

A functional approach to riparian restoration in Austin, Texas

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Abstract

A new functional paradigm is emerging in restoration ecology where focusing on ecosystem processes at both the local and landscape level is replacing natural species preservation. In an increasingly urbanized world, where human modified ecosystems are emerging to contain new species assemblages never before encountered, it becomes imperative to understand both the past and future successional patterns of these newly created “novel” systems. In order to guide riparian restoration in a growing urban center, the City of Austin combined current literature reviews and successional theory with local vegetative knowledge to produce a theoretical framework for urban riparian restoration. Methods of invasion, ecosystem function, indicators of disturbance, and passive and active restoration are discussed. Results suggest that a restored riparian site will have improved water quality and aquatic life, increased cover and structural diversity of floodplain vegetation (native or exotic), a dominant hardwood community, natural soil conditions, a wide and continuous riparian buffer, limited channelization, improved bank stability, and in-stream aquatic habitat. We also demonstrate the advantages of passive restoration and help with identifying sites where spontaneous succession is appropriate. Understanding past disturbance mechanisms will help managers identify appropriate restoration techniques facilitating future succession patterns that promote maximum ecosystem function at the least economic cost.

Introduction

Riparian zones are dynamic systems that reflect the abiotic and biotic conditions of their watersheds. Hydrology, especially in the arid southwest, is the primary driving force dictating the vegetation community and ecosystem services provide by riparian systems (Richardson *et al.* 2007). Availability of water is the major limiting factor, particularly for woody riparian species, where by extended drought and flow modification related to impoundments, diversions, or groundwater pumping can lead to tree mortality (Richardson *et al.* 2007). Altered hydrological regimes have been shown to change riparian community composition, structure, and function, increasing both the encroachment of native upland and non-native woody species (Huddle *et al.* 2011). Saltcedar stand density, a common exotic species in the southwestern United States, has been shown to increase in reaches where water flow was regulated compared with reaches where water flow was unregulated (Huddle *et al.* 2011). In Austin, increased urbanization has shifted the hydrology of riparian zones to that of decreased soil moisture and

reduced groundwater levels (Sung et al. 2011). This has moved the vegetation in these urbanized riparian zones to one favorable to disturbance-tolerant exotics (Sung et al. 2011). Studies have shown that increased anthropogenic disturbance is associated with high abundance of exotic species (Pennington et al. 2010, Sung et al. 2011). Of the 12 riparian forest surveyed in Austin, plant invasion was most strongly correlated to % impervious cover within that sampling reach (Sung et al. 2011). As urbanization is expected to increase in Austin, understanding the mechanisms behind exotic plant invasion becomes increasingly necessary.

Methods of Invasion

Recent studies have linked anthropogenic modified landscapes with increased exotic invasion potential (Moffatt and McLachlan 2004; Pennington et al. 2010; Sung et al. 2011). The invasion of exotic plant species generally follows passive distribution models whereby invaded communities are primarily structured by non-interactive factors (environmental change, dispersal limitation) that are less constraining on the exotics, which thus dominate (MacDougall and Turkington 2005; Pennington et al. 2010; Sung et al. 2011). Successful invasion requires significant propagule pressure and beneficial abiotic and biotic conditions (Catford *et al.* 2009). High propagule pressure can intensify invasion by increasing genetic diversity and the likelihood of being introduced into a favorable environment (Catford *et al.* 2009). Anthropogenic disturbances can alter the abiotic and biotic conditions of an environment whereby creating novel conditions more appropriate to exotic species establishment (Davis 2009). Identifying the main disturbance driver is critical in determining the success of exotics and the impact on native plant communities (Lake and Leishman 2004). Research has shown that sites without any disturbance do not support exotic species invasion (Lake and Leishman 2004). Understanding the methods behind species invasion and associated impacts to ecosystem function is necessary prior to restoration and management of riparian ecosystems. Managing the environment and not individual species is necessary for effective invasive species control (Davis 2009). It's important to remember that very few exotic species possess traits that allow them universal performance advantages over co-occurring natives; rather, increased resource availability and altered disturbance regimes associated with human activities increase the performance of invaders over natives (Daehler 2003). Based on 79 independent native-invasive plant comparisons, alien invaders were not statistically more likely to have higher growth rates, competitive ability, or fecundity than natives (Daehler 2003).

Maintaining Ecosystem function

Riparian systems provide a suite of ecosystem services including, but not limited to, stabilized stream banks, clean water, diverse animal assemblages, and groundwater recharge (Richardson *et al.* 2007). The more degraded an ecosystem, the more fundamentally altered the basic services will become (Hobbs and Cramer 2008). Any change in plant composition will bring about shifts in ecosystem function. Dominant species exert the most influence, and thus the greatest functional changes will occur if the abundance of these species is altered (Richardson *et al.* 2007). The greater the difference in traits between the previously and currently dominant species (native or exotic), the greater will be the change in function (Richardson *et al.* 2007). Understanding the main functional goals of the restoration project as well as the trajectory of the dominant vegetation community will help managers decide what strategies to employ. Recent studies have emphasized that restoration efforts should focus on functional aspects of the ecosystem and should incorporate beneficial exotics (Richardson *et al.* 2007, Hobbs and Cramer 2008, Davis *et al.* 2011). Sogge *et al.* (2008) found that Saltcedar provides habitat for 49 native bird species; and, in the absence of effective restoration activities, its removal could decrease the net riparian habitat value for birds. Researchers need to be clear about (a) what the goals are for restoration and (b) what the options are for achieving these goals (Hobbs and Cramer 2008). Setting realistic, clearly defined goals will determine the extent of intervention required and increase the likelihood of achieving success (Hobbs and Cramer 2008).

Passive vs. Active Restoration

There are three generalized approaches to restore the biota of disturbed site: (1) rely completely on passive (spontaneous succession), (2) exclusively adopt active, technical measures, (3) or a combination of both passive and active techniques toward a target goal (Hobbs and Prach 2008). Passively restored sites exhibit robust biota better adapted to site conditions with increased natural value and wildlife habitat than do actively restored sites (Hobbs and Prach 2008). Passive restoration requires minimal management and is more cost effective than alternative methods. However, passive restoration is often the slower approach and is more dependent on adjacent site conditions. When relying on spontaneous succession the vegetation community of adjacent sites, an approximate 100 meter distance from the disturbed site, is critical for successful restoration (Hobbs and Prach 2008). In general, passive restoration that relies on spontaneous succession should be employed when environmental disturbance is not very extreme (Figure 1) and no negative results (erosion, water contamination, negative aesthetic perception, etc...) are foreseen (Hobbs and Prach 2008). When site productivity and stress are extremely high or low, active (technical reclamation) may be necessary (Figure 1). The persistence of undesirable functional states is an indication that the system may be stuck and will require active intervention to move it to a more desirable state (Hobbs and Prach 2008). Understanding when passive versus active restoration approaches are warranted can increase chances of success and reduced project

