ASSESSING RIPARIAN CONDITION AND PRIORITIZING LOCATIONS FOR STREAMSIDE REFORESTATION PROJECTS: NORTHERN MANABÍ PROVINCE, ECUADOR

by

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ABSTRACT

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Riparian corridors perform ecological functions to a degree that vastly exceeds their spatial area on the landscape. These unique ecotones decrease sedimentation, provide unique wildlife habitat, help attenuate flood waters, and improve stream water quality by regulating and absorbing nutrient and pollutant flows across system boundaries. However, human actions at the landscape scale are a primary threat to the integrity of river ecosystems. This project focuses on maximizing ecological benefits through effective riparian restoration planning within one of the world's most threatened biodiversity hotspots: the coastal semi-deciduous, tropical dry forests of northwestern Ecuador. In order to meet the restoration objectives in a cost-effective manner, satellite remote sensing and geospatial modeling were employed to (a) understand relationships between land use/land cover (LULC) and drinking water quality across four watersheds of varying sizes and levels of forest-to-pasture conversion; (b) accurately identify potential restoration sites along important riparian corridors; and (c) prioritize and recommend restoration sites using a rank system that focuses on restoration feasibility and the potential to improve water quality, hydrologic functioning, and wildlife habitat.

Within the four coastal watersheds in the study area, the severity of deforestation ranges from 24% to 50% mainly due to conversion to pasture for livestock production. This type of land use change further increases by as much as 10% for areas closest to higher order streams showing an increased threat to riparian zones. The substantial loss of riparian forest cover led to the identification of 1,668 potential restoration sites, with an average size of 0.2 ha. Of these potential sites, 3.8% ranked as "high" priority, 47.6% ranked as "moderate" priority and 48.6% ranked as "low" priority. Those sites that are ranked the highest priority for reforestation efforts are larger in size, maximize core-area/edge ratios for prospective wildlife habitat improvements, and have the best potential to enhance riparian buffer functioning once restored.

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1. INTRODUCTION

Historical Land Use in Western Ecuador

Decades of deforestation throughout western Ecuador due to timber harvest, shrimp farming, crop production, and cattle ranching have left a highly diverse set of ecoregions on the brink of collapse (Southgate and Whitaker 1992, Sierra and Stallings 1998, Wunder 2001, Economist 2003, López et al. 2010). Mangrove forests, lowland wet forests, dry forests and montane forests once dominated the landscape westward from the Andes range to the Pacific Ocean. Of the ecosystems most in peril is the tropical dry forest. Less than 1% of primary dry forests remain in disparate parcels stretching from the northwest coast in southern Esmeraldas province towards the central coast in Guayas province and south to Peru, making it one of the most endangered tropical ecosystems on the planet (Dodson and Gentry 1991).

There are, of course, several different types of dry forest along Ecuador's coastline resulting from climactic effects of major ocean currents and elevation gradients. This study focuses on the transitional, semi-deciduous tropical forests that lie near the equator which are geographically unique in that they connect the world's wettest forests in the Chocó of southwestern Columbia to Ecuador's true dry forests further south. Floral and faunal residents from the northern rainforests and southern dry forests make their home in these coastal watersheds creating a dynamic, rich biodiversity hotspot with high levels of endemism.

As a response to high deforestation rates of 198,000 ha/year country-wide (Sanchez 2006) and lingering rural poverty, the government of Ecuador instituted a national program in 2008, called Socio Bosque, to help protect the country's remaining forests through direct payment incentives to landowners . In order to determine the priority regions for conservation, the plan called for a ranking scheme that focused on three main factors: a.) threat of deforestation; b.) the significance of ecosystem services: carbon storage, biodiversity habitat, and water cycle regulation; c.) poverty levels (de Koning et al. 2011). The resulting prioritization map characterized the remaining transitional dry forests in Manabí province in the highest priority category. This designation aligns with the historically famous prioritization of the world's most threatened biodiversity hotspots by Norman Myers (Myers 1988). Myers prioritized highly biodiverse and rapidly deteriorating hotspot biomes in the late 1980's. Due to this region's high rates of deforestation that was threatening the existence of incredible flora/fauna diversity and endemism, Myers ranked western Ecuador as one of the top biodiversity hotspots; second only to Madagascar (Myers 1988, Myers et al. 2000).

The Ceiba Foundation for Tropical Conservation (CFTC)[1] has been involved in conservation efforts in this part of the coast since 2001. CFTC aspires to create a biological corridor with the remaining old growth and mature secondary forests along a 50 km stretch between the coastal ports of Pedernales and Jama through the creation of private reserves or through protection under the government's new payment for ecosystem services (PES) program: Socio Bosque. Ceiba began a partnership with Socio Bosque at its inception in 2008 and has since enrolled 5100 ha of forested land into the conservation program, which accounts for nearly 20% of their proposed corridor (Woodward and Meisl 2010). Despite recent successful efforts on the ground to help protect these last remnants, few studies are being carried out to explore the incredible biology of these forests and how the dynamic land-use transformation in this area affects human health, natural resources, biodiversity, and regional climate change.

The coastal plain of Ecuador is the agricultural backbone of the country. Nearly all the native mangrove forests have been converted to aquaculture ponds while the humid and dry forests transitioned into cropland, palm plantations, banana plantations, or most commonly into pasture for livestock production. In northern Manabí Province, coastal watersheds have been compromised over the last 40+ years due to increased sedimentation after logging, loss of riparian buffers, fecal contamination from livestock, and agrochemical pollution run-off (Diario 2009, Guerrero 2010). These effects have not been effectively quantified to-date and it is likely that time and natural ecosystem recovery mask the historical interactions between land use conversion and water quality; however, current qualitative observations in the region by both conservationists and local residents have prompted action to address the links between land use/land cover (LULC), water availability, and water quality. In particular to Canton Jama, a county within Manabí Province, the current emphasis on watershed functioning and water quality stems from local communities' concerns about heightened water-borne disease breakouts within various towns.

Residents here rely on water drawn from local streams for drinking, cooking, bathing, and small-scale farming. Land conversion from forest to pasture often creates riparian gaps where forest has been cleared right up to stream channel itself. Without a functional riparian forest buffer between adjacent cattle pastures and streams, various water quality pollutants (e.g. fertilizer, fecal coliform bacteria from cow manure, and eroded topsoil) can easily enter water channels and

[1] www.ceiba.org

contaminate local water supplies. The restoration of these degraded streamside riparian zones is critical for both local stakeholders' health, re-establishing quality stream habitat for benthic communities, and for providing corridor connectivity for some of the most protected and oldest forest patches remaining in Manabí Province.

Riparian Corridor Significance

Riparian corridors perform ecological functions to a degree that vastly exceeds their spatial area on the landscape. These unique ecotones serve as the interface between terrestrial and aquatic ecosystems, thus creating one of the most dynamic zones within a landscape (Swanson et al. 1988, Gregory et al. 1991). Among their many services they decrease sedimentation, provide unique wildlife habitat, help attenuate flood waters, provide steam bank stability, and improve water quality by regulating and absorbing nutrient and pollutant flow across system boundaries (Gregory et al. 1991, Allan 2004, Baker et al. 2006). However, human actions at the landscape scale are a primary threat to the integrity of river ecosystems especially if land use change occurs within the riparian zone. There are numerous environmental factors that can affect aquatic systems, yet the presence of a factor is rather dependent on the level of development for a given country or specific sub-region of a country. For example, waterways in highly industrialized Western countries experience a higher threat of exposure to nutrient enrichment, heavy metals, synthetics, and toxic organics. Hydrologic alteration due to creation of levees, dams, roads, and urban development also occurs much more commonly in such regions. Within the context of the remote coastal regions of Ecuador, the main environmental factors that degrade river ecosystems and streamside buffer functioning are riparian clearing/canopy opening, a loss of coarse woody debris, and sedimentation from cropland and cattle pasture.

The amount of solar radiation reaching a stream channel, and thus potential for significant increases in water temperature, is a function of both stream channel width and the structure and composition of riparian vegetation (Gregory et al. 1991). Because the vast majority of stream reaches within this study area do not exceed 10 m in width, significant shading occurs where riparian zones are intact and have not been cleared. Riparian vegetation cover then becomes the dominant factor in influencing stream temperatures. A study in Ontario found stream temperature to be the only variable that clearly explained streams with and without healthy trout populations (Barton et al. 1985). Barton et al. further determined that stream temperature maximum means were inversely correlated to stream bank forest cover upstream from sampling sites. That is, less forest cover within a distance of 2.5 km upstream led to significantly increased water temperatures. Deforestation of riparian canopy clearly alters stream water temperature in an intuitive manner. However, Bourque and Pomeroy (2001) have shown that clear cut timber harvesting outside of forest buffer zones can also raise summer mean stream temperatures by 4-8% in catchments even when riparian forested areas (30-60 m) have not been impaired at all. In other research, the loss of riparian canopy has also been linked to decreases in bank stability and retention of pollutants/nutrients (Lowrance et al. 1984, Osborne and Kovacic 1993, Martin et al. 1999), alteration of organic carbon reaching streams (Findlay et al. 2001), and impacts on macroinvertebrate and fish community composition (Stauffer et al. 2000).

The presence of riparian trees within streamside buffer strips allows for consistent sources of coarse woody debris (CWD). Trees that fall across streams and within riparian zones help to retain water and organic material (e.g. leaves, branches, wood), store sediments and enhance biological productivity within river ecosystems (Ehrman and Lamberti 1992, Gurnell et al. 1995, Maridet et al. 1995). CWD also provides a substrate for feeding, attachment and cover for benthic organisms (Johnson et al. 2003).

The loss of forest in any area of a watershed, whether in the riparian zone or not, exposes previously protected soil to surface runoff forces following rain events. Fine soil particles are picked up and flow across surface pathways where they eventually end up in streams and contribute to the confounding problem of sedimentation. Significant positively correlated relationships have be found between the extent agricultural land use within a catchment and various measures of sediment load including suspended solids, bedload, and substrate embeddedness (Wood and Armitage 1997, Quinn 2000, Sutherland et al. 2002). Although sedimentation is a naturally occurring process, human induced sediment deposition occurs on a scale that lowers habitat quality for aquatic biota. For example, suspended sediment has been shown to lower the reproductive success of tricolor shiner, *Cyprinella trichroistia* (Burkhead and Jelks 2001) and mainstream reaches with high sediment loads that drained agricultural lands significantly reduced fish diversity in the central Chattahoochee River (Walser and Bart 1999). From a watershed management perspective, there is clear evidence for the myriad ecological services which riparian zones provide. The preservation and restoration of these unique ecotones will serve to benefit humans, riverscapes, and landscapes alike.

Land Use, Water Quality, and Human Health in the Tropics

Stream ecosystems are highly impacted by human land use at different spatial scales. Such impacts are usually measured in various physical, chemical, and biological metrics that represent varying degrees of water quality or habitat condition. Within the literature, results vary between studies that explore relationships between land use and these numerous stream response indicators (Allan 2004). The matrix of geomorphological traits, natural vegetation cover, soil substrate, land use alteration and levels of spatial analysis (catchment-wide, stream network, and local reach) must be kept in mind when drawing conclusions from a particular study. This section aims to explore research within tropical ecoregions that focus on the impairment of drinking water quality and riparian condition due to land use change.

Stream ecologists will often sample macroinvertebrate organisms and then calculate a biotic index as an indicator of water quality because certain species are more sensitive to suspended solids, temperature, and pollutants than others (Fenoglio et al. 2002, Figueroa et al. 2003). This index is one of the most commonly used biological metrics and is usually shown to be negatively correlated with agricultural land use and positively correlated with forest cover in the riparian zone (Wang et al. 1997, Miserendino et al. 2011). In the Ecuadorian Amazon, Bojsen and Jacobsen (2003) found that both alpha and beta diversity of macroinvertebrate communities decreased at sites with deforested riparian areas as compared to those sites that were forested. Changes in trophic structure occurred in deforested sites as overall macroinvertebrate abundance increased with a higher relative density of collectors, but lower density of predators. A similar study in Costa Rica determined that riparian forest buffers of at least 15 m can mitigate the loss of macroinvertebrate diversity due to deforestation (Lorion and Kennedy 2009). In addition to riparian land cover metrics, impaired structure and composition of macroinvertebrate assemblages have also been shown to correlate with physical and chemical indicators of degraded water quality (Buss et al. 2004, Soldner et al. 2004).

Other studies have collected indicator data to examine hydrobiogeochemical changes in stream ecosystems. For example, Figueiredo et al. (2010) examined whether cation/anion loads and chemical water properties (pH, turbidity, dissolved oxygen, water temperature) in small streams were affected by deforestation and increased agriculture use in eastern Amazon. They found that the simplest indicators appeared most useful in detecting effects of land use change; particularly, forest cover. For five streams in the Amazon, they determined stream temperature, dissolved oxygen, pH and turbidity are better indicators than biochemical concentrations of cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) and anions (Cl^-, NO_3^-, SO_4^{2-}).

Certain water quality indicators correlate with land use/land cover (LULC) at different spatial scales. Using a historical 23-year water quality dataset from Puerto Rico, Uriarte et al. (2011) reported that turbidity and DO responded to LULC at the catchment-wide scale, while fecal coliform concentrations responded best to LULC and the sub-watershed scale. Fecal contamination in streams through soil leaching is one of the biggest human health concerns for rural communities in Canton Jama. While specific studies have not been carried out in Jama, the high prevalence of enteroinvasive *Escherichia coli* has been documented further up the coast in similar rural regions (Vieira et al. 2007). Additional work in the Seine watershed found that streams flowing through areas partially or completely covered with grazing pasture experienced high loads of fecal bacteria and other suspended solids (George et al. 2004). Increased rainfall further added such contaminants in to local streams. Given the large percentage of pastureland and high rainfall during the wet season in Jama, there is great potential to help improve water quality and reduce water borne disease incidents through reforesting riparian buffer zones.

This project focuses on maximizing ecological benefits through effective riparian restoration planning within one of the world's most threatened biodiversity hotspots: the coastal semi-deciduous, tropical forests of northwestern Ecuador. In order to meet the restoration objectives in a cost-effective manner, several field and digital geographic datasets were either collected or created using remote sensing and geospatial modeling, and then analyzed to (a) measure water quality across watersheds of varying sizes and levels of deforestation; (b) understand relationships between land use/land cover (LULC) and drinking water quality in this particular ecosystem; (c) accurately identify potential restoration units along important riparian corridors; and (d) prioritize and recommend restoration units that will maximize riparian buffering capacity and reduce the threat of water-borne diseases for local communities.

2. MATERIALS & METHODS

Study Area

The province of Manabí is located on the northwest coast of Ecuador whose latitudes extend above and below the equator. The study area in question comprises 4 small watersheds within a county of Manabí Province called Canton Jama (0°3’18 – 0°14’0 S, 80°6’0 - 80°14’11 W, see **Figure 1**). Each watershed is named after the rural communities (<800 persons) that exist near the mouths of the main streams’ channel outlet into the Pacific Ocean. The most northward watershed is Tabuga, followed southward by Camarones, Tasaste, and Don Juan. Three of the catchments encompass <3,000 ha; however, Don Juan is 8,613 ha and is larger than the others combined.

Canton Jama lies directly in the middle of the transition zone that links Ecuador’s driest tropical forests to the south with the famously wet Chocó rainforests of northwest Ecuador and southern Columbia. The cold Humboldt Current runs up the coast from Chile and Peru bringing dry conditions, whereas the Panama Current travels southward bringing warm waters and moist air. This forest transition zone occurs in the regions just north and south of the equator due to the merging and seasonal northward and southward oscillation of these two major ocean currents. As a result, the transitional coastal forests experience a gradient from drier to more humid conditions as you move northward in latitude from 1° S (Dodson and Gentry 1991). There is also an elevation gradient that roughly defines various forest cover types generally referred to by the following classes: 1.) tropical deciduous vegetation is found down in coastal plains to 100 m above sea-level; 2.) moist semi-deciduous forests are located roughly between 100-300m; and 3.) upper elevations (300 – 700 m) transition into evergreen, broadleaf montane forests (Neill 1999, Sierra 1999, **Figure 1**). Dry seasons are variable but typically span from June to the end of November or early December. However, consistent cloud cover help mitigate effects from high temperatures and dryness during this period. Annual precipitation yields anywhere from 1,500 mm to 3,000 mm, with a minimum monthly rainfall of 10mm (Dodson and Gentry 1991, Neill 1999).

