropland. It was observed that the three survey sites furthest downstream also had a significant amount of algae growing on the rocks throughout the river. This can be an indication of eutrophication, which can arise from an influx of runoff carrying a high amount of organic matter. Since these three survey points were in the portion of the river with the highest percentage of land used for crops and ranches, there could be a relationship between the low levels of dissolved oxygen and the proximity of the river to land where fertilizers and manure are frequently washed into the river.

A 2004 study of two tropical Australian streams focused on the effects of low dissolved oxygen levels on macroinvertebrate community structure (Connoly et al. 2004). The results of the study determined that numerous macroinvertebrate taxa, in particular EPT taxa, are highly sensitive to changes in dissolved oxygen and will be space or absent in locations where levels are low. Macroinvertebrates from 2 rivers were exposed to varying levels of dissolved oxygen and it was observed that the threshold in which the majority of them died was at 6.5 milligrams of dissolved oxygen per liter. The study found that the pollution intolerant species were more sensitive to levels as high as 15 milligrams per liter (Connoly et al. 2004). The results of this study could explain the absence of EPT taxa observed at site 9, since macroinvertebrates range in tolerance to pollution and dissolved oxygen levels. Site 9 was ranked as bad water quality and 0 EPT taxa were collected. The dissolved oxygen level was found to be the lowest out of all 10 sample sites and could be an explanation as to the absence of specimens collected in this location.

The land-cover summaries at site 9 indicated that the land was 27% cropland, one of the highest percentages of cropland observed out of the 10 survey points. The high percentage of cropland as well as the proximity of the survey site to the farm may have contributed to both the poor water quality ranking and the low level of dissolved oxygen. EPT taxa may not have been encountered at site 9 since EPT species are highly intolerant to low dissolved oxygen levels (Connoly et al. 2004).

Canopy cover appeared to be independent of land-use since the width of the river at each of the testing sites varied greatly. The percent canopy cover was determined by standing in the midpoint of each stream cross-section and thus width of the river rather than forest cover percentage would most likely be the determining factor.

3. Possible sources of error

Though there is much evidence to support the trend that water quality rank is dependent on land-use and land-cover, it is difficult to determine whether the EPT percentages at each site were related to land-use or related to elevation. The EPT percentages decreased as both elevation and percent forest cover decreased. For this reason, it is unclear whether the anthropogenic effects of the changing land-use gradient from primarily forest cover in Santa Fe to cropland and ranches in San Francisco were affecting water quality ranking at each site. However, it can be inferred that primary land-use affected the water quality rankings at downstream sample sites, all of which were located close to farms and croplands. The sample sites furthest downstream in San Francisco all showed evidence of eutrophication, which could arise from an influx of organic matter from manure and fertilizer. The lowest dissolved oxygen levels out of the 10 survey sites were observed in the three points in San Francisco. Low dissolved oxygen levels are a sign of eutrophication and can subsequently result in poor water quality rankings.

Another possible source of error could have arisen from the sample location bias. Sample sites had to be chosen based on accessibility and subsequently, many sites were of close proximity to roads and frequently used paths. Furthermore, five out of the 10 sampling sites were located within 11 kilometers downstream of the first sampling site in El Pantano and therefore land-cover summaries showed a high percentage of forest cover for these five sites. There were only two sample sites taken from the middle section of the area of study and only three samples taken from the San Francisco area. For this reason, there may not have been enough sample points in the mid-section and the lower section of the Santa Maria River to conclude a relationship between land-use and water quality.

Since this study was only conducted during a two week period, it is hard to draw any generalized conclusions between water quality and land-use. More in-depth studies normally require several years worth of monitoring to more accurately determine if water quality is changing based on changes to land-use. Furthermore, this study was conducted during the dry-season when there is a very small amount of rainfall. It did not rain once during the duration of this study. The water quality ranks and EPT percentages determined for the Santa Maria River during this study could vary greatly if the same study was conducted during the wet season. The increase in runoff from frequent rainfall events could potentially carry a larger amount of toxins, pollutants, and organic matter downslope into the river and contribute to decreased EPT percentages and poorer water quality rankings. The EPT percentages and the water quality rankings determined for this study could be in part due to the fact that there was no runoff during this time of the year. A more accurate study would encompass data from both the wet and the dry season since rainfall and runoff heavily impact the water quality of a river.