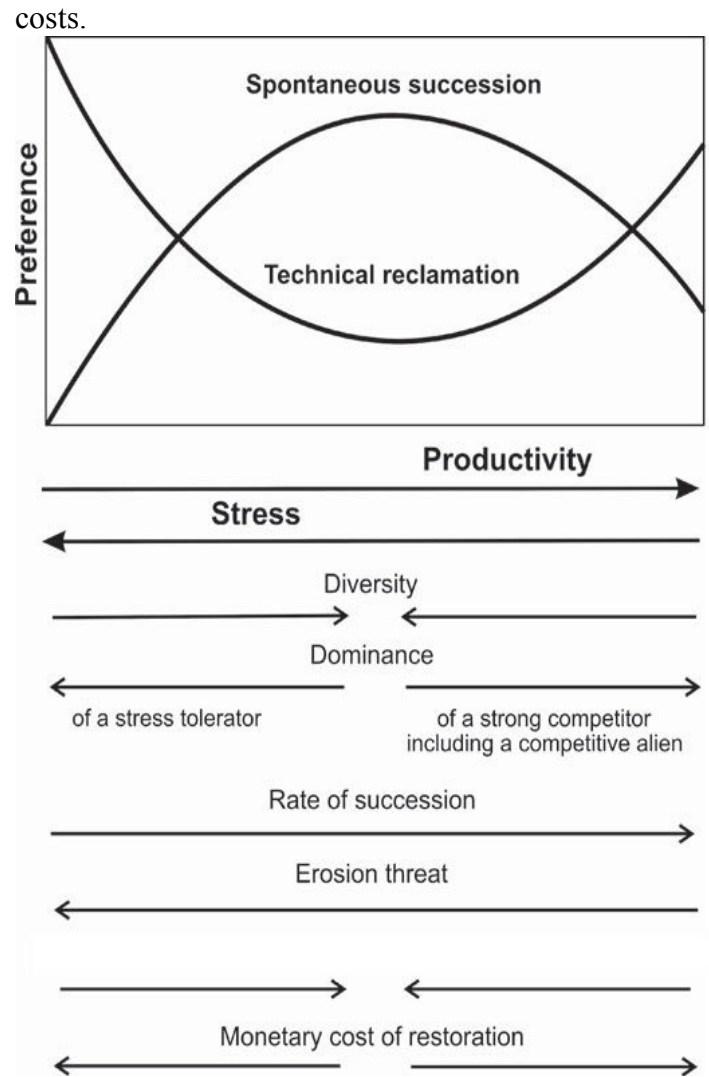


Figure 1: Relative preference of spontaneous succession and technical reclamation along the productivity–stress gradient (Hobbs and Prach 2008).

Indications of Disturbance

Identification of site disturbance is critical prior to designing successful restoration efforts (Lake and Leishman 2004). Understanding the magnitude and frequency of disturbance events in a riparian systems will help managers decide between passive and active management approaches. Commonly, the abundance, diversity, and guild distributions of the vegetative community can be used as indicators of disturbance. The relative proportion of generalists, opportunistic, and vulnerable plant species can be used to identify a gradient of disturbance (Moffatt and McLachlan 2004). Indicators of disturbed riparian forests are opportunistic plant species negatively correlated to diversity (Moffatt and McLachlan 2004). Whereas indicators of high-integrity riparian forests are vulnerable species positively correlated to overall site diversity (Moffatt and McLachlan 2004). Therefore sites with high overall plant diversity (either native or exotic) can be considered of high-value providing essential

ecosystem services (Moffatt and McLachlan 2004, Richardson *et al.* 2007). Research suggests that ecosystem function declines when species diversity is reduced to very low levels (Richardson *et al.* 2007). Comparisons between the understory and overstory plant communities can also be of value. The understory (herb) community reflects a habitats current ecological condition, while overstory (tree) communities are reminders of past environmental condition (Woosley *et al.* 2005). Understanding if significant changes occur between the overstory and understory plant communities will help managers asses which plant species can successfully propagate under current site conditions and identify those species likely to become extirpated in the near future. Recent research by the City of Austin has revealed that relatively small changes in geographic location and drainage area can result in distinct shifts in plant species composition (COA 2011). Understanding these trends as well as which species define a specific region can help managers identify when a restored site has improved functional characteristics or when a degraded site requires some level of restoration (COA 2011). For example, a riparian restoration project on a headwaters stream in the Edwards Plateau region could be deemed to have successfully improved ecosystem function when species such as Trumpet vine, Silktassel, Yaupon holey, Maidenhair fern, etc... (Table 1) have successfully established (reproduced with multiple age classes). When a site can successfully support these defining plant species restoration practitioners can assume some level functional improvement. Conversely, sites where these defining species are absent could be an indication of disturbance and that restoration is needed (COA 2011). Other common indicators of disturbance in urban riparian environments are: (1) land-use and management, (2) soil health, (3) buffer width, (4) water quality, (5) species composition, and (6) hydrology. In Austin increased urbanization (percent impervious cover within the watershed) is related to changes in hydrology resulting in shifts in vegetation composition (Sung *et al.* 2011). Consequently, a certain level of site disturbance can be assumed in urbanized reaches with high percentage of impervious cover. Management strategies are often the most obvious form of disturbance. Mowing, planting, and tree and brush removal are frequent disturbances in urban riparian systems and must be considered prior to restoration planning. Often altering or removing a management disturbance may set an ecosystem on a successional trajectory towards improved ecosystem function (Kauffman *et al.* 1999). Modifications to soil quality can result in reduced ecosystem function and species loss. Soil pH, moisture, and compaction have all been shown to be significantly altered in degraded urban riparian environments (Moffatt *et al.* 2004; Pouyat *et al.* 2007; Gift *et al.* 2010). Adequate riparian buffer width has been shown to filter pollutants, control erosion, prevent flooding, and provide habitat and nutrient inputs into the stream (Barbour 1999; Fischer and Fischenich 2000). Riparian zones with minimal buffers will be unable to provide these essential ecosystem functions. Water quality, most often quantified by relative concentrations of nutrients within the stream, can be an indication of site impairment. Sites with impaired water quality often have excessive algae growth and reduced diversity of sensitive aquatic species (Stacey *et al.* 2006; Mabe 2007; King and Winemiller 2009). Both benthic macroinvertebrate and diatom diversity can be directly impacted by poor water quality (Stacey *et al.* 2006; King and Winemiller 2009). Overall, there is much evidence supporting the claim that maintaining high ecosystem function over time is enhanced by high local and regional species diversity (Duffy 2009). In riparian ecosystems restoration practitioners should focus on maintaining a diverse assemblage of both aquatic and terrestrial flora and fauna. Increased stream channel entrenchment (incision) can be an indication of altered hydrology of the riparian zone and reduced floodplain connectivity (Rosgen 1994). The Absence of floodplain connectivity lowers the water table, reduces nutrient availability, decreases plant germination, growth, and survivorship, and may lead to riparian vegetation loss and invasion of upland species (Stacey *et al.* 2006). Hydrology is the primary driving force dictating the vegetation community and ecosystem services provide by riparian systems (Richardson *et al.* 2007). Understanding the causes of disturbance will help managers decide which restoration techniques are appropriate and later, which variables to measure to indicate success.

Table 1: Template of overstory and groundcover vegetation for City of Austin riparian evaluation. Nomenclature of + indicates species presence and x indicates species that defines the region (both abundant and widespread in the associated sampling region).

Overstory					
Common Names	Scientific Name	EPH	EPB	BPH	BPB
Box Elder	ACER NEGUNDO		x		
Peppervine	AMPELOPSIS ARBOREA		x		+
Trumpet Vine	CAMPSIS RADICANS	x			
Hackberry	CELTIS SPP.	+	+	+	+
Roughleaf Dogwood	CORNUS DRUMMONDII	+	+	+	+
Texas Persimmon	DIOSPYROS TEXANA	x		+	+
Elbow Bush	FORESTIERA PUBESCENS	+	+	x	+
Ash	FRAXINUS SPP.	+	+	+	+
Silktassel	GARRYA LINDHEIMERI	x			
Possumhaw	ILEX DECIDUA	+	+	x	x
Yaupon Holly	ILEX VOMITORIA	x	x	+	
Ashe juniper	JUNIPERUS ASHEI	x	+		
Virginia creeper	PARTHENOCISSUS QUINQUEFOLIA	+	+	+	+
	RUBUS SPP.	+	+	+	+
Soapberry	SAPINDUS SAPONARIA VAR. DRUMMONDII			x	x
	SMILAX SPP.	+	+	+	+
Coralberry	SYMPHORICARPOS ORBICULATUS			x	x
Poison ivy	TOXICODENDRON RADICANS	+	x	+	x
Ceder elm	ULMUS CRASSIFOLIA	+	+	x	x
Sweet mountain grape	VITIS MONTICOLA	+	+	+	+
Mustang Grape	VITIS MUSTANGENSIS	+	+	+	+