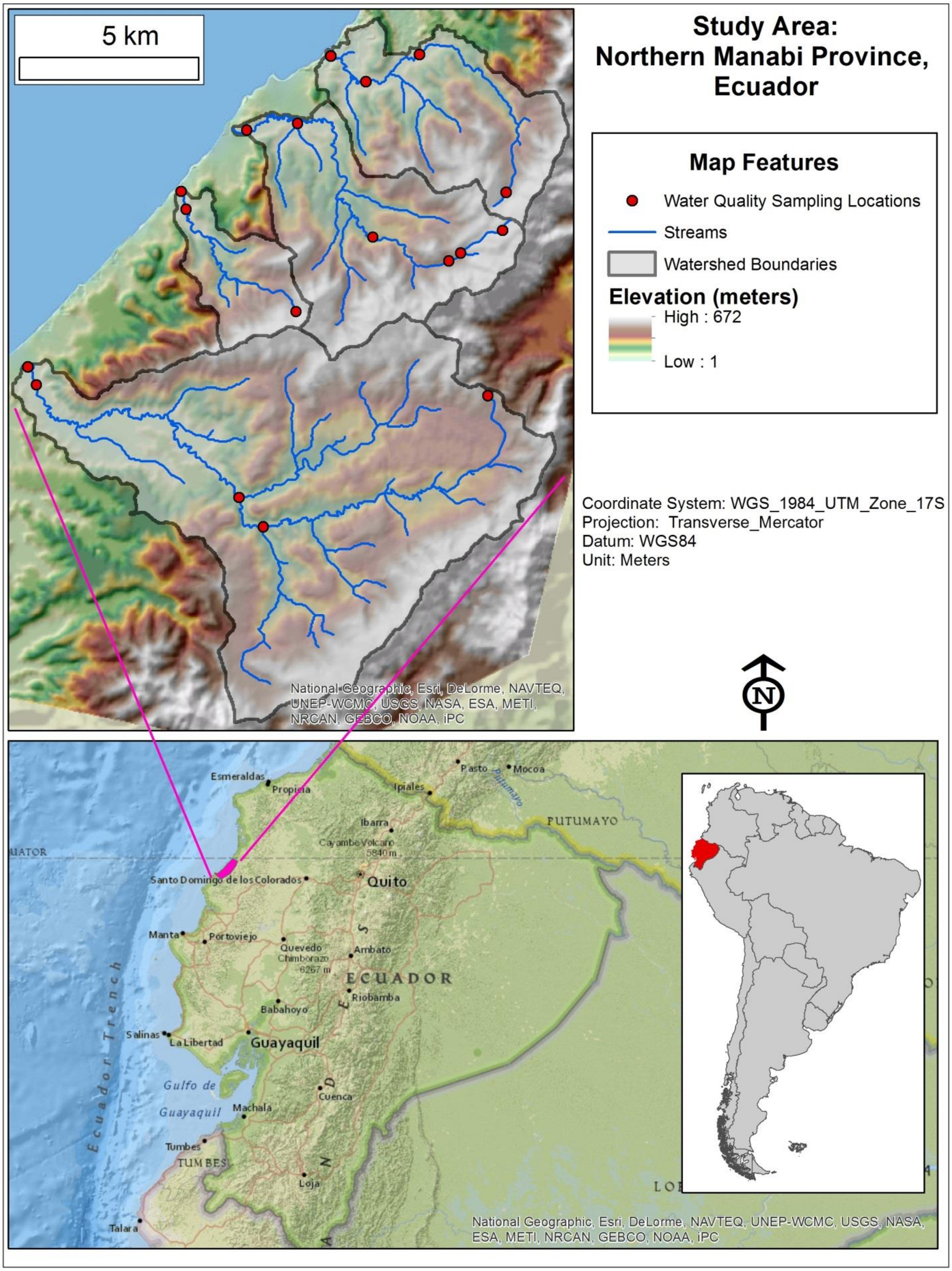

Figure 1. Map of Study Area: Northern Manabi Province, Ecuador

The predominant land use in the region is grassland pasture for cattle grazing. The vast majority of all old-growth forests were first selectively logged for high value timber and then cut, burned and converted to pasture since the mid 1970's (Sierra and Stallings 1998, Wunder 2001, López et al. 2010). Some land-use has altered between pasture and cropland but this occurs on rather small scales for subsistence farming. Remaining forest patches are found at higher elevations where steep slopes prove difficult for successful cultivation or livestock management. Canton Jama and Canton Pedernales hold most of the last remnants of pristine montane and deciduous forest along this part of the coastal cordillera (mountain range). The presence of several intact, neighboring forest patches is a significant reason why the Ceiba Foundation for Tropical Conservation continually works towards protection of these few watersheds with an end goal of establishing a connected forest corridor.

Water Quality Sampling

A total of 18 water quality sampling locations were chosen across the study area: 4 in Tabuga, 6 in Camarones, 3 in Tasaste, and 5 in Don Juan (**Figure 2**). The initial standards for site selection were determined by catchment size and the proximity of local towns to the coastline. At a minimum, each watershed was sampled at the headwaters of the main channel, upstream of town, downstream of town, and at a final drainage point near the end section of the riverine system. However, the towns of Tasaste and Don Juan are situated around the mouth of their respective river and thus the post town sampling site was also the final drainage site. The larger watersheds were also sampled at major forest/pasture boundaries or after the confluence of another major tributary. This assured that we could assess impacts of deforestation, grazing, as well as inputs from human development. All sites needed to be outside of tidal influence, have a length of 100m and contain at least two types of macroinvertebrate habitat. Headwater sites were chosen as the furthest point up the main channel that had deep enough pools for adequate data collection. Local guides (usually the landowner) were hired to find difficult to reach headwater sites.

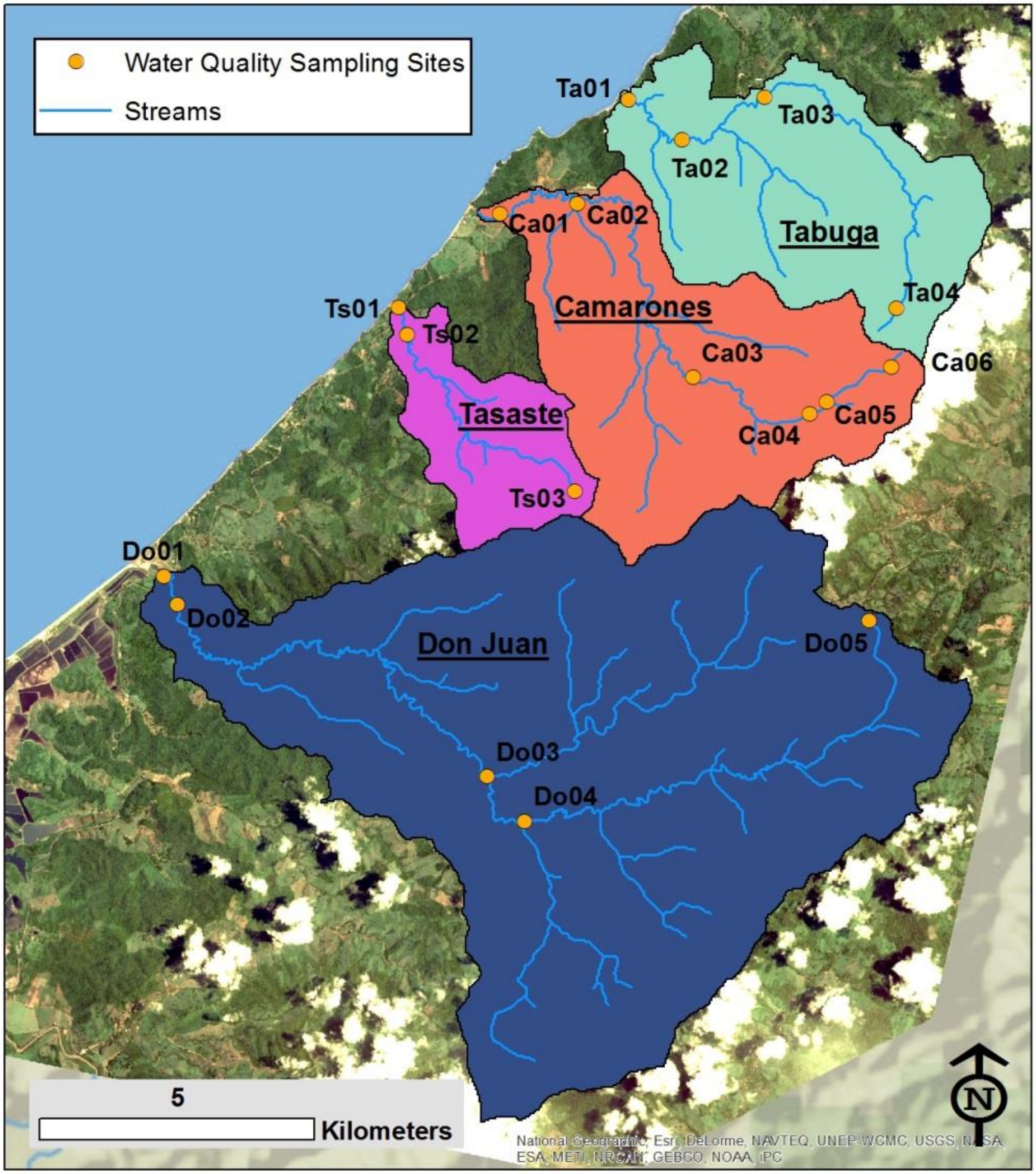

Figure 2. Water Quality Sampling Locations. There are 18 sites in total: 4 in Tabuga, 6 in Camarones, 3 in Tasaste, and 5 in Don Juan

It has long been known and investigated that the health of stream ecosystems are threatened by land use change within its catchment; in particular due to anthropogenic activities (Allan 2004). There are a variety of source indicators of water pollution that can be tested to characterize the condition of a given watershed. Our water sampling procedures were based on Wisconsin's Water Actions Volunteers Network citizen science program but included modifications to adjust for local ecosystem characteristics (WAV 2011) . In addition to basic hydrogeochemical indicator data, we recorded data for preliminary benthic macroinvertebrate surveys, fecal coliform bacteria surveys, and qualitative riparian habitat condition assessments. Such sampling does not require expensive monitoring equipment or the necessary laboratory sample analysis that is needed for nutrient concentration measurements. All water quality parameters can be calculated in the field, except for fecal coliform colony counts. Overall, this sampling method followed a simple approach that allows local citizens to monitor their local fresh water systems.

Temperature: Air and water temperature were measured with both regular thermometers as well as a digital, hand-held YSI Dissolved Oxygen meter.

Dissolved Oxygen (DO): Levels of DO (% saturation and mg/L) were recorded using a YSI Dissolved Oxygen Meter. We also sampled with Hach Dissolved Oxygen test kits when working with community members because this will be the preferred method for future data collection. These kits are simple and economical by utilizing drop count titration procedures.

Stream Flow/Volume: JDC's Flowatch air/liquid flow meter was used for measuring stream discharge velocity. Using the basic concept of distance/time = velocity, we also assessed stream flow by marking a measured distance and recording the amount of time it takes a tennis ball to pass through that section. Discharge volume was calculated using the average stream velocity measurement and the cross-sectional area of a given sample site. Baseflow at headwater sites often proved insufficient for this measurement.

Biotic Index: Three subsamples of macro-invertebrates were collected for each water quality station; two from habitats of highest biodiversity (ie. cobblestone riffles) and one of less diversity (ie. undercut logs, leaf packs). The samples were then combined to survey the species diversity and richness. Being that no investigations have been performed on the freshwater aquatic life in the central and north coast of Ecuador, we have not yet calculated biotic index. Classifications were performed at the level of Order using field guides from Wisconsin benthic macro-invertebrate studies. Samples from this study were taken to the University of San Francisco, Quito (USFQ) in 2011 which generated interest to further investigate aquatic stream ecology on the coast. There are current preparations being made to implement a study solely focused on identifying aquatic organisms from streams along the coast in Manabi Province to provide a more applicable biotic index scoring assessment for stream health.

Habitat Assessment: This method was adapted from the Wisconsin WAVN to quantify a visual assessment of overall stream and riparian health. There are 10 factors which, when rated on a scale of 1-4 (each rating magnitude has a detailed description which lessens subjectivity), give an overall habitat score. The factors are: riparian vegetation, bank vegetation, bank stability, channel alteration, channel flow status, stream velocity/depth, in-stream fish habitat, sediment deposition, embeddedness, and attachment sites for macro-invertebrates. The higher the score, the better the site is considered to support wildlife.

Turbidity: We employed a 120cm turbidity tube to measure the amount of suspended solids (transparency) in the stream for a given site. The tube was first filled with undisturbed water, and then water was released from the tube until the secchi disk at the lower end became visible while looking downward through the water column from above. The length of the tube is marked in cm and the water level was recorded. Multiple trials were taken for an average. Normally, turbidity is measured in NTU units where a higher number corresponds to a great magnitude of suspended solids in the sample. However, when turbidity is measured in cm, a lower number corresponds with the water sample being more turbid. A high measurement (> 100cm) represents very clear and transparent water.

***E. Coli* sampling:** All water samples were taken mid-water column and stored in whirl-packs within a cooler. Upon returning from the field, 1 mL of water sample was placed on a 3M Petrifilm petri plate for each sampling location. The plate was then incubated at 35°C for 24 hours and 48 hours. Blue colonies were counted after each period to note discrepancies between incubation periods. Fecal coliform numbers are represented in colony forming units (CFU) / 100 mL. Samples that could not be plated and incubated immediately following field collection were stored in a refrigerator for a maximum of 1-2 days to restrict bacteria growth.

Land Use/ Land Cover Mapping

Prior to this study, there was a lack of high or even medium quality digital geographic information for this remote region of Ecuador. The country's national land cover, climate, soils, hydrology, terrain, ecotone, and species distributions maps only exist in coarse 1km resolution. For a study area as small as 150 km^2, it is not worthwhile to perform any geographic based analyses at this level of resolution. While specific studies of improved detail have been carried out in other focused regions of the country, the application of remote sensing and landscape modeling has yet to take hold in ecological investigations within Canton Jama, Manabí. I used ENVI 4.8 and 5.0 software for image processing and Arc-GIS 10.1 for geospatial modeling.

Satellite Image Preprocessing

One of the principal goals for this project is to accurately characterize and map riparian corridors both in terms of geographic location and vegetation cover within those corridors. On a landscape scale, the utilization of satellite images gives resource managers a convenient method to assess land cover characteristics. If the satellite sensor has high enough spatial resolution, then it is possible to also manually define stream channels for riverine systems of higher order. However, it is important to understand the benefits and limitations of remotely sensed data and to match the spatial, temporal, and spectral resolution of a particular satellite sensor to fit the needs of a given study area (Chuvieco and Huete 2009). I chose to use SPOT5 images as the basis for creating my land cover classification for 3 reasons: (1) the spatial resolution of 10 meters provides highly improved vegetation class separation along riparian corridors as compared to the traditional 30 m Landsat images; (2) the green, red, and near infrared bands are most suitable for distinguishing ground cover reflectance values of varying vegetation types; (3) the acquired images contained minimal cloud cover for the majority of the study area, especially in low-lying areas where forest cover is the most fragmented.

The two base images for my analysis came from a Planet Action[2] project grant. The Planet Action program is an initiative of Spot Image[3] to provide geographic information and technology for support of landscape studies having a link to climate change as a result from anthropogenic land use change. In order to generate a cloud free LULC classification map across the 4 watersheds, I processed four separate images: two recent SPOT5 images (2008, 2009) and two Landsat ETM+

[2] http://www.planet-action.org/ ; http://www.planet-action.org/web/85-project-detail.php?projectID=9754
[3] http://www.astrium-geo.com/en/143-spot-satellite-imagery

images[4] (2007, 2008) where cloud-free SPOT5 data was not available. Dates of image acquisition were chosen in the middle of the wet season in order to limit variability in vegetation reflectance. The 2007 Landsat image was taken at the end of the dry season, but its spatial integration was limited to a small portion (< 3%) of the total scene and only where the other images were not cloud-free at upper montane forest patches. In general, SPOT5 images made up 87% of the study area without cloud cover, while the other two Landsat images filled the remaining 13% of the study area; nearly all of which was high elevation primary forests held within protected reserves.

Before generating a LULC map from raw satellite imagery, I performed the necessary preprocessing steps that are necessary to ensure that images taken from different sensors and multiple dates are co-registered in geographic and spectral space. First, I implemented an orthorectification procedure on the two SPOT5 images to correctly align the cells to their actual on-the-ground location. This method of georectification was necessary for this study because SPOT sensors acquire images off-nadir, meaning that the angle at which the sensor is pointed towards the earth's surface may be different for two images taken at different dates. For study areas in mountainous areas such as Canton Jama, this difference in angle will cause topographic distortions between the two images. The ENVI 4.8 orthorectification algorithm for SPOT images used ground control points, which I collected in July 2011, and a digital elevation model to register each cell[5] based on horizontal and vertical reference datasets. Next, I carried out a standard image-to-image registration for each of the two Landsat EMT+ images to the 2009 SPOT image with a resulting RMSE error of less than 1 pixel (<30m). Following these registration steps, the four images became aligned in the same geographic coordinate system where overlaying pixels represent the same ground features.

Information received by satellite sensors becomes stored in different digital formats depending on the type of sensor. The next step was therefore to transform the values of the image information to a common energy unit, radiance (e.g. W/m^2), and subsequently a conversion to surface reflectance (ranging from 0 to 1). These radiometric and atmospheric correction algorithms account for variance in sensor-type characteristics (e.g. sensor height, viewing angle, band wavelength ranges) and climatic variables (e.g. illumination, solar zenith, and atmospheric distortions) between the four images. The final preparation involved clipping the images to the study area of the four watersheds and masking out all clouds and cloud shadows from each of the two SPOT images and two Landsat images.