A 2012 study examined the structure of tropical macroinvertebrate communities across a changing land-use gradient (Helson 2012). Macroinvertebrate community structure varied greatly between the wet and the dry season due to the influx of runoff during the wet season. The results of the study indicated that the presence of macroinvertebrate taxa was not only affected by the changing land-use gradient, but also by seasonal variation. It was observed that some taxa present in survey areas during the dry season were absent or in lower numbers when the same areas were surveyed during the wet season (Helson 2012). For this reason, another possible source of error for the Santa Maria study could arise from the fact that samples were only collected during the dry season in this region of Panama. EPT percentages determined for this study can only be used to assess water quality during the dry season in this region of the Santa Maria River. The data for this study can be expected to change from dry season to wet season.

VIII. Conclusions

The objectives of this study were to assess water quality in 10 different locations within the upper 62.8 kilometers of the Santa Maria River using macroinvertebrates as indicators and to see how the water quality changed with proximity to different land-uses. The objectives were achieved by assessing both site-specific water quality using EPT percentages and by determining percent land-cover using the land-cover summaries at each of the 10 points. It was observed that water quality ranks correlated to the primary land-use and land-cover at each site. Throughout the study, it was determined that water quality rankings decreased as forest cover decreased. Subsequently, water quality rankings were found to be poorer in areas with higher percentages of land used for cropland and farmland. Overall, the results indicate a trend between decreasing forest cover and decreasing EPT percentages. The results of the 10 survey points examined for this study reveal that land-use and land-cover have an effect on site-specific water quality in the upper 62.8 kilometers of the Santa Maria River, indicating a trend that land-use and land-cover have an effect on water quality ranking.

Based on the EPT percentages determined from the 10 survey points taken along the 62.8 kilometer stretch of the Santa Maria River, the results of this study determined the overall quality of this portion of the river to be ranked as good on the EPT index. The five points furthest upstream within the first 11 kilometers of the stretch of river surveyed had the highest average forest cover and were all ranked as very good water quality. These first five points were located in areas which were primarily considered broad-leaf evergreen forest. The land-use and land-cover changed from primarily forest cover within the upper 10.3 kilometers of the river tested to a mixture of grassland and cropland as distance from starting point increased. The results of the study indicated that sites furthest downstream had the lowest percentage of forest cover and the poorest water quality rankings. These results provide substantial evidence to back up the conclusion that water quality was affected by land-use and land-cover surrounding the Santa Maria River at each of the 10 survey points.

The three points with the lowest EPT percentages were points 8, 9, and 10 which also showed the lowest percentage of forest cover and the highest percentage of cropland. This indicates a relation between water quality and proximity to areas which have been cleared for agricultural and pasture use. This also correlates with the distance away from Santa Fe as well as changing land-use and land-cover. It was observed that land-use and land-cover changed from primarily forest and mixed-use rural to cropland and farmland as distance away from Santa Fe increased. Percent EPT taxa decreased as land-use changed from significant forest cover in Santa Fe to an average of 43% cropland in the San Francisco sample points.

In terms of the environmental variability between testing sites, the pH ranged from 9.1 to 8.1 which are within the normal values for tropical streams. The dissolved oxygen level in milligrams per liter varied greatly from 21.6 to 16.7, with the highest levels observed within the 11 km of the furthest upstream point. The lowest 3 dissolved oxygen levels were recorded in the San Francisco area. A conclusion can be drawn between proximity of sample sites to farms and cropland. The three sites furthest downstream had the highest percentage of cropland land-use and subsequently the lowest percentage of forest cover.

Future studies to monitor the changing water quality of the Santa Maria River should be done annually and at least once during the dry season and once during the wet season. It is recommended that this study be repeated during the wet season, since 90% of precipitation occurs between the months of June to December in this region of Panama. Samples should be collected during both the wet and the dry season in Veraguas to determine how the water quality ranks and EPT percentages change with an influx of runoff and to account for seasonal variability in macroinvertebrate community structure. It is recommended that a longer period of time than two weeks be spent collecting macroinvertebrate samples in the Santa Maria River and that the evaluation of the overall water quality of the river encompass a larger amount of sample sites.

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