Groundcover					
Common Names	Scientific Name	EPH	EPB	BPH	BPB
Maidenhair fern	ADIANTUM CAPILLUS-VENERIS	x	x		
Annual ragweed	AMBROSIA ARTEMISIIFOLIA		+	x	x
Drummond's aster	ASTER TEXANUS	+	+	+	+
Straggler daisy	CALYPTOCARPUS VIALIS	+	+	+	+
Sedges	CAREX SPP.	+	+	+	+
Hackberry	CELTIS SPP.	+	+	+	+
Ash	FRAXINUS SPP.	+	+	+	+
Poaauhaw	ILEX VOMITORIA	x			
Ashe juniper	JUNIPERUS ASHEI	x	+		
Yellow wood sorrel	OXALIS DILLENII	+	+	+	+
Virginia creeper	PARTHENOCISSUS QUINQUEFOLIA	+	+	+	+
Texas red oak	QUERCUS TEXANA	x			
	RUBUS SPP.	+	+	+	+
Ceder Sage	SALVIA ROEMERIANA	x	+		
Johnsongrass	SORGHUM HALEPENSE			+	+
spreading hedgearsley	TORILIS ARVENSIS		x	+	x
Ceder elm	ULMUS CRASSIFOLIA	+	+	+	+
White crownbeard	VERBESINA VIRGINICA	+	+	+	+

Methods and Results

By combining current literature with ecological theory the City of Austin has designed a framework for diagnosing and later monitoring the improved ecological function of urban riparian systems following restoration activities. A restored riparian site will have improved water quality and aquatic life, increased cover and structural diversity of floodplain vegetation (native or exotic), a dominant hardwood community, minimal soil disturbance (characterized by soil compaction, moisture and pH), a wide and continuous riparian buffer, limited channelization, improved bank stability, and in-stream aquatic habitat. A complete list of each functional metric chosen and associated justification is presented in (Table 2). Detailed methodology is presented in this section and field sheets are available in appendix I.

Table 2: City of Austin metrics for evaluating the functional condition of riparian zones.

Functional Metric	Rational
Macro-algae cover	The percentage of macroalgae cover has been linked to the amount of nutrients in the water column, type of substrate, and amount of available light at a site (Mabe 2007). Collecting this metric may allow restoration practitioners to monitor several key aspects of riparian function simultaneously.
Diatoms	The City of Austin routinely measures and compiles biological integrity data into a single index value. This index combines macroinvertebrate and diatom community structure (COA 2002). Diatoms generally respond more quickly to changes in both their physical and chemical environments than macroinvertebrates and can potentially indicate low level changes in water quality (COA 2002). Specific species of diatoms have been linked to increased nutrients in the water column while other species have been linked to low concentrations of nutrients (King and Winemiller 2009). Community composition metrics will be calculated to help determine aquatic function in the study reach.
Canopy Cover	Temperature heterogeneity within the stream channel is associated with increased aquatic species richness and ecosystem function (Woosley et al. 2005). The amount of solar shading provided by adjacent and in stream riparian vegetation is critical for maintain temperature refugia. Decreased streambank vegetation cover, increased channel width, and reduced stream depth increases exposure, raises water temperatures and impacts aquatic life (Stacey <i>et al.</i> 2006).
Plant cover and structural diversity	High cover and structural diversity of vegetation (groundcover, understory, and canopy) indicates a productive plant community, high species diversity, adequate food resources and habitat for wildlife, and reduced flood impacts along banks (Stacey <i>et al.</i> 2006). Structural diversity is often absent in riparian areas that have been heavily damaged by human activities and can result in native wildlife species being extirpated from the area (Stacey <i>et al.</i> 2006). Patches of dense vegetation, both native and exotic, also play a key role in trapping sediment during periods of over-bank flow (Stacey <i>et al.</i> 2006).

Functional Metric	Rational
Hardwood demography	Size and age class distribution of the dominant tree species indicates recruitment success and disturbance intervals. Missing age classes is often a result of disruptions to natural ecosystem processes and can result in successional changes and species loss (Stacey <i>et al.</i> 2006). Dominant species exert the most influence, and thus the greatest functional changes will occur if the abundance of these species is altered (Richardson <i>et al.</i> 2007).
Recruitment/ Succession	The understory (sapling) community reflects a habitats current ecological condition; while overstory (tree) communities are reminders of past environmental condition (Woosley <i>et al.</i> 2005). Understanding if the understory composition is significantly different from the overstory can be an indication of disturbance that could potentially alter succession and change ecological function.
Riparian zone width	A wide riparian buffer has been shown to filter pollutants, control erosion, prevent flooding, and provide habitat and nutrient inputs into the stream (Barbour 1999; Fischer and Fisichenich 2000). Increased riparian zone width in restored systems has been shown to positively impact macroinvertebrate diversity in Austin streams (Chin <i>et al.</i> 2010). Riparian zone width is also the best predictor of nitrogen loading to water bodies when buffers are “relatively leaky” (Baker et al 2006).
Ratio (Riparian Zone Width to SPTH)	The Federal Ecosystem Management Team (FEMAT) first investigated the relationship between dominant tree species height and the riparian buffer zone in 1993. The site potential tree height (SPTH) is defined as the average maximum height to which a dominant tree will grow if left undisturbed (Sedell et. al. 1993). FEMAT found that factors including root strength, litter fall, shading, and course material input were protected with a buffer of 1 SPTH while factors that affected the microclimate would be protected with a buffer of 3 SPTH (FEMAT 1993).
Gap frequency	Using heuristic models Weller et. al. (1998) showed that the best predictor of nutrient discharge into a stream was the frequency of gaps along stream buffers when the buffers were assumed to be highly retentive. Baker et. al. (2006) expanded upon this thought including frequency of gaps into their “flow-path metrics” which are useful in making comparisons of potential buffer impacts on watersheds.
Entrenchment Ratio	Channel entrenchment (incision) is an indication of floodplain connection and overbank flow (Rosgen 1994; Stacey 2006). The Absence of floodplain connectivity lowers the water table, reduces nutrient availability, decreases plant germination, growth, and survivorship, and may lead to riparian vegetation loss and invasion of upland species (Stacey <i>et al.</i> 2006).
Bank Stability	Unstable vertical banks increase erosion and sediment loading to streams (Stacey <i>et al.</i> 2006). Less sediment deposition in restored systems has been shown to positively impact macroinvertebrate diversity in Austin streams (Chin <i>et al.</i> 2010).

Functional Metric	Rational
Large Woody Debris	The amount, composition, and distribution of Large Woody Debris (LWD) in the stream channel and along the banks provides important aquatic habitat (Stacey <i>et al.</i> 2006). As the diversity and abundance of LWD and other in-stream habitat decreases, habitat structure becomes monotonous, species diversity decreases, and potential for recovery following disturbance is reduced (Barbour 1999). Streams with adequate LWD generally have greater habitat diversity, a more natural stream shape, and greater resistance to flood events (Stacey <i>et al.</i> 2006).
Soil Moisture	Soil moisture has been shown to be negatively correlated to urban land-use (Moffatt <i>et al.</i> 2004; Gift <i>et al.</i> 2010). Hydrologic changes associated with urbanization often result in lower water tables and drier more aerobic soil conditions (Gift <i>et al.</i> 2010). These changes can result in reduced denitrification and altered plant species composition (Gift <i>et al.</i> 2010; Sung <i>et al.</i> 2011). Increasing soil moisture can improve nutrient cycling and biomass production in riparian systems.
Soil pH	pH has been shown to be positively correlated to urbanization in riparian forest systems (Moffatt <i>et al.</i> 2004). Soil pH influences the solubility of nutrients, microbial decomposition, and most chemical transformations in the soil (USDA 1998). Elevated soil pH in urban environments could reduce microbial activity and alter nutrient dynamics (USDA 1998) potentially resulting in shifting plant species composition and reduced ecosystem function.
Soil Compaction	Soil compaction or bulk density is one of the most discerning variables separating forest cover from turf grass (Pouyat <i>et al.</i> 2007). Increasing soil compaction can reduce the soil's ability to function for structural support, water and solute movement, and restrict root growth (USDA 2008). Compaction can result in shallow rooted plants and poor plant growth, reduced vegetative cover, increased erosion, and reduction in water infiltration (USDA 2008). Improvements in soil compaction can be gained by reducing disturbance from vehicle and foot traffic and increasing soil organic matter content (USDA 2008).