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[4] Downloaded from Earth Explorer: http://earthexplorer.usgs.gov/

[5] The term "cell" and "pixel" are considered the same and interchangeable in this discussion

Table 1. **Digital Datasets Used in the Evaluation**

Dataset	Resolution	Bands Used	Source	Date
SPOT5 Satellite (HRG 2)	10 m	**B1**: (green, 0.50 – 0.59 µm) **B2**: (red 0.61 – 0.68 µm) **B3**: (near infrared, 0.78 – 0.89 µm)	SPOT Image/ Planet Action Initiative ©CNES (2011), distribution Spot Image S.A.	3/13/2009
SPOT5 Satellite (HRG 2)	10 m	(same)	SPOT Image/ Planet Action Initiative ©CNES (2011), distribution Spot Image S.A.	4/3/2008
Landsat 7 Satellite (ETM+)	30 m	**B1**: (blue, 0.45-0.52 µm) **B2**: (green, 0.52-0.60 µm) **B3**: (red, 0.63-0.69 µm) **B4**: (near infrared, 0.77-0.90 µm)	U.S. Geological Survey	4/3/2008
Landsat 7 Satellite (ETM+)	30 m	(same)	U.S. Geological Survey	11/27/2007
Digital Elevation Model	30 m		ASTER GDEM2 (NASA) & SavGIS digitized contour lines database (Marc Souris, IRD)	2011
Stream Network	-		Hand-digitized using 5 & 10 meter SPOT5 images, ArcGIS 10.1 Hydrology	
Land Use/ Land Cover Map	10 - 30 m		Created with ENVI 4.8 software using the above imagery	2007-2009

Supervised Classification Methodology

Following the preprocessing steps, I created a separate land use land cover classification (LULC) map for each of the 2008 and 2009 SPOT images, as well as the 2007 and 2008 Landsat images. First, comprehensive training clusters for the classification algorithm were manually digitized as polygons based on my expert knowledge of the landscape, existing protected areas, and pan-sharpened 5 m SPOT5 imagery. For every image, between 2 to 10 polygons were created for each spectral subclass that was sufficiently different[6] from other previously defined subclasses based off the Transformed Divergence separability index (TDI). For example, the Pasture/Active Cropland class in the 2009 SPOT image had 47 spectral subclasses[7], each of which was defined by 2 to 10 polygons. I then ran a supervised classification module which incorporates the maximum likelihood algorithm. Once an image was classified, I merged similar subclasses into their representative main LULC class. Each of the four classified images contained the following seven class types: Forest, Pasture/Active Cropland, Bare Soil/Fallow Cropland, Rural Development, Paved Road, Water, and Unclassified.

Next, the Landsat based classification maps were resampled to 10 m resolution in order to match that of the SPOT-derived maps. Finally, the four images were merged into one LULC map where the base SPOT images composed 87% of the study area and the two supplementary Landsat LULC maps filled in missing regions at higher elevations due to cloud cover in the base images. Because the identification and prioritization of potential riparian restoration sites is highly dependent on the LULC map, it is essential to determine the accuracy of this final map before the discussion of further results. In 2011, I collected 174 GPS ground truthing points that were saved for the accuracy assessment portion of this analysis.

Ground Truth Data Collection

Ground truthing is essential to accurately classifying land use and land cover with satellite imagery. Data points were collected with a GPS receiver of the representative land cover/uses for the given study area so that thematic classifications resulting from satellite images can be compared to on the ground cover. The quantity and quality of ground truth data greatly influences the accuracy of land cover classification maps from remotely sensed data. Previous research suggests at least 50 sample points are used for each land use class as a general rule (Congalton

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[6] >1,700 TDI

[7] Due to variations in reflectance resulting from aspect, slope, magnitude of near-infrared absorption

1996). In this region of Canton Jama there are three major land uses/cover types: deciduous forest (primary and secondary), montane forest (primary and secondary) and pasture. I collected at least 50 points for each of these 3 classes because they cover >98% of the landscape in this region. Less representative classes (e.g. rural development, roads, water) were not sampled to this same extent, but were sampled in proportion to their limited occurrence.

At the time of ground truth data collection in July 2011, I defined deciduous forest, montane forest, pasture/grazing land, active cropland, highway, and rural development as the LULC class types without knowing if, in fact, their surface reflectance characteristics were sufficiently distinct from one another. Indeed, the spectral signature of deciduous forest cover could not be distinguished from that of montane forest during the wet season. Thus, I joined the two classes into a general "Forest" class. Furthermore, pasture grassland and active cropland had similar spectral traits so they were merged into one class. The high resolution imagery afforded the addition of two more classes: bare soil and water (ocean, main river channels, and shrimp ponds). I did not collect ground truth points for these two classes. For the other small spatially represented classes in the region (e.g. development and water), I collected sufficient points to represent their respective coverage on the landscape.

Extremely steep topography, dense vegetation, limited access to dirt roads or trails, lack of a 4x4 vehicle, and difficulties from securing permission from some private landowners all contributed to not performing a stratified or random sampling of ground truthing points. Points were taken on major land parcels for which there was dirt road/trail access and permission from the owner. Each point was taken in a homogenous area of LULC category of at least 50 m^2. All points were taken at least 100 m away from any other point. Along with the cover type, I noted elevation, slope, landowner, time of day, history and other notes for each point. Photos were also taken at points with distinct, representative features for a given class type.

Digital Elevation Model

A digital elevation model (DEM) is a continuous raster dataset whose cell values represent a vertical datum, usually meters above mean sea level. DEM's are considered to be a crucial geospatial dataset for natural resource management and conservation analyses because many other datasets can be extrapolated from it. Hill-shade models, slope, aspect, insolation, hydrologic flow models and stream networks are just a few examples of DEM-derived geographic information systems. The SRTM shuttle mission (Rabus et al. 2003) provides 30 m resolution DEM's for the United States; however, global coverage in only available free of charge for this part of the world through USGS at 90 m resolution. Because this global SRTM data is too coarse for application in this study, I generated a composite DEM. The core of the DEM is an interpolated elevation raster based on a digitized contour database (SavGIS, Marc Souris) at 30 m resolution. Some lowland and headwater regions of the landscape were supplemented with 30 m ASTER GDEM2 (Krieger et al. 2011)[8] elevation values to improve topographic patterns that better match GPS data, previously defined stream networks, and my own on-the-ground knowledge of the landscape. The final DEM had a spatial resolution of 30 m and was used for creating functional watershed datasets with ArcGIS Hydrology tools.

Land Use / Land Cover Metrics

Land use metrics were evaluated at two different spatial scales: catchment-wide and within a fixed-distance of riparian zones (**Figure 3**). At the catchment scale, percent cover for all LULC categories was calculated within the area encompassed by the boundaries of a given watershed. At the local scale along riparian areas, I calculated similar measurements within a 30 and 100 m buffer of each watershed's respective stream network. The term "buffer" here refers to the area enclosed by a Euclidean distance of 30 or 100 m extending out from both sides of a stream channel (resulting in a 60 m & 200 m wide distance extending across stream). It is not meant to denote functional riparian forest buffers in terms of ecosystems services. Such functional buffer may actually be quite different in width from these fixed Euclidean distance buffers. The idea is to provide a simple comparison of nearby stream LULC conditions to compare to whole catchment areas.

Rural communities in this remote region of Ecuador tend to settle near the larger streams of coastal watersheds for various reasons: easy access to water for drinking, cooking and bathing, high soil quality compared to uplands, lower terrain slope which suits development and small scale farming, and a reliable source of water for livestock production. Thus, the comparison of land cover at the catchment scale to that of the stream network scale is an attempt to quantify whether streamside landscapes experience a higher threat of deforestation as we would expect given aforementioned development patterns.

[8] http://asterweb.jpl.nasa.gov/gdem.asp

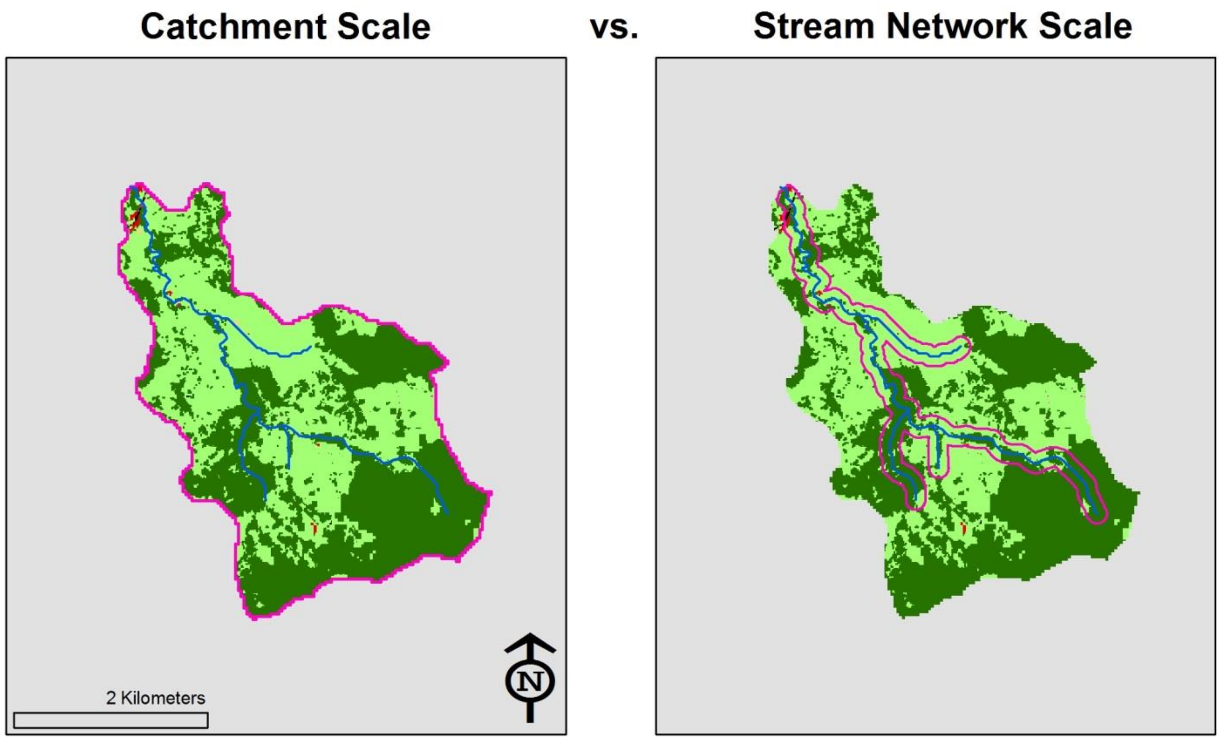

Figure 3. Catchment-Wide vs. Riparian Zone Spatial Scales for Land Use Analysis

Site Identification

The methodology to identify and delineate potential riparian restoration sites in based entirely on creating and/or manipulating geospatial datasets. To build the stream network, I used two methods. First, for all main channels of the four watersheds, I hand digitized polylines using high resolution 5m SPOT5 pan-sharpened images. Second, where stream channels were not visible and for major tributaries I supplemented the hand-digitized stream network with a flow pathway model derived from my DEM.

In order to provide a visual example of the site identification process, I used a zoomed-in view of a portion of the Tabuga watershed at different steps as shown in **Figures 4, 5, and 6**. Once the stream network was developed, I defined a 30-m zone around both sides of each stream in the network (60 m total width) as shown in **Figure 4**. Previous research has shown that the riparian buffering effectiveness of nitrate concentrations, fine sediments, and fecal bacteria surface runoff comes in the first 30 m of a stream bank (Dosskey et al. 2002, McKergow et al. 2004, Mayer et al. 2007, Weller et al. 2011). The implementation of replanting projects outside of this 30 meter zone would not maximize conservation benefits given a limited restoration budget. Lastly all non-forest parcels, except for rural development and roads, were identified within the define riparian zone to become the potential restoration sites (**Figure 5, Figure 6**).

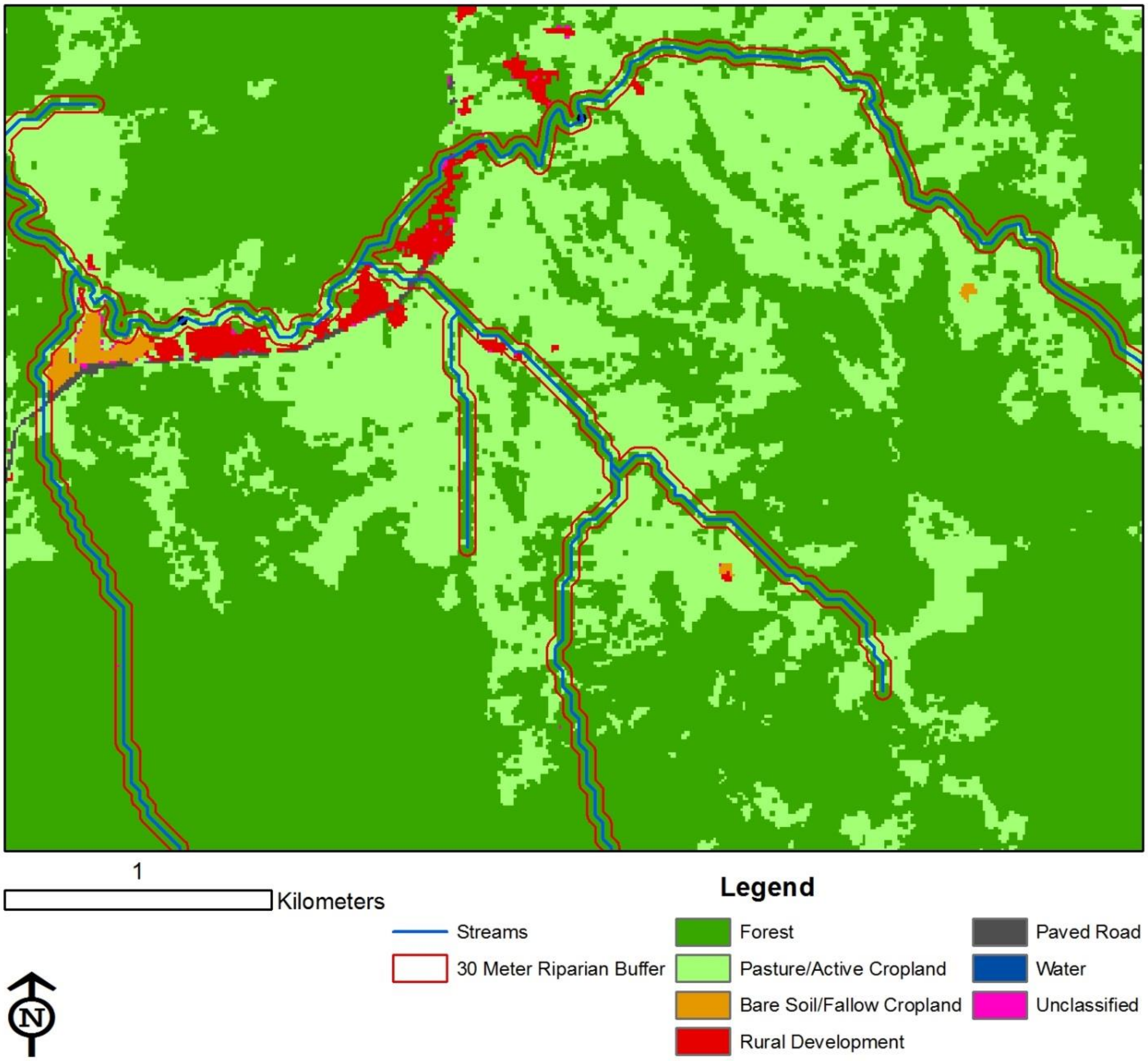

Figure 4. **Site Identification: Step 1, Defining Riparian Zones (30-m buffer around both sides of streams)**

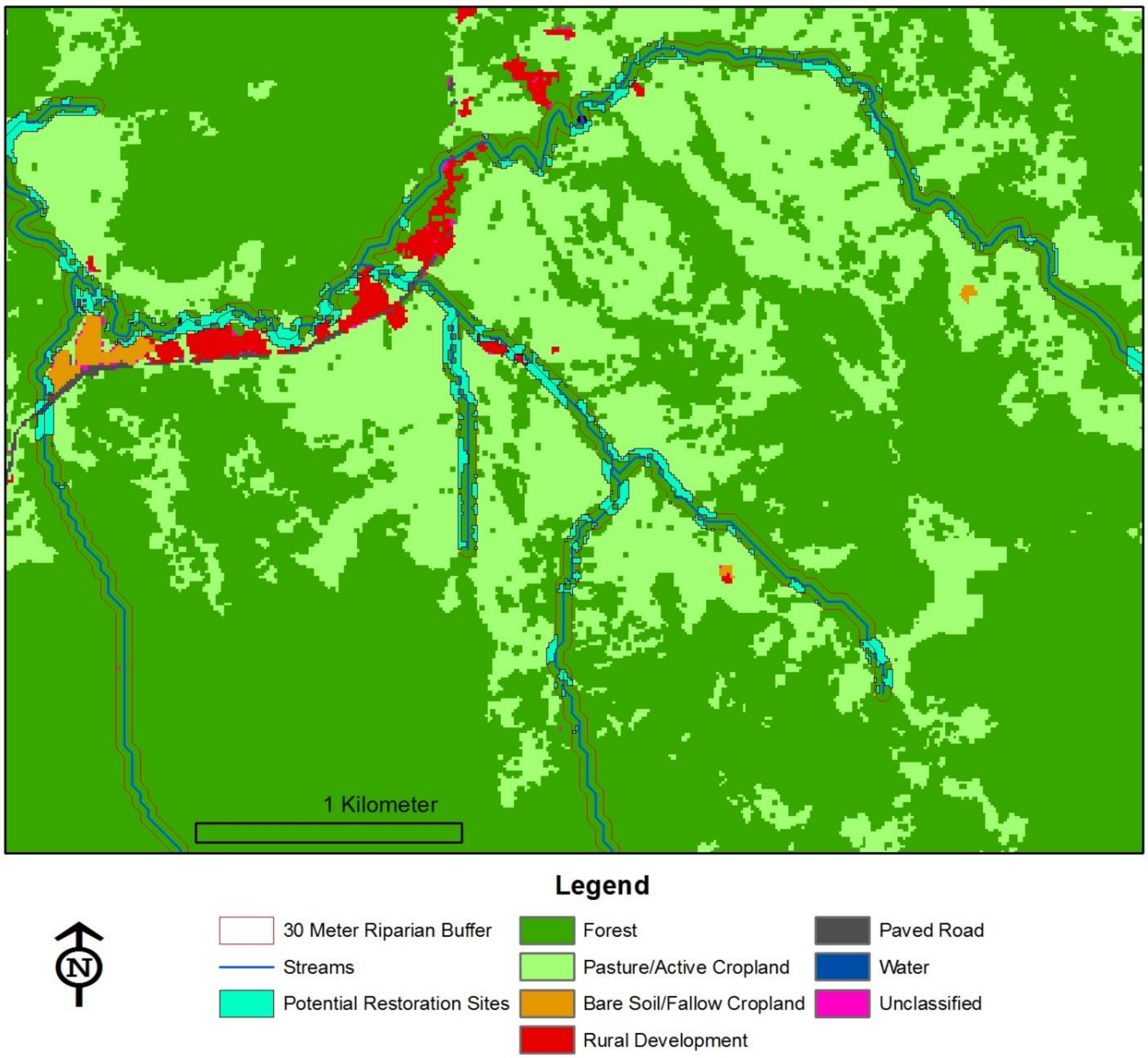

Figure 5. Site Identification: Step 2. Select All Non-Forest parcels within Riparian Buffer.