Establishing sampling transect

The majority of restoration sites within the City of Austin are small, averaging 0.5 stream kilometers or less. Therefore, a 100 meter in stream transect will be sufficient to document functional changes over time. In-stream transects should be selected to capture the range of site conditions that best characterize the restored reach. Transect starting points will be marked by tree tags or associated permanent marker to reference future evaluations. Make sure to denote which direction transect was run (upstream or downstream) on the data sheet (Appendix I). Photographs to illustrate the current conditions at the site should be taken at the upstream and downstream ends of the study reach, at 50 meters looking downstream and upstream, as well as any other location that would be valuable for future comparisons.

Detailed Methods

In order to complete the survey in a timely manner (2-3 hours), it is recommended that four participants separate into two teams (riparian and in-stream). The methodology chosen to evaluate each functional metric is listed below. The field data worksheets are separated between the riparian and in-stream teams and are available in appendix 1.

Macro-algae cover

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Both macro-algae cover and dominant substrate will be recorded along the 100 meter in stream transect. A total of 50 points will be collected, approximately one sample every 2 meters, using a zig-zag method that captures samples from both the center and banks of the stream channel. Measurements will be taken from 1 ft² sections of the stream bottom. Cover will be recorded as percent of filamentous algae cover and is divided into 6 categories (none, < 5%, 5-24%, 25-49%, 50-75%, >75%). Dominant substrate is divided into 6 categories (bedrock, boulder (>256 mm), large cobble (128-256 mm), cobble (64-128), gravel (32-64 mm), and unstable substrate (no rocks >32 mm). Sample algae and substrate only during flowing stream conditions.

Diatom Sampling

Diatom collection are sampled from periphyton containing rocks (epilithon) of riffle habitat within the 100 meter in stream study transect. Three rocks are taken randomly from appropriate riffle habitat (short, relatively shallow and coarse-bedded length of stream over which stream flows at higher velocity) if available. Rocks should be collected from undisturbed areas and should be relatively flat to facilitate consistent sampling area. The objective is to collect a composite sample that is representative of the diatom community from each monitoring site's riffle. To avoid sediment contamination in the sample, rinse off the bottom of each rock to ensure they are reasonably clean of debris and sediments before scraping. A small Petri dish (47cm²) and a sharp scoring object are used to mark the area of the rock to be sampled. This area is then scraped with a wire brush, and the particulate matter deposited into a shallow collecting pan. A sufficient quantity of ambient creek water is used to flush epilithon from each rock. After each scraping, make sure that the wire brush is also thoroughly rinsed for finer plant material into the collection pan. After the rocks have been scraped and rinsed, the contents of the collection pan should be carefully poured into a darkened or opaque bottle (approximately 125ml) and more water is used to flush all remaining particulate matter from the pan.

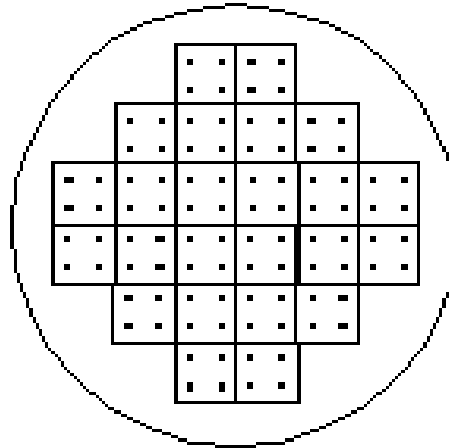
During rinsing, care should be taken to keep the total volume of rinse water (used to flush the sample rocks, wire brush, and pan) does not exceed the volume of the sample bottle (125 mL). Filling the rinse bottle with only 125 mL of creek water can be helpful. Sample bottles should be labeled appropriately with site number, site name, collection date & time, and collector's initials. The samples should be kept on ice until transport to the ERM lab. Upon arrival to the ERM lab the samples should be refrigerated and preserved with 10% buffered formalin (4 mL per 125 mL sample).

Be sure to record flow conditions, size of rocks scraped and densitometer reading of riffle where rocks were collected on data sheet (appendix 2). Additional field notes should be taken from each site to describe the amount and color of periphyton and any other details pertaining to the health of the diatom community (i.e., observable creek sedimentation, etc.).

Canopy Cover

Canopy cover measures the average densities of the overstory vegetation. Take a densitometer measurement and photo at 5, 50, and 95 meters along the in stream transect (in the center of the channel) facing downstream. Hold the densitometer level, 12" – 18" in front of the body so the operators head is just outside of the grids, counting the number of quarter squares not occupied by vegetation (Figure 1). Multiply the total count by 1.04 and subtract from 100 to obtain percent canopy cover. Repeat at each sampling point and average all measurements together to obtain a site average. The photo should be taken directly above observes head with focus on keeping the camera level. A dense riparian canopy is important not only in moderating stream temperatures, but as an indicator of bank stability and sediment and organic matter input potential. A functioning mature riparian zone will have high canopy cover. Low canopy densities can indicate an unhealthy riparian zone or one that is in an earlier successional stage.

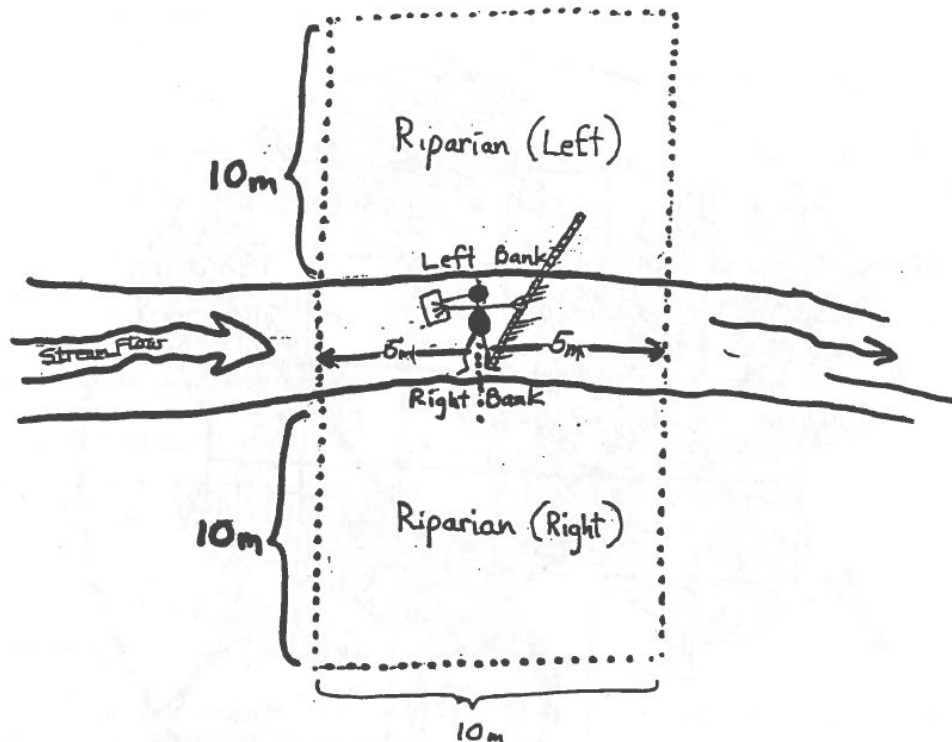
Figure 1: Grid diagram for spherical densiometer. Each box contains four points for potential vegetation cover. If all squares contain vegetation site canopy cover = 100%.



Plant cover and structural diversity

High cover and structural diversity of vegetation (groundcover, middle and upper canopy) indicates a productive plant community. At 5, 50 and 95 meters along the in-stream transect measure the plant cover and structural diversity on each stream bank. Visualize a 100m² sampling plot 5 m upstream and downstream and 10m perpendicular to the stream into the riparian zone (Figure 2). Estimate the percent cover (the shadow cast by a particular layer) of the canopy (cp), understory (us), and groundcover (gc) vegetation layers. The canopy layer is >5m high, the understory is 0.5 to 5m high, and the ground cover is <0.5m high. The surveyor should walk the plot focusing on 1 vegetation category at a time. Running a measuring tape to better define the study plot or dividing transect into smaller units can help to obtain a more accurate estimation. Average the scores for the three layers to achieve an overall score and record on the data sheet (Appendix 1).