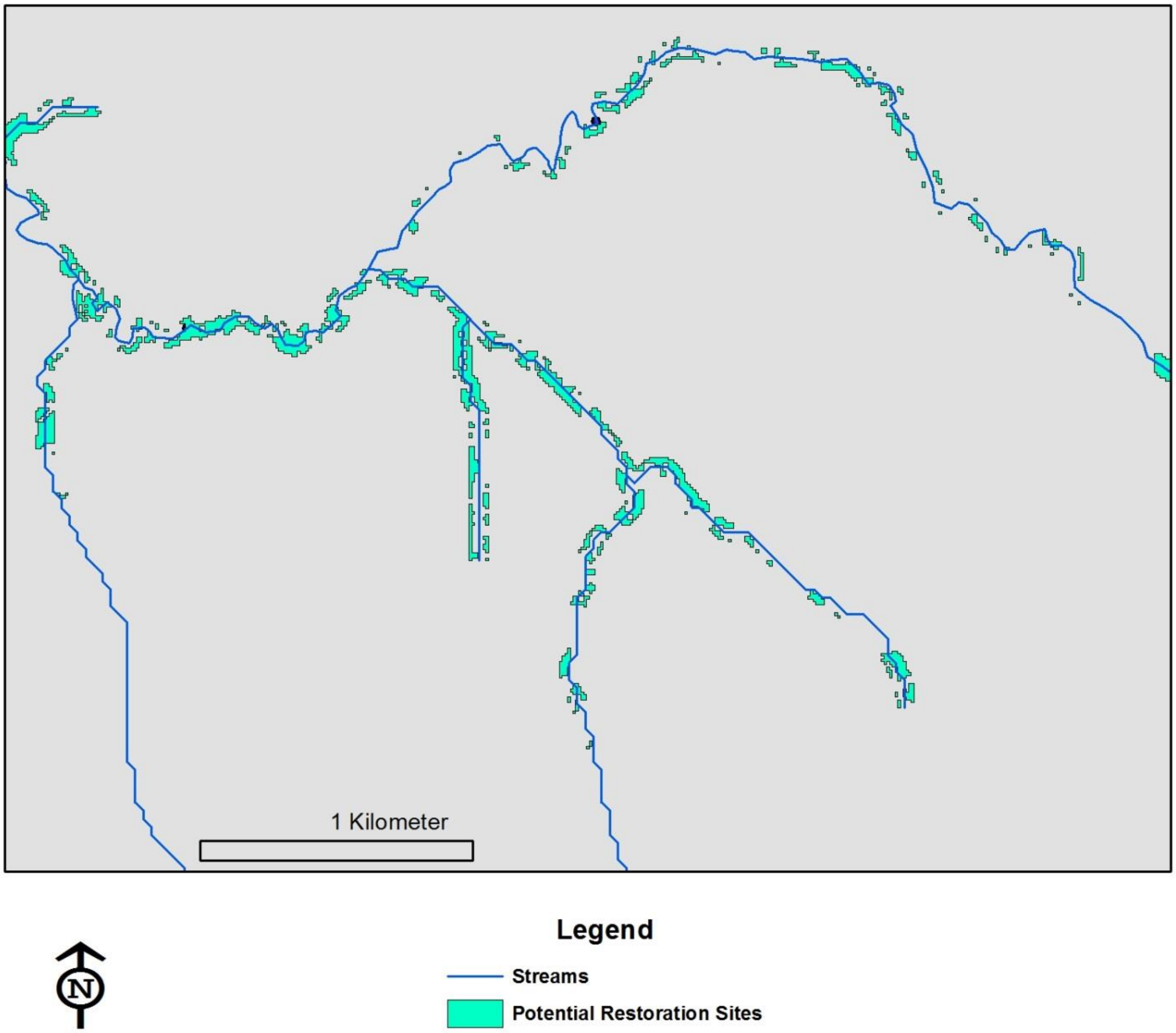

Figure 6. Site Identification Final Results: Each watershed contains a list of all potential restoration sites

Site Prioritization

The prioritization framework utilized geospatial datasets developed from this project to assign a prioritization category of “high”, “moderate, or “low” to each of the potential restoration sites. It is based on a point ranking system that is adaptable and can be replicated for watershed management planning outside of the study area. In order to match the restoration objectives, the framework consists of three main variables: (1) potential to improve water quality and hydrologic function, (b) feasibility, and (c) potential for wildlife habitat enhancement. Each of these variables was composed of a set of criteria based on landscape metrics which assigned a score to each of the restoration units. In all, there are 5 selection criteria (**Table 2**) whose point scores range from 1-3 or 1-6. Higher number scores correspond to higher restoration priority.

Potential to improve water quality and hydrologic function

Criteria 1: Reduction of Riparian Gaps (Score: 1-3)

This metric determines where riparian gaps occur along the stream network. That is, where there is no forest cover between non-point sources of pollution and the stream channel. For sites that lie directly next the stream channel, they are considered to be a riparian gap and are given a score of “3” denoting high priority for restoration. Sites further away from the stream channels which have a forest buffer between itself and the stream are given lower scores and thus lower priority.

Criteria 2: Functional Buffering Capacity (Score: 1-6)

Surface flows in a catchment area do not drain evenly into riparian zones. They are rather concentrated based off geomorphological traits where the majority of surface area drains into a small percentage of the riparian zone (Dosskey et al. 2002, McGlynn and Seibert 2003). This metric basically rates each potential site on its potential to act as a functional buffer with a score of “1” being low potential and “6” being the highest potential. Using a DEM-derived flow accumulation model, the amount of upslope terrain that contributes to flow pathways can be calculated for each potential site. I gave this variable a weight of 1-6 instead of 1-3 because this function is critical to serving the overall objectives of reducing pollution runoff from nearby cattle pastures into waterways.

Table 2. **Restoration Site Prioritization Framework**

	Prioritization Variable	Criteria	Metric	Criteria Score
I.	**Potential to Improve Water Quality and Hydrologic Functioning**			
		1.) Reduction of Riparian Gaps	Lies adjacent to stream channel	3
			Located < 10 m, but does not lie adjacent to stream channel	2
			Located 10 to 30 m from stream channel	1
		2.) Functional Buffering Capacity	Contains a flow-accumulation sum > 1,000	6
			Contains a flow-accumulation sum between 751 to 1000	5
			Contains a flow-accumulation sum between 501 to 750	4
			Contains a flow-accumulation sum between 251 to 500	3
			Contains a flow-accumulation sum between 101 to 250	2
			Contains a flow-accumulation sum <= 100	1
II.	**Feasibility**			
		3.) Distance to Labor & Restoration Resources	Located <= 300 m from Rural Development	3
			Located between 300 m to 1 km from Rural Development	2
			Located > 1 km from Rural Development	1
III.	**Potential to Improve Wildlife Habitat**			
		4.) Habitat Connectivity	Located next to significant forest patch	3
			Located <= 100 meters from significant forest patch	2
			Located > 100 meters from significant forest patch	1
		5.) Core Habitat Area	Area/Edge Ratio > 10	3
			Area/Edge Ratio between 5 to 10	2
			Area/Edge Ratio < 5	1
			Total Numeric Score Range:	**5 to 18**

Feasibility

Criteria 3: Access to labor and restoration resources (Score: 1-3)

The remote nature of portions of these watersheds makes some potential sites less feasible than others. The farther a site is from rural communities and roads, the more costly it will be to carry out reforestation projects. Those sites closes to development were ranked the highest priority ("3") and those furthest away were ranked lowest ("1").

Potential for wildlife habitat enhancement

Criteria 4: Habitat connectivity (Score: 1-3)

In order to encourage maximum forest cover connectivity, I ranked potential restoration sites that lie adjacent to significant forest patches as having the highest priority (score = "3") over other sites that are located further from forests. Sites further away received a score of "1" or "2" because reforestation may simply create an island forest that does connect existing forest habitat.

Criteria 5: Core Habitat Area (Score: 1-3)

This metric calculated an area/edge ratio for each potential restoration area. Habitat patches that maximize core area and limit edge length protect wildlife from the ecological impacts from abundant edge effects such as introduction of invasive species and micro climate warming at ecosystem boundaries. Potential sites with the highest area/edge ratios received high priority scores ("3") and those with lower ratios received lower scores according to the metrics in **Table 2**.

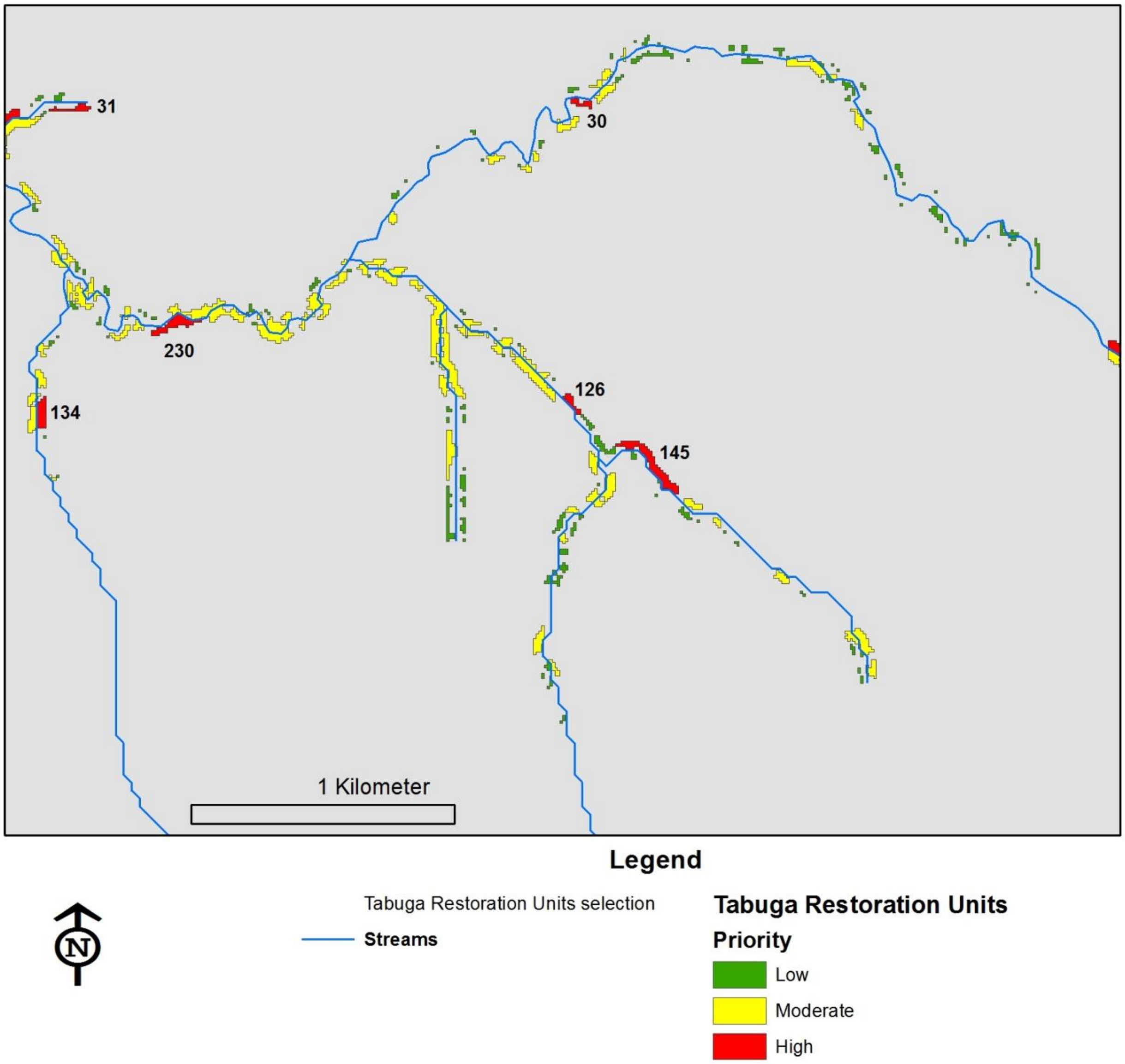

Figure 7. Prioritization Map: An Example from the Tabuga Watershed. Numbered sites in red have highest priority for restoration focus.

Final Prioritization Ranking

Once criteria scores were assessed, they were summed to yield a final prioritization score with possible values ranging from 5-18. According to **Table 3**, restoration sites were then categorized as "high", "moderate", or "low" based on a score range. An example of the application of the prioritization model is shown in **Figure 7**. Similar to the zoomed-in examples in the previous identification methods section, this figure depicts the prioritized restoration units which are color coded to match their respective rating.

Table 3. **Final Prioritization Rank System**

Prioritization Rating:	Score Range:
High	15 - 18
Moderate	10-14
Low	5-9

3. RESULTS

General Land Use, Land Cover Characteristics

The land use land cover map easily depicts the nature of land use along the north coast of Manabí Province (**Figure 8**). Depending on the watershed, between 98-99% of the land is composed of either forest or grazing pasture. Roads, rural development and inactive cropland/bare soil make up the remaining 1-2%. Across the study area, 58.7% of the landscape is covered in forest (primary and secondary) and 40.8% is cattle pasture[9]. In general, all four watersheds in this project area share a similar landscape characterization where lowland valleys and low-moderate sloped hillsides are dominated by pasture and the upland, steeper sloped regions have a higher proportion of semi-deciduous forest or montane forest. For all portions of the study area above an elevation of 300 m, 76% is covered in forest. In the Camarones and Tasaste watersheds, forest cover is over 90% at upper elevations. The final land use/ land cover categories are Forest, Pasture/Active Cropland, Bare Soil/Fallow Cropland, Rural Development, Paved Roads, Water Unclassified.

[9] The pasture class actually includes pasture and active cropland. The % cover of cropland could not be quantified, but is considered to be nominal.

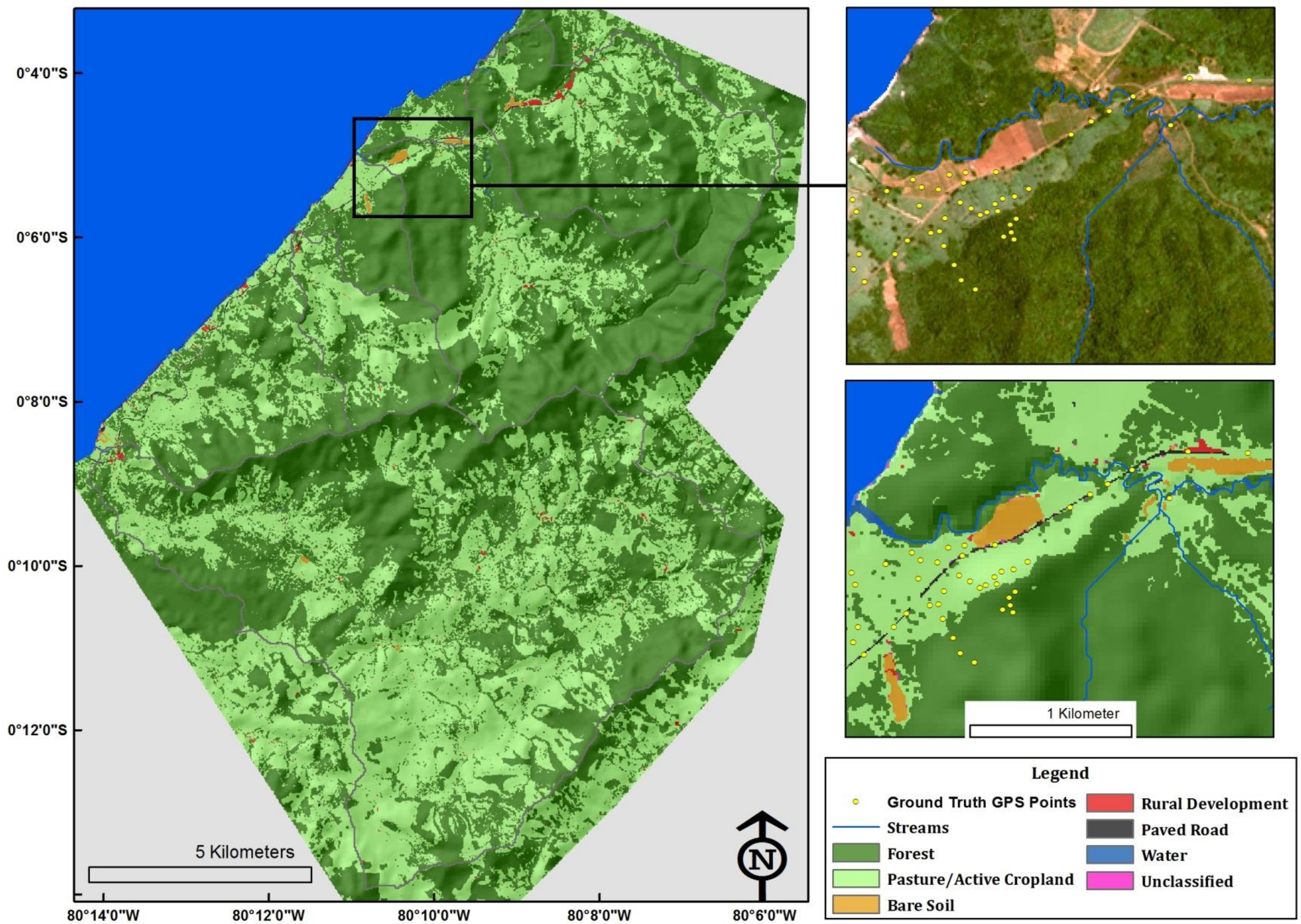

Figure 8. **Final Land Use/Land Cover Classification Map**

LULC Map Accuracy Assessment

Accuracy assessment is an essential part of the mapping process as any analyses relying on this map are subject to its accuracy. In order to gauge how well the supervised classification performed, I compared 174 ground truth GPS points to corresponding locations in the LULC map (**Figure 8**). The final land use land cover categories assessed for accuracy were Forest, Pasture/Active Cropland, Rural Development, and Paved Roads. A detailed accuracy assessment of the LULC classification can be explored through a contingency matrix (**Table 4**). The columns represent all the GPS ground truthing points that were collected, separated by class. The rows show the classified image's representation of those 174 ground truthing points. Numbers along the diagonal denote correctly classified points for a given LULC class. To yield the overall accuracy, the diagonal numbers were summed and then divided by the total GPS points.

Overall accuracy of the map was found to be 92%, indicating the classification performed very well. The producer's accuracy (**Table 5**) indicates how well I classified the satellite imagery by the reference dataset (columns). It defines the errors of omission; that is, when a pixel is misclassified into another class. The Forest class was accurately classified 96.9% of the time and Pasture pixels were classified with an accuracy of 96.3%, leaving only 5 of 152 pixels misclassified between the two classes. Other classes were not classified as accurately; however, when weighted by % area on the landscape they had little impact on map accuracy. For example, total producer's accuracy weighted by area[10] of each class resulted in 96.4%, while user's weighted accuracy was 91.9% (**Tables 5 & 6**).

Table 4. LULC Accuracy Assessment: Contingency Matrix

		Reference Data						
		Forest	**Pasture**	**Bare Soil**	**Rural Dev.**	**Paved Road**	**Water**	**Row Total**
Classified Data	**Forest**	**95**	2	0	0	1	0	**98**
	Pasture	3	**52**	0	1	5	0	**61**
	Bare Soil	0	0	**0**	0	0	0	**0**
	Rural Dev.	0	0	0	**5**	2	0	**7**
	Paved Road	0	0	0	0	**8**	0	**8**
	Water	0	0	0	0	0	**0**	**0**
	Column Total	**98**	**54**	**0**	**6**	**16**	**0**	**174**

Overall Accuracy:
91.95%

[10] Unclassified cells were not assessed for accuracy, therefore the study area % column do not sum to 100%.

Table 5. Producer's Accuracy Weighted by Area

Producer's Accuracy		% of Study Area	Accuracy Weighted by Area
Forest	**96.9%**	58.72%	56.92%
Pasture	**96.3%**	40.79%	39.28%
Bare Soil	0.0%	0.15%	0.00%
Rural Dev	83.3%	0.20%	0.16%
Paved Ro:	50.0%	0.04%	0.02%
Water	0.0%	0.05%	0.00%
		Total Weighted Accuracy:	**96.39%**

Table 6. User's Accuracy Weighted by Area

User's Accuracy		% of Study Area	Accuracy Weighted by Area
Forest	**96.9%**	58.72%	56.92%
Pasture	**85.2%**	40.79%	34.77%
Bare Soil	0.0%	0.15%	0.00%
Rural Dev.	71.4%	0.20%	0.14%
Paved Road	100.0%	0.04%	0.04%
Water	0.0%	0.05%	0.00%
		Total Weighted Accuracy:	**91.88%**

LULC Summary: Catchment Scale

Both Tabuga and Camarones watersheds have comparable catchment size and land cover statistics. The former is comprised of 2,306 ha and with 72.5% forest cover, while Camarones is slightly bigger at 2,843 ha and has 74.8% forest cover (**Table 7**). Tasaste is the smallest of the four sites with less than 1,000 ha. Nearly half of Tasaste's forests have been converted to grazing pasture. A similar story is shared for Don Juan, where forests make up 50.3% of the catchment area; however, that equates 4,000 ha of lost forest or 28% of the entire study area. The difference between lower levels of deforestation in Tabuga and Camarones (25 - 28%) and that found in Tasaste and Don Juan (~50%) can be explained by the fact that large portions of the former two watersheds share the highest and steepest ridgelines in the county of Jama, making these regions unsuitable for timber extraction and agriculture development.

Table 7. **LULC Summary: Catchment-Wide Scale**

Basin	Catchment Area (ha)	Land Cover Type Forest	Pasture/ Active Cropland	Bare Soil/ Fallow Cropland	Other *	Unclassified
Tabuga	2,306	**72.5%**	**26.5%**	0.2%	0.7%	0.1%
Camarones	2,843	**74.8%**	**24.4%**	0.4%	0.3%	0.0%
Tasaste	894	**53.1%**	**46.4%**	0.1%	0.3%	0.1%
Don Juan	8,614	**50.3%**	**49.4%**	0.1%	0.2%	0.1%

* Includes Rural Development, Roads and Water

LULC Summary: Stream Network Scale

In order to better understand land cover dynamics near streams, LULC metrics were calculated within fixed-distances of 30 & 100 m from major riparian corridors.

30-Meter Buffer

For upstream areas above each water quality sampling location, the area and percent cover of each land use category was calculated within a 30-m buffer (**Table 8**). Of the 18 sampling locations shown in Table 4, those sampling site names denoted in green reside at or near the downstream outlet and those in orange are headwater sampling sites. Sampling location names with progressively higher numbers correspond to a location further upstream along the main channel for a given watershed. For example, Ca01 is the outlet sampling location for Camarones watershed (**Figure 2, Table 8**). Metrics calculated for this row represent land cover contained within a 30-m buffer around the entire stream network of the Camarones watershed. Ca06 is the furthest upstream sample location near the headwaters and thus LULC metrics calculated for this row only include a limited buffer area around headwater sites and include nothing downstream from that location. This same scale reference should be applied to all intermediate sampling locations between the outlet and headwaters. Refer to **Figure 2** for a map of the sampling locations.

For all watersheds except Camarones, streamside forest cover is slightly higher when compared to the entire catchment statistics shown in the previous section. As explained by the green rows which encompass the whole stream network, forest cover increases by ~7% for Tabuga and Don Juan, while Tasaste increases by ~2%. Camarones decreases in forest cover by ~ 2%. As one continues upstream through the sampling locations, a gradual rise in forest cover occurs. This is consistent with previous assessments where forest cover increases with elevation. All headwater sites have 100% forest cover at this scale.

Table 8. **LULC Summary: Stream Network Scale (30 m)**

		Land Cover Area (ha)				Land Cover %		
Stream	Sampling Location	Forest	Pasture/ Active Cropland	Other *	Total Area	Forest	Pasture/ Active Cropland	Other *
Tabuga								
	Ta01	87	21	2	110	**79.2%**	**19.4%**	1.4%
	Ta02	67	18	1	85	78.0%	20.6%	1.4%
	Ta03	35	7	0	43	82.5%	17.5%	0.0%
	Ta04	3	0	0	3	**100.0%**	**0.0%**	0.0%
Camarones								
	Ca01	112	41	1	154	**72.6%**	**26.9%**	0.6%
	Ca02	83	34	0	117	70.6%	29.0%	0.4%
	Ca03	32	2	0	34	92.9%	7.1%	0.0%
	Ca04	15	0	0	15	100.0%	0.0%	0.0%
	Ca05	10	0	0	10	100.0%	0.0%	0.0%
	Ca06	2	0	0	2	**100.0%**	**0.0%**	0.0%
Tasaste								
	Ts01	27	21	0	49	**55.4%**	**43.8%**	0.8%
	Ts02	25	20	0	45	55.8%	43.7%	0.5%
	Ts03	0.1	0	0	0.1	**100.0%**	**0.0%**	0.0%
Don Juan								
	Do01	216	159	2	378	**57.2%**	**42.2%**	0.6%
	Do02	215	156	2	373	57.5%	41.9%	0.5%
	Do03	153	110	2	265	57.8%	41.6%	0.6%
	Do04	79	39	0	119	66.7%	32.9%	0.4%
	Do05	0.5	0	0	0.5	**100.0%**	**0.0%**	0.0%

* Includes Bare Soil, Rural Development, Roads, Water and Unclassified

100-Meter Buffer

By expanding beyond the 30-m riparian zone to a 100-m buffer, we can see how land use patterns are shaped more generally near stream channels. Forest cover within a 100 m buffer upstream of each sampling location is lower for all watersheds (**Table 9**). Ta01 sees a drop from 79.2% to 63.4%. Ca01 forest cover comes down to 64.5% from 72.6%. Both Ts01 and Do01 decrease in forest cover by ~10%. Similarly to the 30-m scale, all watersheds experience higher forest cover as you step through sampling locations up to the headwaters site. Compared to the catchment wide characteristics (**Table 7**), forest cover is also universally lower for all watersheds indicating that the threat of conversion from forest to pasture and cropland is greater along zones more centrally located to high-order stream channels (**Figure 9**).

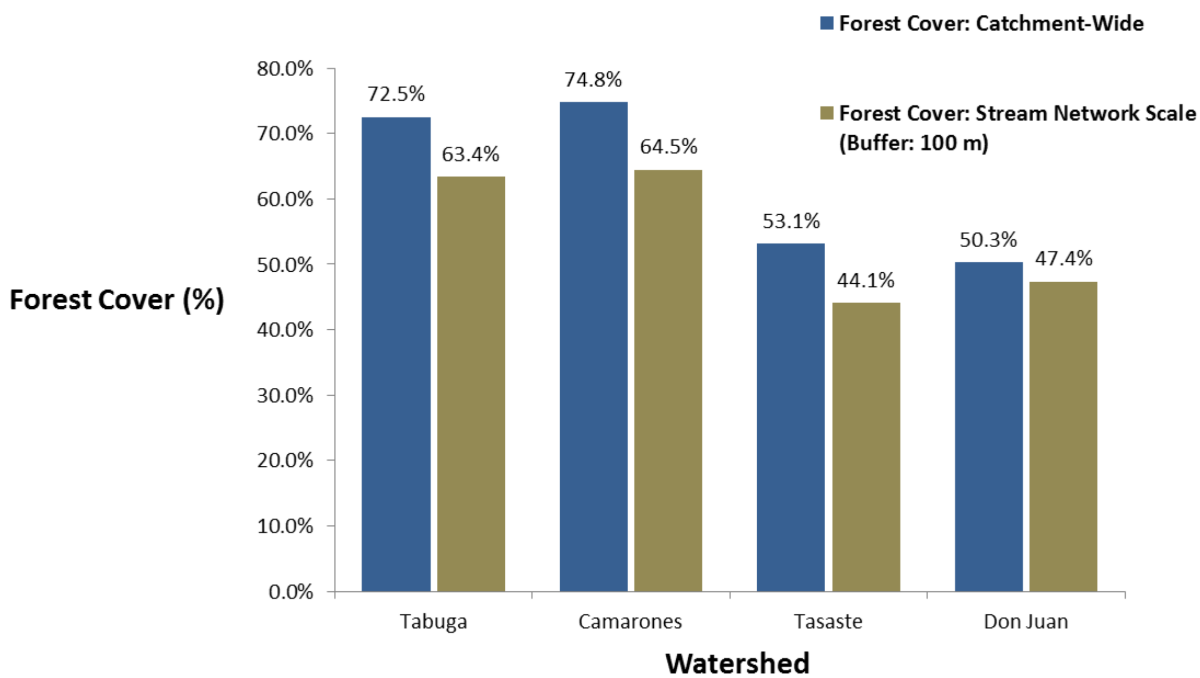

Figure 9. **Forest Cover Comparison: Catchment vs. Stream Network (100 m)**

Table 9. LULC Summary: Stream Network Scale (100 m)

Stream	Samping Location	Land Cover Area (ha) Forest	Pasture/ Active Cropland	Other *	Total Area	Land Cover % Forest	Pasture/ Active Cropland	Other *
Tabuga								
	Ta01	261	137	14	412	**63.4%**	**33.3%**	3.3%
	Ta02	195	118	8	322	60.7%	36.7%	2.6%
	Ta03	105	54	0	159	65.9%	33.9%	0.1%
	Ta04	14	0	0	14	**100.0%**	**0.0%**	0.0%
Camarones								
	Ca01	363	191	9	562	**64.5%**	**34.0%**	1.5%
	Ca02	266	165	4	435	61.2%	37.9%	0.9%
	Ca03	108	19	0	127	85.4%	14.6%	0.0%
	Ca04	55	0	0	56	99.5%	0.5%	0.0%
	Ca05	38	0	0	38	100.0%	0.0%	0.0%
	Ca06	7	0	0	7	**100.0%**	**0.0%**	0.0%
Tasaste								
	Ts01	77	95	2	175	**44.1%**	**54.5%**	1.4%
	Ts02	73	89	1	163	44.8%	54.7%	0.5%
	Ts03	1	0	0	1	**100.0%**	**0.0%**	0.0%
Don Juan								
	Do01	666	730	11	1407	**47.4%**	**51.9%**	0.8%
	Do02	663	721	9	1393	47.6%	51.7%	0.6%
	Do03	455	545	7	1006	45.2%	54.1%	0.7%
	Do04	226	204	1	432	52.4%	47.3%	0.3%
	Do05	2	1	0	3	**71.0%**	**29.0%**	0.0%

* Includes Bare Soil, Rural Development, Roads, Water and Unclassified

Land Use Impacts on Water Quality

Based on preliminary water quality data collected in the summers of 2011-2012, it appears that temperature, turbidity, and habitat assessment score are the most prevalent indicators showing an effect of land use patterns on stream health and water quality within this region. Stream temperature was negatively correlated ($p<0.001$) with % forest cover within a 30-m wide riparian zone (60-m total), as expected from previous research (**Figure 10**). The amount of suspended solids (e.g. turbidity) was also showed a significant negative relationship to % forest cover calculated from the entire upslope drainage to a given water quality sampling site (**Figure 11**). Conversely, higher % pasture cover in a sampling point's drainage area resulted in more turbid water samples. Overall riparian condition at each sampling location was assessed through a habitat assessment score. This score was calculated using field observations for 10 habitat condition factors. Riparian condition scores strongly increased ($p<0.001$) with increasing forest cover in the riparian zone (**Figure 12**). Although these simple linear regressions give strong indication that % forest cover is a predictor of stream health and water quality indicators, further data collection of benthic macroinvertebrate surveys, fecal coliform counts, DO, pH, conductivity and nutrient concentrations will be necessary to fully understand more detailed relationships between land use and water quality in this rural region of coast Ecuador.