Figure 2: 100m² sampling plot 5 m upstream and downstream and 10m perpendicular to the stream into the riparian zone (Cite).



Hardwood Demography- At 5, 50 and 95 meters along the in-stream transect measure the plant cover and structural diversity on each stream bank. Visualize a 100m² sampling plot 5 m upstream and downstream and 10m perpendicular to the stream into the riparian zone (Figure 2). Within each plot determine and record the dominant native tree present (highest percent coverage of the study plot, the shadow cast by a particular layer) and record the presence or absence of multiple age classes (seedlings, saplings, mature, and snags). Seedlings are defined as 12" or less having sprouted within the last year, saplings are > 12" in height but have yet to reach half its mature height and lack a full defined canopy, mature trees are approaching their maximum height and display a full developed canopy, and snags are dead trees with little to no vegetation and reduced canopy coverage often resulting from broken limbs.

Riparian Zone Width

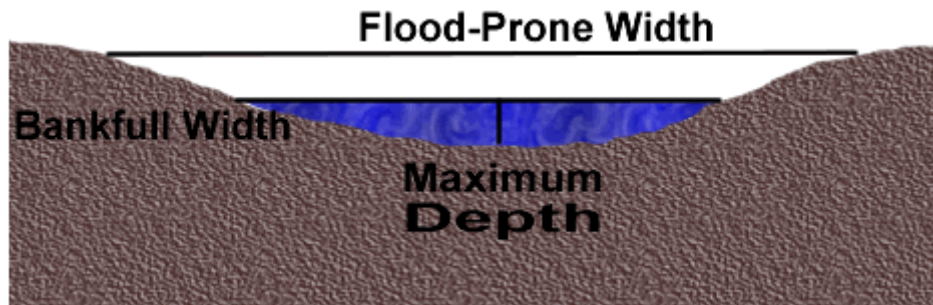
At 5, 50 and 95 meters along the in-stream transect measure the riparian zone width on both banks. Run a measuring tape from bankfull perpendicular away from the stream channel to the edge of the riparian zone. The edge of the riparian zone buffer is often dictated by a human structure (house, fence, road, etc...) or management activity (mowing) that inhibits plants to grow and alters the availability of the soil and vegetation to filter surface runoff.

Entrenchment Ratio

Channel entrenchment is a measure of channel incision and is an indication of floodplain connection. The entrenchment ratio is determined by dividing the width of the flood prone area by the bankfull width (Figure 3). The flood prone area is defined by measuring the width of the channel at twice bankfull depth. Bankfull corresponds to the start of the floodplain and is indicated by a break in slope from the channel bank, a change in vegetation from bare surfaces or annual wetland species to perennial water-tolerant or upland species, and from a change in the size distribution of surface sediments. Entrenchment measurements should be taken at 5, 50, and 95 meters along the in stream

transect. A ratio value from 1-1.4 indicates entrenchment, 1.41-2.2 indicates moderate entrenchment, and a ratio >2.2 indicates a slightly entrenched system (Rosgen 1994).

Figure 3: Figure illustrating how to calculate entrenchment ratio. Entrenchment ratio = Flood-Prone Width/Bankfull Width. Flood-Prone Width = 2(Thalweg Depth). Bankfull height level can be indicated by topographic, vegetation, and sediment differences marking the boundary between the active channel (1.5 yr flood event) with the flood plain.



Bank Stability

Throughout the entire 100 meter in-stream transect estimate the length of the channel bank where there is active erosion, near-vertical cut banks. Loose substrate, scour marks, and slumping banks are all signs of unstable banks. Talley all 1 meter sections along both stream banks that have active erosion and divide by 200 then multiply by 100 to obtain an overall site percentage.

Figure 4: Evidence of active, vertical bank erosion on Walnut Creek Austin, TX.



Soil Moisture

Within each 100m² sampling plot measure the percent soil moisture. Measurements should be taken with the soil moisture probe in the center of the sampling plot. The center of the sampling plot is considered to be 5m from each bank at 5, 50 and 95 meters on the in-stream transect. The soil probe tester plates must be chemically cleaned prior to use by rubbing with conditioning film. Soften soil in spot to be tested, break up pieces if it's hardened, and remove grass, leaves, pebbles and other debris. Insert soil tester so metal plates are fully covered and press the soil tightly around the tester so that the metal plates are in close contact with the soil. Press the button to read soil moisture content on the lower scale. Hold the button in the depressed position for 2 – 3 minutes until value stabilizes. Record

the reading obtained and repeat for a total of three measurements should be taken from each plot (3 x 6 = 18 total measurements).

Soil pH

Within each 100m² sampling plot measure soil pH. Measurements should be taken with the soil pH probe in the center of the sampling plot. The center of the sampling plot is considered to be 5m from each bank at 5, 50 and 95 meters on the in-stream transect. The soil probe tester plates must be chemically cleaned prior to use by rubbing with conditioning film. Soften soil in spot to be tested, break up pieces if it's hardened, and remove grass, leaves, pebbles and other debris. Insert soil tester so metal plates are fully covered and press the soil tightly around the tester so that the metal plates are in close contact with the soil. Read the pH value from the upper scale. Generally the tester needle swings to the right and then stabilizes after 2 – 3 minutes. Note: pH meter requires some soil moisture to be present. If the indicator needle does not deflect moisten the soil slightly with distilled water and try again. Do not take soil moisture measurements at this location if the soil has been moistened with distilled water. Record the reading obtained and repeat for a total of three measurements should be taken from each plot (3 x 6 = 18 total measurements).

Soil Compaction

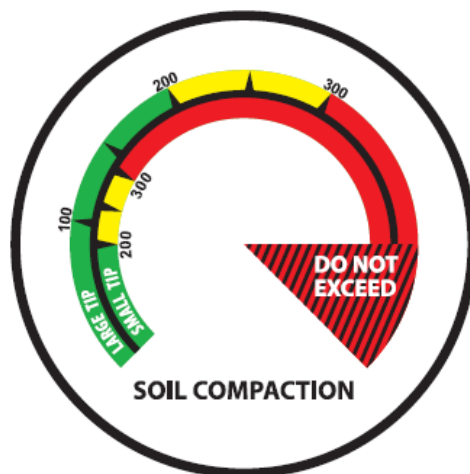
Within each 100m² sampling plot measure the percent soil compaction. Measurements should be taken with the soil compaction meter in the center of the sampling plot. Soil compaction should be the first measured variable in order to minimize soil disturbance prior to measurement. The center of the sampling plot is considered to be 5m from each bank at 5, 50 and 95 meters on the in-stream transect. Position the tip of the tester on the ground in the area you wish to test. Apply even downward pressure on both handles of the tester to keep the shaft and tip penetrating the soil at a slow even pace. The tester shaft is marked at three inch intervals for easy depth measurement. As the tester's shaft penetrates the soil, the gauge reading at the 3 inch depth should be recorded (be sure to use the correct scale for the size tip that you are using on the shaft as indicated on the dial face) (photo 6). A total of three measurements should be taken from each plot (3 x 6 = 18 total measurements) and averaged together to obtain an overall site average. When the tester is not in use, loosen the shock collar's wing nut and slide the shock collar up the shaft until it comes in contact with the plastic housing and tighten the wing nut. This will help prevent damage to your Soil Compaction Tester.

Figure 5: Gauge of soil compaction meter. The upper scale is used with the larger (3/4" diameter) while the lower scale is used with the smaller (1/2" diameter) steel tip.

Green (0 - 200 psi)
Good Growing Conditions

Yellow (200 - 300 psi)
Fair Growing Conditions

Red (300 psi and above)
Poor Growing Conditions



Ratio (Riparian Zone Width to SPTH)

For each dominant hardwood species calculate the Riparian Zone Width to SPTH ratio. Divide the measured riparian zone width at each study plot by the associated site potential tree height (SPTH). SPTH is defined as the average maximum height to which a dominant tree will grow if left undisturbed and can be found from the USDA plants database or appropriate literature source. Make sure to use the riparian zone width that corresponds to the appropriate vegetation plot.

Gap Frequency

Throughout the entire 100 meter in-stream transect estimate the relative frequency of riparian buffer gaps. A riparian buffer gap is defined as a void in vegetation larger than 1 meter where surface runoff has an unimpeded, no vegetation higher than 12", path to the stream channel. Optimal buffers are nearly continuous with a relative gap frequency < 25 %; suboptimal buffers have a relative gap frequency between 25-50 %; Marginal buffers have a relative gap frequency between 50-75%; and poor buffers have a relative gap frequency > 75%. Tally the number 1 meter gaps along both banks of the in-stream transect and divide by 200 then multiply by 100 to obtain an overall site percentage.

Large Woody Debris

Throughout the entire 100 meter in-stream transect count the number of Large Woody Debris pieces (LWD). LWD is defined as wood that is partially exposed to the water or located within the active stream channel and is at least 6" in diameter and 3' long. Optimal study reaches have > 6 LWD pieces; suboptimal study reaches have 4-6 LWD pieces; Marginal study reaches have 1-3 LWD pieces; and poor buffers have no LWD pieces.

Discussion

One of the major challenges to successful restoration projects are setting clearly defined goals and determining the appropriate extent of intervention required (Hobbs and Cramer 2008). Focusing restoration goals on functional aspects associated with ecosystem processes rather than historical baselines is becoming increasingly important in highly urbanized areas (Davis *et al.* 2011). Changing ecological conditions in the City of Austin is resulting in the formation of novel ecosystems comprising of new species assemblages and habitat conditions never before encountered. It is imperative that we put aside notions of the past and embrace an understanding of the processes essential for human growth and sustainability. The methods for evaluating riparian zone function presented in this document provide a foundation upon which to develop additional understanding and to better define restoration goals. The validity of these parameters need to be tested in the field and refined over time. With proper pre site evaluation and continued monitoring the City of Austin will be able to promote maximum ecosystem function at the least economic cost.

Passive vs. active restoration

As discussed earlier there are a positives and negatives associated with both passive and active restoration approaches. Being able to accurately diagnose a potential restoration site prior to implementation can increase chances of success and lower project costs (Holl and Aide 2010). Understanding if the main ecosystem disturbance driver is anthropogenic or natural can help restoration practitioners to decide between active and passive restoration. Active restoration is recommended for degraded sites where the primary disturbance regime is naturally reoccurring or a human alteration that the community is unable or unwilling to remedy. Passive restoration is recommended for sites where a rare natural disturbance event (extreme flood, drought, excessive rain, disease, etc...) has occurred or where a temporary (e.g. construction) or easily modified (e.g. mowing) human disturbance has taken place. Often altering or removing a management disturbance may set an ecosystem on a successional trajectory towards improved ecosystem function (Kauffman et al. 1999). The following site indicators can be used in the decision making process:

1. Age class distribution of dominant native and exotic tree species indicates recruitment success and disturbance intervals. Missing age classes can indicate a disruption of natural ecosystem processes and can result in successional changes and species loss (Stacey *et al.* 2006). Dominant species exert the most influence, and thus the greatest functional changes will occur if the abundance of these species is altered (Richardson *et al.* 2007). Sites where the dominant native species has multiple age classes with seedlings or saplings having sprouted recently can rely on passive restoration. Conversely, dominant native species with minimal recruitment and missing age classes can be a sign of changing site conditions that may require management effort to improve ecosystem function. Removal of invasive exotic plant species can potentially be avoided on sites where only one age class is present and no seedlings or saplings have recently sprouted. Often, invasive exotic species will become established following a rare natural disturbance event or temporary human modification; however, their continued reproductive success will be hindered following the return of normal site conditions. Conversely, if the dominant exotic tree species has multiple age classes with recently sprouted saplings or concerns over seed dispersal to surrounding vulnerable habitats are a priority, then active exotic removal is warranted. Understanding the successional trends of the dominant native and exotic tree species will help managers' assess which plants are likely to propagate under current site conditions and identify those species likely to become extirpated in the near future. If time allows it is recommended that following any change in anthropogenic disturbance, active restoration be postponed to allow sufficient time for native species response (Holl and Aide 2010). The understory community reflects a habitats current ecological condition and is a good indication of future succession trends (Woodsley *et al.* 2005).
2. The surrounding vegetation community (Holl and Aide 2010). Source populations of desirable species in close proximity to the restored site are necessary for passive restoration approaches. In general the vegetation community within 100 meters of the site should be considered as the viable seed source (Hobbs and Prach 2008). In riparian restoration projects directly adjacent to an active stream channel, that receive regular flood waters, this range can be extended and all upstream vegetation can be considered as a viable seed source. Special caution should be considered in highly urbanized areas where over 60% of invasive woody species have a horticulture past and are distributed by highly mobile dispersal vectors (birds and wind) (Richardson and Rejmanek 2011).
3. Defining plant species can be used in minimally impacted riparian areas as an indication of functional improvements. Although the likely hood of returning a degraded site back to a previously defined historical baseline is becoming an increasingly difficult and often unnecessary restoration goal, the ability of a site to support a defining plant community (Table 1), that is characteristic of relatively pristine unaltered reference sites, can be used as an indication of improved ecological function. Studies performed by the City of Austin found distinct differences in the vegetation composition among relatively unaltered sites based on changes in ecological region and drainage size (COA 2011). In addition certain defining plant species (both abundant and widespread in the associated sampling region) were identified. The presence of these defining plant species at a site can be an indication that ecological conditions are relatively unaltered and that passive restoration techniques are appropriate (COA 2011). Conversely, the absence of these defining plant species could be an indication of disturbance and that active restoration is needed (COA 2011). Careful consideration must be taken in patchy environments where site conditions may be present but source populations of defining species are absent.
4. Soil integrity. Soil compaction or bulk density reflects the soil's ability to function for structural support, water and solute movement, soil aeration, and can cause restriction to root growth (USDA 2008). Visual assessments of soil area integrity and soil compaction measurements can be used to assess a sites ability to support vegetation. A degraded site where soil compaction is high will likely require active restoration techniques to restore vegetative cover.
5. Hydrologic alteration. Interruptions in longitudinal or lateral connectivity of a stream are indications of disturbance that likely require active restoration measures to improve riparian zone function. The lack of lateral floodplain connectivity, often resulting from increased channel

incision, can result in reductions in overbank flow, lowering of the water table, increased nitrogen availability, decreased plant germination, growth, and survivorship, and may lead to riparian vegetation loss and invasion of upland species (Rosgen 1994; Groffman *et al.* 2002; Stacey 2006). Groffman *et al.* (2002) found that hydrologic changes associated with urbanization (lowering of the water table) can cause riparian zones to be sources rather than sinks for nitrate. This increase in available nitrogen in urban riparian zones can result in increased invasion potential (Davis *et al.* 2000). Coffman's (2007) work illustrates that *Arundo donax* may take advantage of anthropogenic enriched nitrogen levels in riparian ecosystems whereby outcompeting its native competitors. It is important to remember that deeply channelized streams can have riparian zones that function more like dry upland environments; no longer being able to support obligate and facultative wetland species. Stream systems lacking longitudinal connectivity due to upstream impoundments may also require active restoration. Impounded streams are subjected to a high degree of hydrologic disturbance (controlled water releases, draw downs, etc...) that results in increased disturbance, solute loading, nutrient enrichment, and unstable food webs (Havel *et al.* 2005). Increased nutrient enrichment, which is characteristic of urban reservoirs, coupled with the high degree of hydrologic disturbance results in unstable food webs and enhanced invisibility (Havel *et al.* 2005).