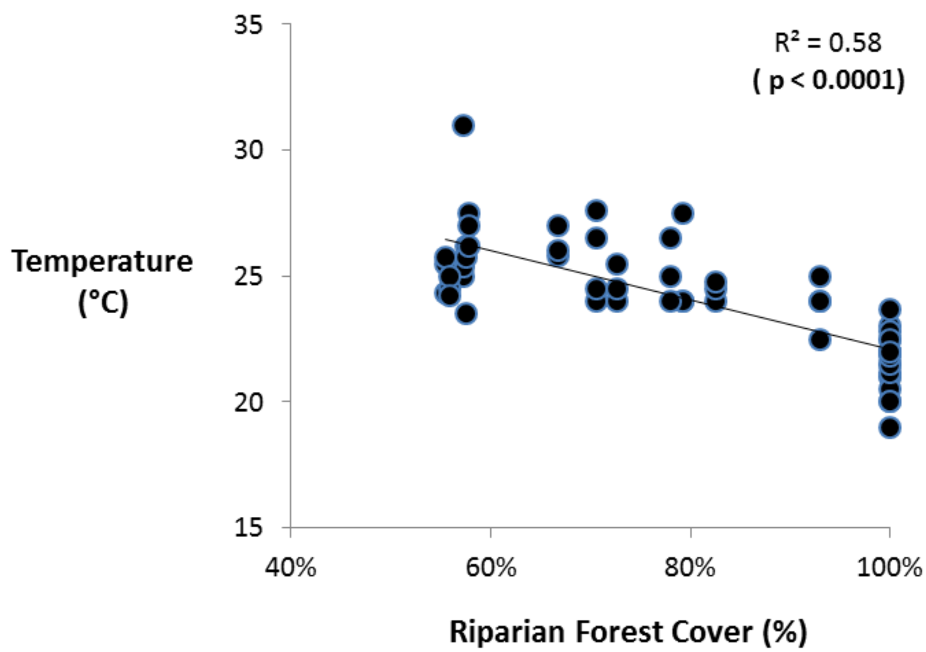

Figure 10. **Land Use Effects on Stream Temperature; p value is for a test of slope significantly different from zero**

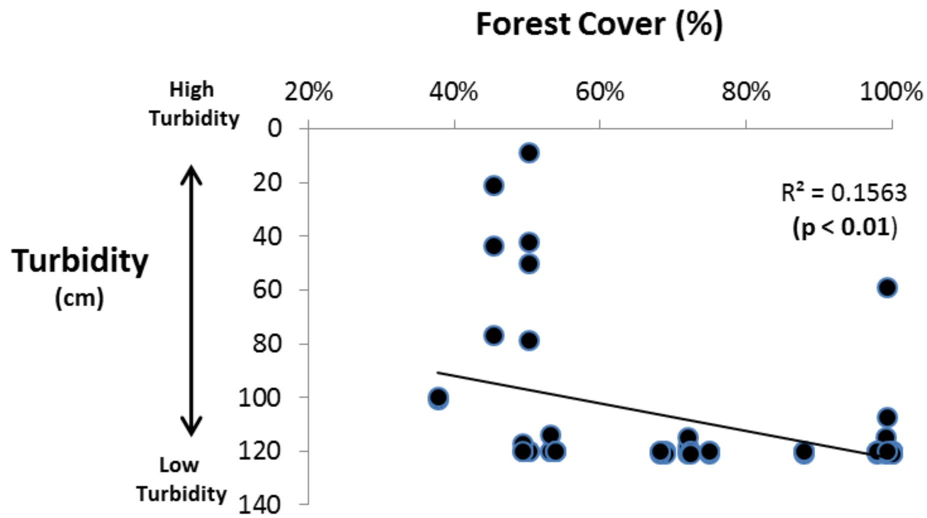

Figure 11. **Land Use Effects on Turbidity; p value is for a test of slope significantly different from zero**

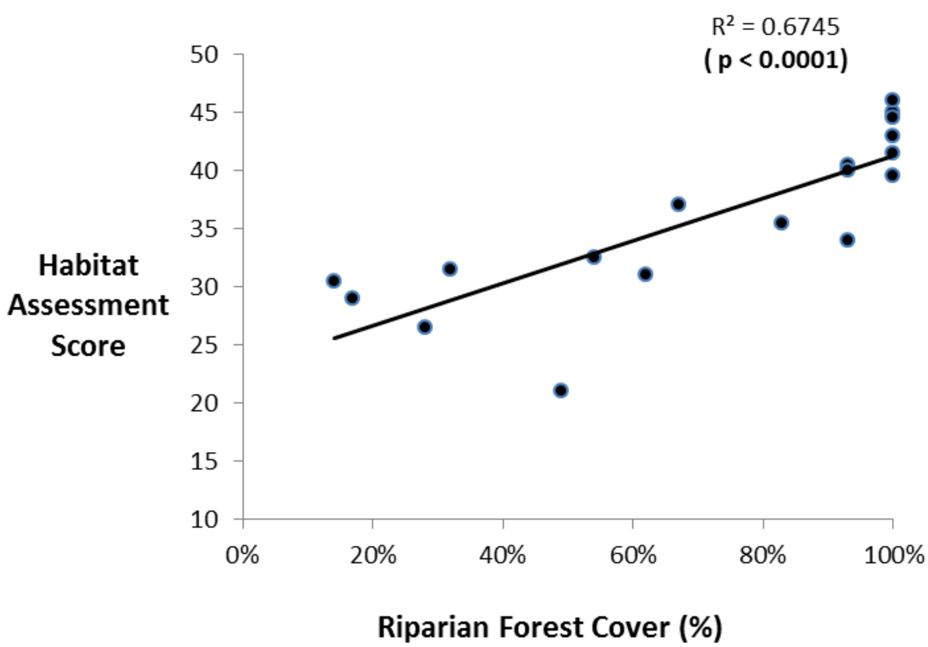

Figure 12. **Land Use Effects on Riparian Condition/Habitat Score; p value is for a test of slope significantly different from zero**

Identification of Potential Restoration Sites

A total of 1,668 riparian restoration sites were identified across the study area for a total of 318 ha that have potential for reforestation (**Table 10**). They range in size from 100 m^2 (minimum mapping unit: 1 pixel = 10 m x 10 m) to 4.1 ha, with a mean of 0.19 ha. The number of restoration sites for each watershed is proportional to the size of the catchment in which they are located.

Table 10. Summary of Restoration Unit Identification

	WATERSHED			
Landscape Metric	**Tabuga**	**Camarones**	**Tasaste**	**Don Juan**
Catchment Area (ha)	2,306	2,843	894	8,614
# of Potential Restoration Sites	269	324	104	971
Potential Restoration Area (ha)	30	55	27	206
Minimum Site Area (m^2)	100	100	100	100
Maximum Site Area (ha)	0.9	1.7	4.1	2.1
Mean Site Area (m^2)	1,108	1,684	2,633	2,214
Total Restoration Stream Channel Length (linear m)	10,587	14,292	2,143	34,378

Tabuga

Within the Tabuga watershed, 269 potential riparian restoration units were identified which range in size from 100 m^2 to 8,988 m^2 (~.90 ha). Together they total 30 ha and span 10,587 linear meters of stream channel (**Table 10**). The vast majority of these restoration units are located around Tabuga's main stream channel and at lower elevation tributaries where forest-to-pasture conversion is abundant. Low order streams that lie at higher elevations were generally encompassed by intact forest.

Camarones

The Camarones watershed is slightly larger than the Tabuga watershed by 600 ha (**Table 10**). As expected, it contains more potential restoration sites. Three hundred twenty-four sites were identified which yield 55 acres of potential restoration area. The maximum site is 1.7 ha, nearly double the largest site within the Tabuga watershed.

Tasaste

Tasaste is the smallest of the four watersheds and contains 104 potential restoration sites for a total of 27 ha in area (**Table 10**). However, it has the largest mean site area (.26 ha) and the largest maximum restoration site area (4.1 ha). This is attributed to long segments of contiguous riparian forest gaps along one of the main tributaries to Tasaste's main channel. Overall, there are fewer riparian zones in need of restoration because of the watershed's size. Just 2,143 linear meters of stream channel length were identified as potential restoration sites.

Don Juan

The large size of Don Juan (8,614 ha) combined with high deforestation (~50%) cause it to be the largest source of restoration sites. In all, 971 sites were identified that pool together 206 ha of potential riparian reforestation area. The topography is rather different in Don Juan as compared to the other watersheds. In general, hillsides are more accessible and there are far fewer high elevation peaks with steep slopes. As such, the conversion from forest to pasture is more prevalent and occurs throughout the watershed even near upper reaches. It follows that the spatial extent of restoration sites is more widespread and less localized than in the other watersheds.

Prioritization of Riparian Restoration Sites

After applying the prioritization model to the 1,668 potential restoration sites, just 63 sites were identified as "high" priority across the four watersheds (**Table 11**). Of the remaining potential sites, approximately 48% were ranked as "moderate", while another 48% ranked as "low" priority. On a per-hectare basis, the amount of "high" priority sites was proportional to catchment size. The largest watershed, Camarones, has 40 sites, while the smallest watershed, Tasaste, has just 6 sites.

Table 11. **Summary of Results from Site Prioritization**

	Priority Site Rankings				
Watershed	**Hi**	**Moderate**	**Low**		**Potential Sites**
Tabuga	10	142	117		269
Camarones	7	129	188		324
Tasaste	6	55	43		104
Don Juan	40	469	462		971
				Total:	1668
Total Sites by Rank:	63	795	810	1668	
Proportion of Sites by Rank:	3.8%	47.7%	48.6%	100%	

A Case Study: Tabuga Watershed

The results of the riparian restoration prioritization model are described below. Though each of the four watersheds underwent the same analysis and prioritization, I will focus in detail on the Tabuga watershed in terms of model performance and ranking potential sites for restoration recommendations. The Ceiba Foundation for Tropical Conservation has strong community ties in Tabuga and it is most likely this watershed would serve as the pilot area for initial reforestation projects.

Table 12. Summary of Criteria Score Results: Tabuga Watershed

Restoration Site Rankings	Potential to improve water quality & hydrologic functioning		Feasibility	Potential to improve wildlife habitat	
	Reduction of Riparian Gaps	Flow-Based Buffering Capacity	Access to Labor & Restoration Resources	Habitat Connectivity	Core Habitat Area
Sites Ranking "High"					
% of sites	47%	3%	48%	99%	5%
No. of sites	125	8	130	267	12
Area (ha)	23.4	3.6	16.2	29.8	6.2
Sites Ranking "Moderate"					
% of sites	14%	5%	43%	1%	33%
No. of sites	39	13	115	2	90
Area (ha)	3.8	4.5	12.3	0.02	18.6
Sites Ranking "Low"					
% of sites	39%	92%	9%	0%	62%
No. of sites	105	248	24	0	167
Area (ha)	2.6	21.7	1.3	0.0	5.0

Criteria 1: Reduction of Riparian Gaps

Nearly half the sites (47%) scored high in this category indicating that riparian gaps occur quite frequently throughout the watershed. The remaining 53% of the potential sites have a forested buffer located between themselves and the stream channel.

Criteria 2: Flow-Based Buffering Capacity

Only 3% of the 269 potential sites in this watershed were ranked high priority based on their potential buffering capacity. Because this criteria is ranked with double weight than the other variables (scored 1-6), the fact that it is also highly selective based on flow accumulation metrics means that only those potential sites that rank high here will have a high priority ranking overall. Given the large number of initial potential sites, this is an ideal scenario for focusing in on those parcels that offer the best potential to meet restoration objectives. It also means the model is doing its job of assigning priority value based on actual landscape features.

Criteria 3: Access to Labor & Restoration Resources

Most of the sites rank as high or moderate for this measure. Only 9% of restoration sites rank low because they are too far from roads or labor sources to be feasible. This statistic reaffirms the earlier findings that the furthest locations deep in the watershed are typically at higher elevations where minimal land use conversion has occurred.

Criteria 4: Habitat Connectivity

This measure was the least selective in assigning high priority rankings. Nearly all (99%) of the potential sites received a high priority score. Future modification of this model will examine landscape analyses in relation to forest connectivity that will help discern between sites that offer the best ecological services from linking forest patches of differing size and location to other land uses.

Criteria 5: Core Habitat Area

The majority of Tabuga's restoration sites score low for this measure based on their core area/edge ratio. Because many sites are small and composed of a single pixel (100 m^2), this measure helped the model focus on areas of significant size that were more realistic for reforestation efforts and provided core area value for potential wildlife habitat improvement. Only 5% of the sites had a large enough area/edge ratio to be ranked as high priority. Criteria 2 and 5 are the most selective in determining overall top priority sites for the Tabuga watershed. Similar results occurred for the other three watersheds in the study.

4. DISCUSSION

Interpretation of Results

The analysis of land cover change has shown that within the four coastal watersheds in the study area, the severity of deforestation ranges from 24% to 50% primarily due to conversion to pasture for livestock production. This type of land use change further increases by as much as 10% for areas closest to higher order streams showing an increased threat to riparian zones. Keeping in mind that loss of native forest cover throughout the vast majority of the coastal plain reaches a staggering 80%-98%, it becomes clear that the preservation of these last forest fragments is critical to the overall conservation goals in western Ecuador. The severity of deforestation at the catchment-wide scale gives an early indication of overall watershed degradation and the potential for reduced ecological functioning. However, catchment-wide summary metrics only measure proportions of LULC and provide no insight into location of land use conversion. Determining land use patterns within buffers of streams offers an approach to examine how land is managed within the more accessible locations.

Inside riparian zones of 30 m surrounding streams (60 m total width), forest cover increased nominally across all watersheds (except for Camarones which slightly decreased) when compared to the catchment measurement (**Tables 7 & 8**). It appears there is a minor preference for preserving a functional riparian buffer that is consistent with best management practices. As the literature suggests, most riparian effectiveness occurs within the first 30 m of the stream channel (Mayer et al. 2007). In general, forest cover along these narrow riparian areas is more or less consistent with general forest cover in the catchment. Unfortunately, for watersheds with the highest levels of deforestation (Tasaste and Don Juan), even an increase of 7% of forested riparian area may offer little protection from a landscape that has lost half of its forest cover. At the very least, riparian areas do not experience more forest loss when compared to the catchment scale.

The health of a given segment of stream is not entirely indicative of land cover within a narrow 30 m zone. Upslope geomorphology and land use play critical roles in the transport of nutrients, sources of organic matter, bacteria, fine sediments, and pollutants to stream networks. By examining metrics within a 100-m riparian zone, the picture becomes clearer as to how land use is characterized in broader areas adjacent to streams. All watersheds experience distinct drops in forest cover between catchment-wide and the 100-meter buffer scale as shown in **Figure 9.**

Using preliminary water quality data from 18 sampling locations across the study area, significant relationships were found between forest cover and the most standard stream health indicators. Stream temperature, turbidity and habitat assessment (riparian health assessment) proved to be the simplest and best indicators for detecting the effects of land use change on stream water quality in this part western Ecuador. Stream temperature showed a significant negative correlation with increasing % forest cover within a 30-m riparian buffer zone (60-m total width). This empirically supports the notion that intact riparian canopy provides shade and moderates potential solar radiation heating of water temperature. Turbidity, a measurement of suspended particles in water and regarded as the simplest visual indicator of drinking water quality, increased at sampling locations with higher proportions of cattle pasture within their drainage area. Lastly, an in depth habitat assessment yielded riparian condition scores that were strongly and positively correlated with increased forest cover in the proximate riparian zone[11]. Such findings were expected and match results from similar assessments as carried out in the eastern Amazon of Brazil (Figueiredo et al. 2010).

As mentioned previously, Canton Jama has the majority of the highest peaks along the coastal mountain range in western Ecuador. Thus, it is not surprising to find the last few remnants of semi-deciduous dry forest and coastal montane forest here. Fortunately, conservation NGO's like the Ceiba Foundation for Tropical Conservation (CFTC), Fundación Jatun Sacha, Third Millennium Alliance, and Conservation International have all contributed to establishing protected reserves. Several of these have proved to be important partners for the Ecuadorian government by helping enroll landowners in the Socio Bosque payment for ecosystem services program over the past three years. Moving forward, these key stakeholders will provide a crucial role in the expanded protection of these special forests through the implementation of reforestation projects aimed at connecting forest patches via riparian corridors. As CFTC continues to work in Canton Jama studying relations between land use, water quality and human health, there is promise that future watershed management goals will benefit both the well-being of remaining forest fragments and the local communities that rely on freshwater resources. This project has taken the first step in identifying and prioritizing the most suitable sites for riparian habitat restoration at the watershed scale.

Among the 1,668 potential restoration sites identified within the study area, only 3.8% scored in the highest priority class. These top ranked sites for reforestation consideration are larger in size, maximize core area for wildlife habitat, and have the best potential to enhance riparian buffer functioning once restored. Alternatively, the lowest ranked sites were smaller in

[11] Defined by 30 meter distance out from each side of the stream bank and then 100 meters upstream of a sampling location

size, had low core area in relation to the sites' perimeter, and less ability to provide buffer functioning because they contained little or no upslope surface flow pathways. Based on the prioritization methodology, this was expected for two reasons. First, the identification procedure identified all non-forest parcels[12] within a total 60-m buffer from the stream channel as potential restoration sites. However, this allowed for parcels comprised of a single cell (10 x 10 m) to be considered a potential site. Sites of this small size scored low for the area/edge ratio criteria and would not be sufficiently large to enhance wildlife habitat.

Secondly, not all streamside riparian areas have the ability to buffer surface runoff. Upslope geomorphology determines which areas receive abundant, moderate, or minimal surface flow. For example, a study in New Zealand found that within a 280-ha watershed, 85% of surface runoff entered streams through only 28% of the riparian zone (McGlynn and Seibert 2003). As mentioned in section 3, I added increased weight to the functional buffering capacity scoring metric[13] to account for this highly selective landscape feature. Given a limited restoration budget, the main goal with restoration planning on a large scale is to focus on riparian zones that will maximize ecological services. This project's objectives focus principally on the improvement of drinking water quality by mitigating surface flow containing fine sediment and fecal bacteria from adjacent grazing pastures. It would not be consistent with goals or be cost-effective to plant native trees along a streamside zone that receives minimal upslope surface flow from non-point sources of pollution.