Recommendations

Field testing of these riparian functional metrics is necessary prior to implementation as a routine site evaluation for restoration projects. Comparing sites with known degradation to those that are relatively pristine will guide the importance of each parameter. Additional research on the benefits of passive restoration in Austin and identifying disturbance mediated responses by invasive exotic species are needed. Understanding the likely disturbance drivers of species invasion will help managers decide on appropriate control and management actions. Often an exotic species is deemed invasive simply on anecdotal evidence or recommendations from other states whereby the ecological linkages of exotic species in Texas environments remains unknown. Being able to more appropriately rank the invasive threat of exotic species to the City of Austin, while better understanding the environmental mechanisms driving exotic spread, will allow monetary resources to be more appropriately allocated.

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Appendix 1

City of Austin - Riparian Functional Assessment

Riparian Worksheet

Site #: _____ Site Name: _____ Date: _____ Time: _____ Staff: _____

Establish vegetation sampling plots: at 5, 50 and 95 meters along the in-stream transect. Starting at 5 meters along the right hand bank, establish the first 100m² sample plot that runs 5m upstream and downstream and 10m perpendicular to the stream into the riparian zone beginning at the bankfull demarcation (Figure 1). Bankfull corresponds to the start of the floodplain and is indicated by a break in slope from the channel, a change in vegetation from bare surfaces or annual wetland species to perennial water-tolerant or upland species, and from a change in the size distribution of surface sediments. Begin by measuring soil compaction, pH and moisture (steps 1-3) in the center of the study plot. The center of the sampling plot is considered to be 5m from each bankfull demarcation at 5, 50 and 95 meters on the in-stream transect. Vegetation sampling should commence following soil measurements and should encompass the entire 100m² sample plot (steps 4-6). Finally riparian zone width (step7) should be measured before proceeding to the next sample plot. Repeat steps 1-7 for each sample plot.

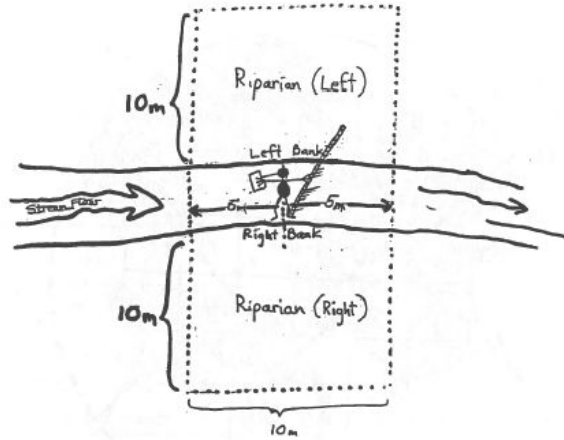


Figure 1: 100m² sampling plot 5 m upstream and downstream and 10m perpendicular to the stream into the riparian zone.

1. Soil Compaction- From the center of the sample plot position the tip of the tester on the ground in the area you wish to test. Apply even downward pressure on both handles of the tester to keep the shaft and tip penetrating the soil at a slow even pace. The tester shaft is marked at three inch intervals for easy depth measurement. As the tester's shaft penetrates the soil, the gauge reading at the 3 inch depth should be recorded (be sure to use the correct scale for the size tip that you are using on the shaft as indicated on the dial face). A total of three measurements should be taken from each plot (3 x 6 = 18 total measurements).

Plot 1 (5m RB)	Plot 2 (5m LB)	Plot 3 (50m RB)	Plot 4 (50m LB)	Plot 5 (95m RB)	Plot 6 (95m LB)
#1 _____ #2 _____ #3 _____	#1 _____ #2 _____ #3 _____	#1 _____ #2 _____ #3 _____	#1 _____ #2 _____ #3 _____	#1 _____ #2 _____ #3 _____	#1 _____ #2 _____ #3 _____

2. Soil Moisture- The soil probe tester plates must be chemically cleaned prior to use by rubbing with conditioning film. Soften soil in spot to be tested, break up pieces if it's hardened, and remove grass, leaves, pebbles and other debris. Insert soil tester so metal plates are fully covered and press the soil tightly around the tester so that the metal plates are in close contact with the soil. Press the button to read soil moisture content on the lower scale. Hold the button in the depressed position for 2 – 3 minutes or until value stabilizes. Record the reading obtained and repeat for a total of three measurements should be taken from each plot (3 x 6 = 18 total measurements).

Plot 1 (5m RB)	Plot 2 (5m LB)	Plot 3 (50m RB)	Plot 4 (50m LB)	Plot 5 (95m RB)	Plot 6 (95m LB)
#1 _____ #2 _____ #3 _____	#1 _____ #2 _____ #3 _____	#1 _____ #2 _____ #3 _____	#1 _____ #2 _____ #3 _____	#1 _____ #2 _____ #3 _____	#1 _____ #2 _____ #3 _____

3. Soil pH- Repeat the procedure above (step 5) to measure Soil pH within each 100m² sampling plot. Read the pH value from the upper scale. Generally the tester needle swings to the right and then stabilizes after 2 – 3 minutes. **Note:** pH meter requires some soil moisture to be present. If the indicator needle does not deflect moisten the soil slightly with distilled water and try again. Do not take soil moisture measurements at this location if the soil has been moistened with distilled water.

Plot 1 (5m RB)	Plot 2 (5m LB)	Plot 3 (50m RB)	Plot 4 (50m LB)	Plot 5 (95m RB)	Plot 6 (95m LB)
#1 _____ #2 _____ #3 _____	#1 _____ #2 _____ #3 _____	#1 _____ #2 _____ #3 _____	#1 _____ #2 _____ #3 _____	#1 _____ #2 _____ #3 _____	#1 _____ #2 _____ #3 _____

4. Plant cover and structural diversity- Within each 100m² sample plot estimate the percent cover (the shadow cast by a particular layer) of the canopy (cp), understory (us), and groundcover (gc) vegetation layers. The canopy layer is >5m high, the understory is 0.5 to 5m high, and the ground cover is <0.5m high (roughly knee height). Only consider vegetation within the sampling plot. The surveyors should walk the plot focusing on 1 vegetation category at a time and then agree on one value to record. Running a measuring tape to better define the study plot or dividing transect into smaller units can help to obtain a more accurate estimation.

Plot 1 (5m RB)	Plot 2 (5m LB)	Plot 3 (50m RB)	Plot 4 (50m LB)	Plot 5 (95m RB)	Plot 6 (95m LB)
cp _____ us _____ gc _____	cp _____ us _____ gc _____	cp _____ us _____ gc _____	cp _____ us _____ gc _____	cp _____ us _____ gc _____	cp _____ us _____ gc _____

City of Austin - Riparian Functional Assessment

5. Hardwood Demography- Within each 100m² sampling record the dominant tree present (highest percent coverage of study plot, the shadow cast by a particular layer) and record the presence or absence of multiple age classes (seedlings, saplings, mature, and snags). Seedlings are defined as 12" or less having sprouted within the last year, saplings are > 12" in height but have yet to reach half its mature height and lack a full defined canopy, mature trees are approaching their maximum height and display a full developed canopy, and snags are dead trees with little to no vegetation and reduced canopy coverage often resulting from broken limbs.

Plot 1 (5m RB)	Plot 2 (5m LB)	plot 3 (50m RB)	Plot 4 (50m LB)	Plot 5 (95m RB)	Plot 6 (95m LB)
Species _____	Species _____	Species _____	Species _____	Species _____	Species _____
Classes present: seedling, immature, mature, snags.	Classes present: seedling, immature, mature, snags.	Classes present: seedling, immature, mature, snags.	Classes present: seedling, immature, mature, snags.	Classes present: seedling, immature, mature, snags.	Classes present: seedling, immature, mature, snags.

6. Recruitment/ Succession- Within each 100m² sampling plot record the dominant seedling present (highest percent coverage). Record the number of plots that have a different seedling species than the dominant hardwood species of the same plot.

Plot 1 (5m RB)	Plot 2 (5m LB)	plot 3 (50m RB)	Plot 4 (50m LB)	Plot 5 (95m RB)	Plot 6 (95m LB)
Species _____	Species _____	Species _____	Species _____	Species _____	Species _____

7. Riparian Zone Width- At 5, 50 and 95 meters along the in-stream transect measure the riparian zone width on both banks. Run a measuring tape from bankfull perpendicular away from the stream channel to the edge of the riparian zone. The edge of the riparian zone buffer is often dictated by a human structure (house, fence, road, etc...) or management activity (mowing) that inhibits plants to grow and alters the availability of the soil and vegetation to filter surface runoff.