Use and Limitations of Watershed Restoration Planning

This study uses the best available geospatial data to begin the restoration planning process that would be otherwise impossible through in-depth field studies due to lack of time, human resources and finances. The methodology employed here is the most cost-effective and repeatable method for prioritizing potential restorable land parcels. The prioritization model has been applied to four different watersheds showing its applicability and flexibility across different catchment boundaries. Should further data become available, the model is also adaptable to incorporate new information. Similar GIS-based restoration planning projects in Mexico and South America developed ranking schemes that contained socioeconomic and cultural datasets specific to a given focus area in addition to ecology based datasets (Gonzalez-Espinosa et al. 2007, Orsi and Geneletti

[12] Excludes rural development and roads, which are considered to be permanent land uses.
[13] Ranked 1-6 instead of 1-3.

2010, Orsi et al. 2011). Such information could augment the restoration planning within Canton Jama.

There are certain limitations that arise when solely relying on existing geospatial data for planning restoration projects. Certainly, the addition of further high quality datasets would enhance the model robustness. For example, a large portion of the stream network used in this project was generated with a 30-m resolution digital elevation model. In terms of flow pathways, this resolution is fairly coarse and fails to account for the micro-topography that exists in all landscapes. This loss of complexity generalizes surface flow patterns and may not fully describe potential runoff impacts into streams. As new remote sensing technologies become operational, these uncertainties will be addressed. In particular to DEMs, the TanDEM-X mission will soon offer higher quality global elevation datasets with spatial resolution of 12 m and vertical error of 2 m starting in 2014 (Lopez-Dekker et al. 2011). In the meantime, on the ground verification of the results from my prioritization model will provide insight into the effectiveness of the composite DEM[14] that was used for identifying riparian zones containing high flow accumulation.

Another source of error comes from the accuracy of the LULC map which served as one of the base datasets for the restoration planning model. Based on the initial assessment showing a weighted producer's accuracy of 96%, the classification performed very well. However, it should be noted that the whole study area does not likely have this level of accuracy when considering current ground cover. There is a two to four year gap between the satellite image acquisition dates and ground control data collection in 2011. This amount of time is sufficient for minor land use change. Such change would likely represent loss of forest cover as opposed to regeneration of secondary forests. Also, there may not be a clear distinction between forest and pasture in areas where pasture is beginning regeneration of secondary forest. The ground truthing points were accurately identified within large, homogeneous land cover parcels while those near edges experienced higher misclassification. Because riparian areas contain complex and fragmented forest/pasture/cropland borders, there might be more inherent error in classifying these regions of the landscape.

A more vigorous accuracy measurement based on a comprehensive and random sampling across Canton Jama would strengthen the classification accuracy assessment. Yet, unrestricted access to private lands and a substantial investment of time and money would be necessary for this type of data collection. At this point in time, it is rather outside the scope of local stakeholder's

[14] SavGIS & ASTER GDEM2 (NASA)

resources. Clearly, using satellite imagery of 10-m resolution, this supervised classification has resulted in a robust and validated LULC map based on the best available ground truthing reference datasets.

5. RECOMMENDATIONS & CONCLUSION

Riparian Restoration Management Guidelines

Similar to how the LULC map needed an accuracy assessment, the results from the prioritization model must be validated through on the ground field observations. My initial suggestion for CFTC is to use the restoration site list for each of the watersheds and carry out field initial examinations of the highest ranked sites. The top 10 list for Tabuga is shown in **Table 13** as an example. I have generated a separate ArcGIS shapefile for each watershed that contains the polygon boundaries, location, attributes, and prioritization ranking of all potential restoration sites within a given watershed. The prioritization ranking of the top 50 restoration sites for each watershed can be examined in detail in **Appendix Tables A1-A4**.

Table 13. Top 10 Restoration Sites: Tabuga Watershed

Top 10	Site ID	Final Criteria Score
1	182	18
2	126	17
3	178	17
4	230	17
5	269	17
6	30	16
7	134	16
8	31	15
9	121	15
10	145	15

Depending on the results from the validation, the model can undergo a series of modifications to increase accuracy for identifying potential riparian zones that will better meet CTFC's restoration goals. Restoration projects are always limited by available funding. In order to realize the implementation of such projects, fundraising ought to be the highest priority in coming years. A cost analysis for riparian reforestation projects in coastal Ecuador was outside the range of analysis for this project; however, it should be considered before applying for and securing funds. Well-funded projects can bring much needed economic relief to rural communities by hiring a labor force and also ensure the potential for full implementation and project success.

Water Quality Data Collection

This section outlines recommendations for future water quality data collection with the assumption that sufficient human and financial resources are available to carry out this level of work. If possible, sampling consistently at least once a month, year-round would go a long way in providing a continuous and reliable water quality dataset. This is important in the short run to assess how current land use patterns relate to stream health and drinking water quality, but will also be pertinent in the future for post-restoration monitoring. It would be even more ideal to sample twice a month. Any sampling instruments should be calibrated frequently to ensure proper measurements over time. Also, certain indicators such as temperature and dissolved oxygen respond to daily oscillations, therefore data collection should occur at consistent times of day to ensure validity of comparisons across sites or over time.

In regards to water quality and human health, the protocol could be augmented to sample for indicators most directly related to drinking water quality. An initial effort has been made to collect fecal coliform bacteria data; however, rigorous and repeated sampling will be needed because coliform counts vary drastically over space and short periods of time. Additional indicators of consideration include pH, conductivity, nutrient concentrations, presence of heavy metals, and turbidity measured in NTU units. The combination of information from this type of sampling and human health surveys/interviews taken in local communities will further shed light on water quality and human health linkages.

The analysis of water quantity in these watersheds has yet to be explored. If possible, the measurements of discharge following rain events and during wet season base flow may provide insight as to how deforestation may be impacting the availability of water draining from the watershed.

Additional GIS Data Collection

Geospatial datasets taken with a GPS receiver are considered to serve as reference datasets with the least amount of locational error. The accuracy of the stream network could be greatly enhanced by delineating the main channels and major tributaries on foot with a GPS device. Since cropland areas were hard to distinguish from pasture land, new and large active cropland should be traversed and added to a GIS dataset. It would also serve the project well to determine land ownership information on parcels considered to be of high priority for restoration. It is highly likely that landowners may not want to reforest riparian areas that are under current production and generating income. Lastly, anytime there is potential to collect additional LULC ground truth points it would benefit the confidence of the accuracy assessment.

Conclusion

In summary, I have created a new suite of digital geographic datasets that are significant to this region of high conservation value including the following: land use/land cover map (10 m resolution) and ground-truthing dataset, a cloud-free composite satellite image (2 images from SPOT5, 2 from Landsat ETM+), a hand-digitized stream network based on high resolution SPOT5 images (5 m) and a hydrologic flow accumulation model, a digital elevation model, watershed and sub-catchment boundaries, and a geospatial toolkit that incorporates the above databases to effectively locate riparian corridors that are in greatest need of reforestation.

Although the watersheds of Tabuga, Camarones, Tasaste and Don Juan have not lost as much forest cover in comparison to the majority of coastal Ecuador, evidence from this study suggests that forest to pasture conversion of 24% to 50% negatively impacts riparian condition and water quality sufficiently to warrant the need for habitat restoration projects. Using the best available geospatial data, this evaluation has identified and prioritized a total of 63 riparian restoration units across the four watersheds[15]. These sites represent the most likely candidates for meeting the restoration objectives of improving water quality and providing wildlife habitat connectivity. The prioritization model proved highly effective and adaptable across different watersheds. The fact that it selected only 3.8% of the 1,668 potential sites as highest priority shows that restoration planning through remote sensing and geospatial modeling is the quickest and most affordable method for determining where to begin restoration efforts across a 14,000+ ha landscape.

[15] Tabuga: 10, Camarones: 7, Tasaste: 6, and Don Juan: 40

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APPENDIX A

TABLE A1: TOP 50 RESTORATION SITES, TABUGA WATERSHED

ID	AREA	AREA_HA	EDGE	AREA_EDGE	STRM_FID	STRM_DIST	RURAL_DIST	FORBUF_DIS	SUM_FLOW	C1	C2	C3	C4	C5	RANK
182	8715	0.87	787	11.1	4	0.00	170.0	0.00	2179.00	3	6	3	3	3	18
126	1913	0.19	285	6.7	2	0.00	192.4	0.00	1121.00	3	6	3	3	2	17
178	3250	0.32	374	8.7	4	0.00	201.0	0.00	8682.00	3	6	3	3	2	17
230	5066	0.51	547	9.3	69	0.00	0.0	0.00	3335.00	3	6	3	3	2	17
269	5299	0.53	478	11.1	0	0.00	515.4	0.00	1133.00	3	6	2	3	3	17
30	1600	0.16	260	6.2	69	0.59	108.2	0.00	2760.00	2	6	3	3	2	16
134	3750	0.38	310	12.1	8	0.00	0.0	0.00	536.00	3	4	3	3	3	16
31	2500	0.25	400	6.3	0	5.00	530.0	0.00	1081.00	2	6	2	3	2	15
121	7195	0.72	750	9.6	69	0.00	882.0	0.00	913.00	3	5	2	3	2	15
145	8987	0.90	872	10.3	6	0.00	299.7	0.00	313.00	3	3	3	3	3	15
107	4704	0.47	489	9.6	69	0.00	0.0	0.00	484.00	3	3	3	3	2	14
148	3362	0.34	325	10.3	10	0.00	450.0	0.00	330.00	3	3	2	3	3	14
228	1918	0.19	331	5.8	69	0.00	0.0	0.00	270.00	3	3	3	3	2	14
244	2100	0.21	250	8.4	3	0.00	153.1	0.00	334.00	3	3	3	3	2	14
260	7675	0.77	845	9.1	1	0.00	89.4	0.00	340.00	3	3	3	3	2	14
268	2850	0.28	290	9.8	8	0.00	0.0	0.00	299.00	3	3	3	3	2	14
16	4413	0.44	438	10.1	69	0.00	594.1	0.00	108.00	3	2	2	3	3	13
28	2605	0.26	308	8.4	69	0.00	0.0	0.00	102.00	3	2	3	3	2	13
35	1799	0.18	259	6.9	69	0.00	832.2	0.00	472.00	3	3	2	3	2	13
98	2431	0.24	272	8.9	69	0.00	7.1	0.00	191.00	3	2	3	3	2	13
100	5594	0.56	682	8.2	69	0.00	9.3	0.00	105.00	3	2	3	3	2	13
120	6250	0.63	607	10.3	2	0.00	0.0	0.00	51.00	3	1	3	3	3	13
142	3900	0.39	450	8.7	3	0.00	328.9	0.00	392.00	3	3	2	3	2	13
172	1600	0.16	220	7.3	6	0.00	210.0	0.00	210.00	3	2	3	3	2	13
187	3450	0.35	341	10.1	6	0.00	546.9	0.00	214.00	3	2	2	3	3	13
231	3996	0.40	429	9.3	69	0.00	17.9	0.00	118.00	3	2	3	3	2	13
242	2098	0.21	329	6.4	4	0.00	308.7	0.00	321.00	3	3	2	3	2	13
254	1500	0.15	305	4.9	2	0.00	20.0	0.00	255.00	3	3	3	3	1	13
36	2255	0.23	296	7.6	69	0.00	103.1	0.00	63.00	3	1	3	3	2	12
38	5126	0.51	646	7.9	69	0.00	541.2	0.00	139.00	3	2	2	3	2	12
44	7463	0.75	695	10.7	0	0.00	442.0	0.00	29.00	3	1	2	3	3	12
46	798	0.08	139	5.7	69	0.00	170.0	0.00	0.00	3	1	3	3	2	12
47	1400	0.14	220	6.4	69	3.88	56.6	0.00	147.00	2	2	3	3	2	12
60	1143	0.11	154	7.4	69	0.00	28.3	0.00	0.00	3	1	3	3	2	12
68	3017	0.30	489	6.2	69	0.00	10.0	0.00	3.00	3	1	3	3	2	12
74	2612	0.26	321	8.1	1	0.00	0.0	0.00	46.00	3	1	3	3	2	12
76	1900	0.19	286	6.6	69	0.00	0.0	0.00	2.00	3	1	3	3	2	12
82	4568	0.46	624	7.3	69	0.00	0.0	0.00	27.00	3	1	3	3	2	12
91	866	0.09	157	5.5	69	0.00	59.0	0.00	12.00	3	1	3	3	2	12
97	986	0.10	177	5.6	69	0.00	0.0	0.00	6.00	3	1	3	3	2	12
101	1250	0.12	202	6.2	2	0.00	0.0	0.00	12.00	3	1	3	3	2	12
106	1800	0.18	300	6.0	69	9.58	20.0	0.00	157.00	2	2	3	3	2	12
110	1438	0.14	175	8.2	2	0.00	5.0	0.00	85.00	3	1	3	3	2	12
111	1050	0.11	194	5.4	8	0.00	50.0	0.00	75.00	3	1	3	3	2	12
117	1900	0.19	240	7.9	8	0.00	0.0	0.00	42.00	3	1	3	3	2	12
119	8937	0.89	938	9.5	3	0.00	60.0	0.00	76.00	3	1	3	3	2	12
122	1200	0.12	170	7.1	8	0.00	0.0	0.00	88.00	3	1	3	3	2	12
127	481	0.05	97	5.0	69	0.00	850.9	0.00	490.00	3	3	2	3	1	12
138	2100	0.21	250	8.4	2	0.00	429.5	0.00	120.00	3	2	2	3	2	12
149	1750	0.17	214	8.2	6	0.00	213.8	0.00	0.00	3	1	3	3	2	12

TABLE A2: TOP 50 RESTORATION SITES, CAMARONES WATERSHED

ID	AREA	AREA_HA	EDGE	AREA_EDGE	STRM_FID	STRM_DIST	RURAL_DIST	FORBUF_DIS	SUM_FLOW	C1	C2	C3	C4	C5	RANK
138	7605	0.76	719	11	68	0.00	0.00	0.00	5090	3	6	3	3	3	18
223	5263	0.53	540	10	68	0.00	22.67	0.00	3271	3	6	3	3	2	17
68	15577	1.56	1295	12	68	0.00	10.00	0.00	1360	3	4	3	3	3	16
220	13518	1.35	1052	13	12	0.00	19.35	0.00	1295	3	4	3	3	3	16
20	2781	0.28	348	8	68	0.00	0.00	0.00	1289	3	4	3	3	2	15
212	5475	0.55	545	10	21	0.00	1023.43	0.00	2477	3	5	1	3	3	15
226	9863	0.99	1168	8	15	0.00	666.03	0.00	2684	3	5	2	3	2	15
43	4529	0.45	595	8	68	0.00	0.00	0.00	898	3	3	3	3	2	14
150	4092	0.41	500	8	68	0.00	281.60	0.00	763	3	3	3	3	2	14
224	8809	0.88	806	11	15	0.00	0.00	0.00	389	3	2	3	3	3	14
246	14585	1.46	1342	11	68	0.00	47.40	0.00	357	3	2	3	3	3	14
283	3737	0.37	321	12	68	0.00	0.00	0.00	501	3	2	3	3	3	14
33	1300	0.13	240	5	68	7.31	0.00	0.00	778	2	3	3	3	2	13
73	1129	0.11	155	7	12	0.00	192.35	0.00	274	3	2	3	3	2	13
86	9238	0.92	820	11	68	0.00	0.00	0.00	179	3	1	3	3	3	13
168	15375	1.54	1079	14	15	0.00	536.00	0.00	510	3	2	2	3	3	13
200	6000	0.60	558	11	17	0.00	252.98	0.00	150	3	1	3	3	3	13
206	17050	1.71	1537	11	21	0.00	395.00	0.00	523	3	2	2	3	3	13
216	6075	0.61	558	11	68	0.00	0.00	0.00	151	3	1	3	3	3	13
222	10492	1.05	1140	9	16	0.00	0.00	0.00	525	3	2	3	3	2	13
282	8737	0.87	918	10	16	0.00	3.90	0.00	305	3	2	3	3	2	13
290	5015	0.50	391	13	15	0.00	20.00	0.00	144	3	1	3	3	3	13
312	4550	0.45	445	10	15	0.00	130.38	0.00	118	3	1	3	3	3	13
317	9337	0.93	798	12	15	0.00	607.45	0.00	549	3	2	2	3	3	13
345	3702	0.37	408	9	12	0.00	297.06	0.00	437	3	2	3	3	2	13
355	10487	1.05	883	12	12	0.00	0.00	0.00	225	3	1	3	3	3	13
372	8674	0.87	868	10	11	0.00	195.29	0.00	567	3	2	3	3	2	13
18	2381	0.24	276	9	68	0.00	0.00	0.00	104	3	1	3	3	2	12
23	3200	0.32	320	10	68	0.45	50.00	0.00	171	3	1	3	3	2	12
28	3092	0.31	413	7	68	0.00	0.00	0.00	209	3	1	3	3	2	12
35	4257	0.43	409	10	68	0.00	140.00	0.00	39	3	0	3	3	3	12
47	3624	0.36	417	9	68	0.00	127.28	0.00	224	3	1	3	3	2	12
48	10869	1.09	1065	10	5	0.00	70.69	0.00	69	3	0	3	3	3	12
74	7836	0.78	855	9	12	0.00	281.60	0.00	112	3	1	3	3	2	12
123	11932	1.19	1151	10	15	0.00	113.14	0.00	49	3	0	3	3	3	12
217	4975	0.50	441	11	68	0.00	0.00	0.00	37	3	0	3	3	3	12
218	5934	0.59	519	11	5	0.00	141.02	0.00	21	3	0	3	3	3	12
219	2830	0.28	373	8	5	0.00	80.79	0.00	212	3	1	3	3	2	12
221	5887	0.59	554	11	16	0.00	50.00	0.00	12	3	0	3	3	3	12
225	6955	0.70	724	10	68	0.00	0.00	0.00	189	3	1	3	3	2	12
254	2230	0.22	267	8	68	0.00	212.13	0.00	125	3	1	3	3	2	12
287	2788	0.28	333	8	68	0.00	64.03	0.00	134	3	1	3	3	2	12
289	4320	0.43	522	8	68	0.00	46.07	0.00	249	3	1	3	3	2	12
291	5390	0.54	805	7	15	0.00	41.32	0.00	110	3	1	3	3	2	12
300	1838	0.18	181	10	21	0.00	514.78	0.00	144	3	1	2	3	3	12
306	5700	0.57	558	10	17	0.00	253.18	0.00	58	3	0	3	3	3	12
368	5451	0.55	536	10	5	0.00	145.77	0.00	30	3	0	3	3	3	12
19	2733	0.27	359	8	68	0.00	130.00	0.00	64	3	0	3	3	2	11
31	990	0.10	186	5	68	0.00	80.62	0.00	5	3	0	3	3	2	11
63	1763	0.18	257	7	9	0.00	920.22	0.00	148	3	1	2	3	2	11

TABLE A3: TOP 50 RESTORATION SITES, TASASTE WATERSHED

ID	AREA	AREA_HA	EDGE	AREA_EDGE	STRM_FID	STRM_DIST	RURAL_DIST	FORBUF_DIS	SUM_FLOW	C1	C2	C3	C4	C5	RANK
104	35413	3.54	2598	14	13	0.00	35	0.00	8330	3	6	3	3	3	18
19	41444	4.14	3056	14	13	0.00	0	0.00	2179	3	5	3	3	3	17
65	4256	0.43	541	8	19	0.00	190	0.00	4591	3	6	3	3	2	17
40	3433	0.34	460	7	67	0.00	430	0.00	2917	3	5	2	3	2	15
64	6869	0.69	737	9	19	0.00	0	0.00	1547	3	4	3	3	2	15
73	2869	0.29	327	9	67	0.00	104	0.00	1983	3	4	3	3	2	15
8	1000	0.10	180	6	67	6.20	161	0.00	1704	2	4	3	3	2	14
12	10383	1.04	823	13	67	0.00	109	0.00	472	3	2	3	3	3	14
22	14658	1.47	1424	10	67	0.00	322	0.00	828	3	3	2	3	3	14
50	10675	1.07	962	11	19	0.00	110	0.00	293	3	2	3	3	3	14
56	2762	0.28	280	10	67	0.00	277	0.00	773	3	3	3	3	2	14
59	7609	0.76	635	12	67	0.00	20	0.00	464	3	2	3	3	3	14
4	2366	0.24	242	10	67	0.00	0	0.00	334	3	2	3	3	2	13
9	10434	1.04	944	11	67	0.00	0	0.00	129	3	1	3	3	3	13
55	4564	0.46	529	9	67	0.00	85	0.00	362	3	2	3	3	2	13
63	7948	0.79	702	11	67	0.00	171	0.00	206	3	1	3	3	3	13
93	5791	0.58	479	12	67	0.00	56	0.00	155	3	1	3	3	3	13
95	7352	0.74	675	11	67	0.00	134	0.00	119	3	1	3	3	3	13
6	1299	0.13	181	7	67	0.00	10	0.00	146	3	1	3	3	2	12
10	4678	0.47	364	13	67	0.00	286	0.00	54	3	0	3	3	3	12
54	2450	0.24	290	8	20	0.00	488	0.00	660	3	2	2	3	2	12
58	3978	0.40	464	9	67	0.00	130	0.00	217	3	1	3	3	2	12
62	4594	0.46	560	8	67	0.00	26	0.00	234	3	1	3	3	2	12
94	3555	0.36	326	11	67	0.00	0	0.00	32	3	0	3	3	3	12
2	919	0.09	144	6	67	0.00	0	0.00	4	3	0	3	3	2	11
11	900	0.09	160	6	67	0.00	180	0.00	52	3	0	3	3	2	11
29	3772	0.38	396	10	67	0.00	324	0.00	148	3	1	2	3	2	11
31	2086	0.21	240	9	67	0.00	209	0.00	63	3	0	3	3	2	11
44	3540	0.35	348	10	67	0.00	849	0.00	54	3	0	2	3	3	11
48	4039	0.40	437	9	67	0.00	999	0.00	208	3	1	2	3	2	11
66	1155	0.12	199	6	67	0.00	0	0.00	19	3	0	3	3	2	11
72	954	0.10	168	6	67	0.00	255	0.00	0	3	0	3	3	2	11
74	5847	0.58	619	9	67	0.00	210	0.00	4	3	0	3	3	2	11
83	1314	0.13	203	6	67	0.00	230	0.00	74	3	0	3	3	2	11
84	3167	0.32	308	10	67	0.00	454	0.00	83	3	0	2	3	3	11
92	855	0.09	150	6	67	0.00	250	0.00	0	3	0	3	3	2	11
96	426	0.04	107	4	67	0.00	118	0.00	166	3	1	3	3	1	11
97	2385	0.24	275	9	67	0.00	43	0.00	54	3	0	3	3	2	11
98	4152	0.42	531	8	67	0.00	0	0.00	61	3	0	3	3	2	11
101	809	0.08	157	5	19	0.00	112	0.00	0	3	0	3	3	2	11
103	4657	0.47	503	9	13	0.00	150	0.00	7	3	0	3	3	2	11
1	1900	0.19	220	9	67	2.66	0	0.00	0	2	0	3	3	2	10
13	480	0.05	96	5	67	0.00	222	0.00	0	3	0	3	3	1	10
15	559	0.06	134	4	67	0.00	233	0.00	19	3	0	3	3	1	10
28	426	0.04	105	4	67	0.00	282	0.00	0	3	0	3	3	1	10
32	1000	0.10	160	6	67	3.03	133	0.00	36	2	0	3	3	2	10
41	400	0.04	100	4	20	0.00	607	0.00	111	3	1	2	3	1	10
46	4135	0.41	541	8	67	0.00	767	0.00	54	3	0	2	3	2	10
67	157	0.02	81	2	67	0.00	30	0.00	0	3	0	3	3	1	10
68	207	0.02	72	3	67	0.00	0	0.00	0	3	0	3	3	1	10

TABLE A4: TOP 50 RESTORATION SITES, DON JUAN WATERSHED

ID	AREA	AREA_HA	EDGE	AREA_EDGE	STRM_FID	STRM_DIST	RURAL_DIST	FORBUF_DIS	SUM_FLOW	C1	C2	C3	C4	C5	RANK
159	500	0.05	120	4	25	14.1	914	0.00	0	1	6	3	3	3	18
290	100	0.01	40	3	25	21.2	967	0.00	0	1	6	3	3	3	18
342	300	0.03	80	4	25	14.1	981	0.00	9	1	6	3	3	3	18
823	300	0.03	80	4	25	0.0	1026	0.00	10	3	6	3	3	3	18
843	300	0.03	80	4	25	15.0	993	0.00	0	1	6	3	3	3	18
944	200	0.02	60	3	25	0.0	1048	0.00	5	3	6	3	3	3	18
180	700	0.07	140	5	25	0.0	1068	0.00	15	3	6	2	3	3	17
224	100	0.01	40	3	66	12.2	0	0.00	0	1	6	2	3	3	17
545	100	0.01	40	3	25	21.2	1099	0.00	1	1	6	3	3	2	17
560	200	0.02	60	3	25	14.1	1064	0.00	19	1	5	3	3	3	17
616	1000	0.10	160	6	66	1.9	22	0.00	0	2	6	2	3	3	17
646	3800	0.38	620	6	66	6.4	0	0.00	16	2	6	2	3	3	17
651	1300	0.13	200	7	66	5.2	80	0.00	43	2	5	3	3	3	17
819	6270	0.63	585	11	66	0.0	0	0.00	202	3	6	3	2	3	17
25	2300	0.23	320	7	66	5.0	82	0.00	1498	2	6	3	3	2	16
164	200	0.02	60	3	66	16.2	0	0.00	2	1	6	2	3	2	16
249	6113	0.61	542	11	25	0.0	898	0.00	85	3	4	3	3	3	16
337	3803	0.38	380	10	66	0.0	0	0.00	24	3	6	2	3	2	16
403	100	0.01	40	3	66	25.0	10	0.00	2	1	5	3	3	2	16
539	1112	0.11	157	7	34	0.0	755	0.00	7	3	5	3	2	3	16
609	450	0.05	110	4	25	0.0	804	0.00	0	3	6	2	3	2	16
617	1700	0.17	197	9	34	0.0	712	0.00	5	3	5	2	3	3	16
618	1200	0.12	180	7	24	0.0	224	0.00	111	3	6	1	3	3	16
640	100	0.01	40	3	24	5.0	201	0.00	0	2	4	3	3	3	16
678	1700	0.17	260	7	24	5.0	124	0.00	3545	2	5	3	3	2	16
831	200	0.02	60	3	25	25.0	746	0.00	12	1	6	2	2	3	16
848	600	0.06	140	4	24	15.0	150	0.00	0	1	4	3	3	3	16
866	100	0.01	40	3	23	20.0	909	0.00	4	1	5	3	3	2	16
902	400	0.04	100	4	22	10.0	910	0.00	3548	2	6	2	3	2	16
948	200	0.02	60	3	23	14.1	840	0.00	20	1	6	2	2	3	16
50	400	0.04	108	4	23	0.0	842	0.00	0	3	3	3	3	3	15
341	100	0.01	40	3	66	23.4	114	0.00	506	1	4	2	3	3	15
417	100	0.01	40	3	26	21.2	835	0.00	18	1	4	2	3	3	15
449	100	0.01	40	3	23	14.1	818	0.00	2	1	6	1	3	2	15
458	200	0.02	60	3	66	16.7	106	0.00	509	1	6	1	3	2	15
530	200	0.02	60	3	26	15.8	819	0.00	12	1	5	2	3	2	15
568	100	0.01	40	3	26	25.0	813	0.00	0	1	3	3	3	3	15
771	3550	0.36	420	8	25	0.0	564	0.00	274	3	4	3	3	2	15
847	3738	0.37	369	10	24	0.0	136	0.00	268	3	4	2	3	3	15
947	250	0.02	70	4	25	0.0	550	0.00	0	3	4	2	3	3	15
15	600	0.06	140	4	24	14.1	103	0.00	80	1	4	3	3	2	14
29	100	0.01	40	3	24	21.2	106	0.00	5	1	6	2	3	1	14
39	1550	0.16	230	7	24	0.0	713	0.00	1362	3	2	3	3	3	14
43	100	0.01	40	3	24	21.2	70	20.00	0	1	4	2	3	2	14
51	600	0.06	140	4	24	25.0	73	0.00	33	1	2	3	3	3	14
62	4100	0.41	454	9	34	0.0	469	0.00	261	3	3	3	3	2	14
90	800	0.08	140	6	26	7.1	737	0.00	2	2	4	2	3	2	14
152	800	0.08	140	6	25	7.1	492	0.00	133	2	3	2	3	3	14
248	100	0.01	40	3	34	25.0	469	0.00	5	1	3	2	3	3	14
269	16714	1.67	1500	11	66	0.0	0	0.00	994	3	2	3	3	3	14

APPENDIX B

Prioritization Model Script: Tabuga Watershed

```
# -*- coding: utf-8 -*-

# ---------------------------------------------------------------------------

# Prioritization Model.py

# Created on: 2013-04-26 15:42:30.00000

#   (generated by ArcGIS/ModelBuilder)

# Description:

# ---------------------------------------------------------------------------


# Import arcpy module

import arcpy


# Local variables:

SitesAll_0312_shp =
"C:\\Users\\Public\\Documents\\MP\\workspace\\data\\Model_Data\\SitesAll_0312.shp"

Jama_LULC_2009 = "Jama_LULC_2009"

ClassificationBoundary = "ClassificationBoundary"

SitesAll_0312 = "SitesAll_0312"

TabugaSites = "TabugaSites"

SitesAll_0312__12_ = "SitesAll_0312"

tmp2009_LULC_shp =
"C:\\Users\\Public\\Documents\\MP\\workspace\\data\\Model_Data\\scratch\\tmp2009_LULC.shp"

v2009_lulc_shp =
"C:\\Users\\Public\\Documents\\MP\\workspace\\data\\Model_Data\\scratch\\2009_lulc.shp"


# Process: Add Field
```

```
arcpy.AddField_management(SitesAll_0312, "C1", "LONG", "", "", "", "", "NULLABLE", "NON_REQUIRED", "")

# Process: Add Field (2)
arcpy.AddField_management(SitesAll_0312, "C2", "LONG", "", "", "", "", "NULLABLE", "NON_REQUIRED", "")

# Process: Add Field (4)
arcpy.AddField_management(SitesAll_0312, "C4", "LONG", "", "", "", "", "NULLABLE", "NON_REQUIRED", "")

# Process: Add Field (5)
arcpy.AddField_management(SitesAll_0312, "C5", "LONG", "", "", "", "", "NULLABLE", "NON_REQUIRED", "")

# Process: Add Field (6)
arcpy.AddField_management(SitesAll_0312, "C6", "LONG", "", "", "", "", "NULLABLE", "NON_REQUIRED", "")

# Process: Calculate Field
arcpy.CalculateField_management(SitesAll_0312__12_, "C1", "Rank( !STRM_DIST!)", "PYTHON_9.3", "def Rank(x):\\n  if x <= 1:\\n    return 3\\n  elif x <=10:\\n    return 2\\n  else:\\n    return 1")

# Process: Calculate Field (2)
arcpy.CalculateField_management(SitesAll_0312__12_, "C2", "Rank(!RURAL_DIST!)", "PYTHON_9.3", "def Rank(x):\\n  if x <= 300:\\n    return 3\\n  elif x <=1000:\\n    return 2\\n  else:\\n    return 1")

# Process: Calculate Field (4)
```

```
arcpy.CalculateField_management(SitesAll_0312__12_, "C4", "Rank( !AREA_EDGE! )", "PYTHON_9.3",
"def Rank(x):\\n  if x <= 5:\\n    return 1\\n  elif x <=10:\\n    return 2\\n  elif x <=15:\\n    return 3\\n")


# Process: Calculate Field (5)

arcpy.CalculateField_management(SitesAll_0312__12_, "C5", "Rank( !FORBUF_DIS!)", "PYTHON_9.3",
"def Rank(x):\\n  if x == 0:\\n    return 3\\n  elif x <=100:\\n    return 2\\n  else:\\n    return 1")


# Process: Raster to Polygon

tempEnvironment0 = arcpy.env.snapRaster

arcpy.env.snapRaster = ""

tempEnvironment1 = arcpy.env.extent

arcpy.env.extent = "584992.934 9974307.889 600472.934 9993807.889"

tempEnvironment2 = arcpy.env.cellSize

arcpy.env.cellSize = "MAXOF"

tempEnvironment3 = arcpy.env.mask

arcpy.env.mask = "watersheds_jolley"

arcpy.RasterToPolygon_conversion(Jama_LULC_2009, tmp2009_LULC_shp, "NO_SIMPLIFY", "Value")

arcpy.env.snapRaster = tempEnvironment0

arcpy.env.extent = tempEnvironment1

arcpy.env.cellSize = tempEnvironment2

arcpy.env.mask = tempEnvironment3


# Process: Clip

arcpy.Clip_analysis(tmp2009_LULC_shp, ClassificationBoundary, v2009_lulc_shp, "")


# Process: Calculate Field (6)
```

```
arcpy.CalculateField_management(SitesAll_0312__12_, "C6", "Rank( !SUM_FLOW! )", "PYTHON_9.3", "def Rank(x):\\n  if x <= 100:\\n    return 0\\n  elif x <=250:\\n    return 1\\n  elif x <=750:\\n    return 2\\n  elif x <=1000:\\n    return 3\\n  elif x <=2000:\\n    return 4\\n  elif x <=3000:\\n    return 5\\n  else:\\n    return 6")


# Process: Calculate Field (7)

arcpy.CalculateField_management(TabugaSites, "C6", "Rank( !SUM_FLOW! )", "PYTHON_9.3", "def Rank(x):\\n  if x <= 100:\\n    return 1\\n  elif x <=250:\\n    return 2\\n  elif x <=500:\\n    return 3\\n  elif x <=750:\\n    return 4\\n  elif x <= 1000:\\n    return 5\\n  else:\\n    return 6")


# Process: Calculate Field (8)

arcpy.CalculateField_management(TabugaSites, "C4", "Rank( !AREA_EDGE! )", "PYTHON_9.3", "def Rank(x):\\n  if x <= 5:\\n    return 1\\n  elif x <=10:\\n    return 2\\n  elif x <=15:\\n    return 3\\n")
```