Measurement 1 (5m)	Measurement 2 (50m)	Measurement 3(95m)
RB _____ LB _____	RB _____ LB _____	RB _____ LB _____

1 meter = 3.28 ft

8. Ratio (Riparian Zone Width to SPTH) - For each dominant hardwood species calculate the Riparian Zone Width to SPTH ratio. Divide the measured riparian zone width at each study plot by the associated site potential tree height (SPTH). SPTH is defined as the average maximum height to which a dominant tree will grow if left undisturbed and can be found from the USDA plants database or appropriate literature source. Make sure to use the riparian zone width that corresponds to the appropriate vegetation plot.

Plot 1 (5m RB)	Plot 2 (5m LB)	Plot 3 (50m RB)	Plot 4 (50m LB)	Plot 5 (95m RB)	Plot 6 (95m LB)
W _____(ft) / H _____(ft)	W _____(ft) / H _____(ft)	W _____(ft) / H _____(ft)	W _____(ft) / H _____(ft)	W _____(ft) / H _____(ft)	W _____(ft) / H _____(ft)

Site Notes:

City of Austin - Riparian Functional Assessment

In-stream Worksheet

Site #:	Site Name:	Date:	Time:	Staff:	
Photo #	0m facing u/s	50m facing u/s	50m facing d/s	100m facing d/s	Transect bearing: u/s d/s

Establish the in-stream transect: beginning at the appropriate benchmark (GPS coordinates, tree tag, or flagging) making sure to pay attention to transect bearing, either u/s or d/s of the benchmark. The person running transect should pay attention to appropriate riffle habitat to collect diatom sampling rocks. Rocks should be collected on the return trip with an effort on sampling multiple riffle habitats if available. Following diatom rock scraping (step 1) participants should proceed with the algae transect and canopy measurements (step 2-3). An underwater viewing bucket is required to define the visual sampling area during algae cover estimates and a densitometer is needed to take canopy measurements. Entrenchment ratio (step 4) measurements require 3 participants and should be taken along with the vegetation sampling at 5, 50 and 95 meters along the in-stream transect when time allows. Finally gap frequency, bank stability, and large woody debris (step 5-7) calculations should be taken throughout the entire 100 meter in-stream transect. Both gap frequency and bank stability require measurements to be taken on both banks and consist of 200 meters of sampling. Make sure to have an expandable ruler or yard stick when measuring large woody debris.

1. Diatom Sampling- Collect diatoms from three randomly selected rocks from appropriate riffle habitat. Rocks should be collected from undisturbed areas and should be relatively flat to facilitate consistent sampling area. Rinse off the bottom of each rock to ensure they are reasonably clean of debris and sediments, then using a small petri dish and sharp object to mark the area of the rock to be sampled. Scrape the sampling area with a wire brush and rinse the periphyton into the sampling tray with ambient water. After each scraping, make sure that the wire brush is also thoroughly rinsed for finer plant material into the collection pan. After the rocks have been scraped and rinsed, the contents of the collection pan should be carefully poured into a darkened or opaque bottle (approximately 125ml) and more water is used to flush all remaining particulate matter from the pan. During rinsing, care should be taken to keep the total volume of rinse water (used to flush the sample rocks, wire brush, and pan) does not exceed the volume of the sample bottle (125 mL). Filling the rinse bottle with only 125 mL of creek water can be helpful. Sample bottles should be labeled appropriately with site number, site name, collection date & time, and collector's initials. The samples should be kept on ice until transport to the ERM lab. Upon arrival to the ERM lab the samples should be refrigerated and preserved with 10% buffered formalin (4 mL per 125 mL sample). Be sure to record size of rocks scraped and densitometer reading of riffle where rocks were collected on data sheet below. Additional field notes should be taken from each site to describe the amount and color of periphyton and any other details pertaining to the health of the diatom community (i.e., observable creek sedimentation, etc.). Only sample diatoms under flowing stream conditions.

Notes:	Densitometer _____%
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2. Macro-algae cover- Using the zig-zag method, collect a total of 50 macro-algae points along the 100 meter in stream transect. Take one measurement approximately every 2 meters, making sure to capture samples from both the center and banks of the active stream channel. Using the underwater viewing bucket to define the visual sampling area estimate the percent cover of macro-algae (large filamentous algae) and dominant substrate category at every sampling point. Only sample algae and substrate under flowing stream conditions.

Point	Cover	Substrate	Notes
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
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Point	Cover	Substrate	Notes
26			
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49			
50			

Cover	
0	None
1	< 5%
2	5-24%
3	25-49%
4	50-75%
5	> 75%
Thickness	
0	bedrock - no loose substrate
1	Boulder (>256 mm)
2	Large Cobble (128-256 mm)
3	Cobble (64-128 mm)
4	Gravel (32-64 mm)
5	unstable substrate - no rocks > 32 mm
Sampling Instructions	
* Transect, diagonally across reach d/s to u/s	
* 50 equally spaced points (= every 2 meters)	
* Estimate macro-algae cover using a underwater view bucket (0.05 ft ²)	
* Record cover and substrate category	

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3. Canopy Cover- Take a densiometer measurement and photo at 5, 50, and 95 meters along the in stream transect facing downstream. Hold the densiometer level, 12" – 18" in front of the body so the operators head is just outside of the grids, counting the number of quarter squares not occupied by vegetation. Multiply the total count by 1.04 and subtract from 100 to obtain percent canopy cover. The photo should be taken directly above observes head keeping camera level.

Measurement 1	Measurement 2	Measurement 3
5m _____ P# _____	50m _____ P# _____	95m _____ P# _____

4. Entrenchment- Entrenchment measurements should be taken at 5, 50, and 95 meters along the in-stream transect. The entrenchment ratio is determined by dividing the width of the flood prone area by the bankfull width. The flood prone area is defined by measuring the width of the channel at twice bankfull depth. Depth should be taken at the stream thalweg (deepest section of the channel). Bankfull corresponds to the start of the floodplain and is indicated by a break in slope from the channel, a change in vegetation from bare surfaces or annual wetland species to perennial water-tolerant or upland species, and from a change in the size distribution of surface sediments.

Measurement 1 (5m)	Measurement 2 (50m)	Measurement 3 (95m)
Bankfull _____ Depth _____ 2x _____	Bankfull _____ Depth _____ 2x _____	Bankfull _____ Depth _____ 2x _____

5. Gap Frequency- Throughout the entire 100 meter in-stream transect estimate the relative frequency of riparian buffer gaps. A riparian buffer gap is defined as a void in vegetation ≥ 1 meter wide and 5m from bankfull perpendicular into the riparian zone where surface runoff has an unimpeded path to the stream channel. An unimpeded path exists if no vegetation higher than 12" is present. Only consider woody vegetation that is multi-stemmed or single trunks ≥ 5 inches in diameter. Talley all 1 meter buffer gaps along both banks of the in-stream transect and divide by 200 then multiply by 100 to obtain an overall site percentage.

Number of 1 meter gaps: _____

6. Bank instability- Throughout the entire 100 meter in-stream transect estimate the length of the channel bank where there is active erosion, near-vertical cut banks. Loose substrate, scour marks, and slumping banks are all signs of unstable banks. Talley all 1 meter sections along both stream banks that have active erosion and divide by 200 then multiply by 100 to obtain an overall site percentage.

Number of 1 meter erosion sections: _____

7. Large Woody Debris- Is defined as wood that is partially exposed to the water or located within the active stream channel and is at least 6" in diameter and 3' long. Throughout the entire 100 meter in-stream transect record the number of large woody debris pieces. Optimal study reaches have > 6 LWD pieces; suboptimal study reaches have 4-6 LWD pieces; Marginal study reaches have 1-3 LWD pieces; and poor buffers have no LWD pieces.

Number of Large Woody Debris Pieces: _____

Site Notes: