PROTECTING WATER QUALITY AND CONNECTING PROTECTED PLACES IN TEXAS USING RIPARIAN CONNECTIVITY NETWORKS

by

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ABSTRACT

Widespread development and land use changes across the United States (U.S.) have fragmented its landscape, altering the flow of resources between natural environments and significantly reducing habitat connectivity. While habitat connectivity is critical for many environmental and societal benefits, it has historically played a secondary role in the management of U.S. public lands. The establishment of a Riparian Connectivity Network (RCN), to connect protected habitat by the protection of riparian lands, has been proposed as a framework to address this issue. I investigated the potential of the RCN framework to increase connectivity and protect water quality in HUC-8 watersheds within the state of Texas with particular focus on the role of stream mitigation banks. Watersheds of interest were identified as those with the largest expected increase in impervious surface, largest percent of area protected, and lowest percent of riparian lands protected. I then created a stream prioritization scheme within each HUC-8 to identify stream reaches that would be considered in the establishment of a mitigation bank; this prioritization was based on stream order (prioritizing headwaters over larger streams) and land cover (prioritizing more degraded lands for their potential to be improved by mitigation). The shortest path able to link as many protected areas as possible was then isolated from the prioritization model to create an RCN showing which portions of the network could be fulfilled by Clean Water Act (CWA) mitigation not normally considered in a connectivity context. The RCN concept has the potential to combine various environmental efforts operating in the riparian zone in order to improve

water quality and increase ecological connectivity.

1. INTRODUCTION

In a time when human impacts are felt across the globe, the world's ecosystems are experiencing ever-increasing pressures and disturbances. These pressures have widespread impacts, notably global climate and landuse changes (Vitousek et al. 1997). While these and other impacts create many challenges for the world's ecosystems, landuse change is arguably the most visible and has many direct impacts resulting from urban and agricultural land conversions (Foley et al. 2005). Of these many environmental effects, habitat fragmentation and reduced water quality are particularly prominent and problematic (Alberti and Marzluff 2004, Vörösmarty et al. 2000).

Although these environmental impacts can be intense and far reaching, there are a variety of ways in which they can be mitigated. Protection of land for the preservation of ecological functions is one such method. Protection of lands historically were the result of government ownership of land, however today formal protections extend to private lands as well through a variety of means, both voluntary (through mechanisms such as conservation easements) and regulatory (through required regulations and mitigations enforced through legislation such as the Clean Water Act (CWA) and Endangered Species Act (ESA). While many lands have been protected for ecological purposes, habitat fragmentation and landuse changes occurring around these protected areas reduce their resiliency and result in reduced water quality (Hamilton et al 2013).

Connectivity supports resiliency in many ways, including disturbance avoidance and recolonization, as well as increased access to a larger pool of resources (Bengtsson et al. 2003, Taylor et al. 1993). While connectivity can be achieved from a variety of approaches, connectivity via riparian corridors provides multiple benefits. Riparian corridors connect uplands to lowlands, make use of existing regulatory frameworks, protect a disproportionately large amount of ecosystem services, and improve water quality among other benefits (Thompson 2004, Jones et al. 2010). The concept of a Riparian Connectivity Network (RCN; sensu Fremier et al. 2015) provides a useful framework to investigate existing protected riparian corridors and can be used to identify future riparian parcels to prioritize for conservation with the goal of increasing connectivity and improving water quality.

The purpose of this study is to identify the potential for an RCN to increase connectivity between protected areas and improve water quality at a watershed scale. I used the state of Texas as my study area, due to its large area yet small percentage of protected area (1.87 percent). Using HUC-8 watersheds within Texas, this study examined: (1) how much of an RCN already exists within each watershed, (2) the amount of development pressure each watershed is expected to experience, and (3) which stream reaches have a high priority for conservation efforts to improve water quality and increase connectivity.

2. LITERATURE REVIEW

2.1 Protected Areas

The U.S. has roughly 640 million acres of federal, public land protected for a variety of uses, some including protections for wildlife habitat (USGS 2017). These protected lands face many challenges in the conservation of biodiversity in a time when human influences are widely felt. Invasive species, habitat fragmentation, climate change, and many other factors have placed strain on the country's ecological communities. Widespread development and land use changes across the United States (U.S.) have fragmented its landscape, altering the flow of resources between natural environments and significantly reducing habitat connectivity (Hansen and DeFries 2007, Fischer and Lindenmayer 2007). This often results in many areas of critical habitat being surrounded by human activities that isolate them from surrounding habitat and introduce disturbances that impact the health of the ecosystem (Hansen and DeFries 2007). This reduces the ability of many areas of critical habitat to adapt to changing environmental conditions often reducing the resiliency (i.e., the ability of a system to absorb a disturbance while maintaining its structure and function) of these protected places (Walker and Salt 2006).

While the preservation of habitat is critical for many environmental and societal benefits, it has historically played a secondary role in the management of U.S. public lands (Fremier et al. 2015). Protected areas in the U.S. were historically placed in areas containing unique geographic features and aesthetic value. While these areas were designed in part to protect wildlife, the conservation of biodiversity was not a primary factor in site selection for many of these protected areas (Aycrigg et al. 2013). While governmental managing entities often don't consider ecological systems in the management of protected areas, recent attention by nonprofits and scientists has been placed on the importance of functional ecosystems and ecosystem services within these protected areas, as well as conserving and restoring areas that can provide functional connections between them (Fremier et al. 2015).

2.2 Resiliency

Pressures and disturbances place stress on natural systems. In their natural state these systems would be of sufficient size and complexity to maintain an ecological memory in undisturbed areas that would provide resources for the recovery of the disturbed sectors (Bengtsson et al. 2003). These same rules apply in an era dominated by human induced disturbances, yet many of these reserves now lack the appropriate resources to recover from large disturbances, resulting in less resilient ecosystems. Resilience is defined as a system's ability to absorb a disturbance while still maintaining its ecological structure and function (Walker and Salt 2006). The high amount of landscape modification that exists today leads to the loss of native habitat and fragmentation of the existing landscape. This can lead to the decline of many species and potentially result in extinction or extirpation of key species from isolated habitat fragments (Fischer and Lindenmayer 2007).

As habitat fragmentation continues, it will likely result in further reduction in the resiliency of habitat patches as they continue to become more isolated from the greater ecosystem. While there are many ways in which the issue of declining resiliency can be addressed, increasing the connectivity between habitat patches has been suggested as a means by which this can be achieved. Connectivity can increase resiliency in many ways, including disturbance avoidance and recolonization as well as increased access to a larger resource pool for many species (Bengtsson et al. 2003, Taylor et al. 1993). The creation of habitat corridors can help mitigate some of the problems associated with habitat fragmentation. These corridors have been observed to increase movement of biota between habitat patches by 50% compared to patches lacking corridors according to an analysis of 35 studies involving 78 different species (Gilbert-Norton et al. 2010). They also allow biotic resources to avoid the disturbance by moving to adjacent reserves, and to aid in recolonization after a disturbance (Johnston et al. 2013). Landscape connectivity is a key element in the survival of many organism populations, and ignoring its importance can lead to negative outcomes in conservation efforts (Taylor et al. 1993). It is also important to note that there is a distinction between functional connectivity and structural connectivity or connectedness (Baudry and Merriam 1988). While two patches of habitat may be structurally connected, having a high degree of connectedness, they may not be functionally connected, therefore having a low degree of connectivity. This important distinction should be taken into account when engaging in connectivity planning, as care must be taken that the structural connections planned and created produce functional corridors that allow for the movement of biotic resources between connected habitats.

2.3 Riparian Zones

Riparian ecosystems are those at the interface between terrestrial and aquatic environments (Gregory et al. 1991). These zones are influenced by many processes, both aquatic and terrestrial and experience sharp changes in many environmental factors due to their transitionary nature (Gregory et al. 1991). While what composes the riparian zone is not always easily delineated, their boundaries extend outward into the floodplain, as well as into the canopy of the accompanying riverside vegetation (Gregory et al. 1991). Riparian zones are also important in that, relative to size, they provide a disproportionately large amount of ecosystem services (Brauman et al. 2007, Jones et al. 2010). Ecosystem services are the benefits that humans receive from functioning ecosystems. While riparian zones provide many different ecosystem services, one of particular interest in environmental policy/management are those pertaining to water quality.

Nonpoint source pollution is a critical problem for the quality of the nation's waters, with two thirds of this pollution coming from agricultural sources (Lee et al. 2003). Riparian buffers along stream networks have been shown to filter runoff, removing sediment and nutrients before it enters the stream (Lee et al. 2003, Lowrance et al. 1997, Mayer et al. 2007). Although studies suggest that various factors such as buffer width and soil depth influence the effectiveness of riparian buffers to filter runoff and improve water quality, they still serve important functions for water quality (Lowrance et al. 1997, Mayer et al. 2007). This lends riparian conservation efforts the opportunity to serve two important environmental services simultaneously: increase water quality by protecting and restoring riparian habitat, as well as to increase functional connectivity within a region by structurally connecting habitat patches along a riparian network.

2.4 Riparian Connectivity Network

One method proposed to increase connectivity of protected areas has been the establishment of a Riparian Connectivity Network (RCN; Fremier et al. 2015). The goal of a RCN is to protect riparian habitat, providing uninterrupted corridors that allow for the movement and migration of plant and animal species between larger portions of usable habitat connected by the network. There are many methods for creating corridors between protected areas; however, the focus on riparian lands has several benefits over other methods of increasing connectivity. Studies have shown that riparian corridors, even those disturbed by human activities, may serve as corridors for movement when undisturbed corridors are not available (Hilty and Merenlender 2004).

Riparian corridors, while not usually large in area, may often provide suitable habitat through which wildlife may move in otherwise unsuitable areas, especially in an urban setting (Rouquette et al. 2013). Of particular interest to the focus of creating riparian corridors, is the ability to make use of existing federal laws and regulations that already provide protections for riparian areas (Thompson 2004). This would allow the creation of such a network to proceed without the challenges of creating new laws or policy changes that would be necessary to implement similar connectivity networks outside of riparian zones. The use of the river network to define habitat corridors has the benefit of being predefined, reducing complexity of determining which lands should be protected in the establishment of the corridor. The stream network also extends across the landscape in a dendritic pattern, offering wide coverage, as well as connecting uplands to lowlands, which could be ignored in the establishment of other corridors (Fremier et al. 2015). Beyond the benefits for connectivity and biodiversity, riparian habitat conservation can improve water quality, preserve aesthetic landscapes, and protect areas that provide a disproportionately large amount of ecosystem services Bernhardt et al. 2005, Jones et al. 2010).

While the goal of increasing the connectivity of protected areas is to create resilient ecosystems and conserve biodiversity, there are also concerns of potential negative impacts. Studies in Kruger National Park in South Africa have proposed that invasive plant species have the potential to invade protected areas along uninterrupted riparian networks from upstream (Foxcroft et al. 2007). There are also concerns that these corridors may promote the spread of pathogens, or may allow predators to infiltrate areas protected for the conservation of prey species (Haddad et al. 2014). While these concerns have been noted, the potential benefits of habitat connectivity likely outweigh the potential risks of corridor creation (Haddad et al. 2014).

Connectivity networks focused on the riparian areas of river networks, and therefore watersheds, can also make use of scalability. This would allow the creation of smaller riparian connectivity networks in smaller watersheds to become incorporated into networks of the larger watersheds within which they are nested. This can become important as part of landscape-scale conservation efforts (Urban et al. 1987).

2.5 Conservation Easements

Traditional protected public lands in the U.S. are heavily skewed toward the western portion of the nation, west of Texas and the Great Plains. This makes the implementation of an RCN, and other conservation measures, logistically more difficult in the eastern half of the nation where there are much smaller amounts of ‘traditional protected lands' (i.e., federal, state, county, and city lands protected for their historical, cultural, or environmental values). Protection in these areas requires the inclusion and cooperation of local landowners, which in many areas can be numerous, in conservation planning and implantation. Federally protected lands create an extensive network of ecosystems, but they are inadequate to properly protect ecosystem integrity (Fremier et al. 2015). While there has been a marked decrease in the growth rate of public lands, there has been a sharp increase in conservation on private lands (Villamagna et al. 2015). Conservation easements, legal documents negotiated between the landowner and easement holder placing certain restrictions on private lands, have become a popular mechanism for conservation in recent years currently protecting more than 56 million acres of private land across the country (McLendon 2016).

Conservation easements can be useful in areas of the country where public land acquisitions are difficult due to budgetary or political reasons, as is the case in Texas. Easements are also popular on large tracts of family lands, as they provide tax benefits and also prevent the land from being subdivided. This allows families to pass their lands on to the next generation without being burdened by taxes or pressure to sell the land to potential developers. Working lands also receive additional attention from government programs (such as the Texas Farm and Ranchlands Conservation Program) seeking to protect working lands for their value as open, undeveloped space which provides benefits to the surrounding environment and provides many ecosystem services not provided by impervious, developed land (McGuire 2017). This has the benefit of protecting private property rights while allowing a customizable mechanism to protect certain environmental qualities of private lands.

Because of this, many entities, particularly non-profits and land trusts such as The Nature Conservancy, hold easements on many properties to protect valuable habitats. A sample of The Nature Conservancy's easements showed that 80% have provisions for the protection of habitat, yet more than half allowed for the construction of new buildings and 46% allowed the lands to be worked, with limitations (Rissman et al. 2007). Some doubt the effectiveness of conservation easements to adequately preserve the many ecosystem services that are provided by native habitat, but easements have been shown to preserve these services at equivalent or greater rates than protected places (Villamagna et al. 2015). This provides support for the use of easements as part of a larger conservation mechanism to promote resilient ecosystems.

2.6 Mitigation Banks

Another conservation mechanism that should be considered in the creation of a RCN is mitigation banking. Mitigation banks are areas in which restoration activities are undertaken to improve stream and riparian habitat, and then credits are sold to developers who must provide mitigation for their projects (Lave 2006, Ruhl et al. 2005). This allows for the pooling of resources from many development projects to restore a single, larger area of habitat. The two main drivers for mitigation banking are the Endangered Species Act (ESA) and the CWA. Both of these pieces of legislation require mitigation in response to damages inflicted upon endangered species, wetlands, or water quality. The U.S. Fish and Wildlife Service (USFWS) has issued federal guidelines for implementing conservation banks for the purpose of mitigating takes against endangered species (USFWS 2003). These banks are areas of protected habitat and are appropriately managed for species of concern, and may sell species credits to developers who impact these species in another location (Bunn 2014). Wetland and stream mitigation banks are permitted by the U.S. Army Corps of Engineers (USACE) under section 10 of the Rivers and Harbors Act of 1899 and section 404 of the CWA (USACE 2011). Wetland mitigation banks are areas of restored wetlands that can be credited by the USACE based on the quality of the restored wetlands, and sold to developers to offset damages to wetlands in other locations. Stream mitigation banks are areas of restored stream, which are issued credits by the USACE based on the results of the restoration and its improvements to water quality, which again are sold to satisfy mitigation requirements for projects disturbing stream and water quality elsewhere. While all three mitigation methods have great potential for conservation efforts in the future, for the purposes of this study I focused primarily on stream mitigation banks, also referred to here simply as 'banks'. This is due to their constraint to riparian habitat and their potential use in increasing connectivity along the stream network.

While there are concerns as to the variability in ecological value between banks, they have the potential to serve an important role in conservation should certain standards and criteria be met (Bunn et al. 2014). The mechanism of mitigation banking is likely to become more popular in the future as it is perceived as a simpler and less expensive process than the permitting required for on-site mitigation (Lave et al. 2008). While more studies are needed to ensure that ecological standards and societal values are met, in areas of the country where funds are rarely allocated for the purchase of public land, such market-based conservation methods will be necessary to increase the connectivity and resiliency of protected areas.

3. RESEARCH METHODS

My study is situated in Texas, a state whose lands are overwhelmingly held by private citizens and only has a small foundation of protected lands. This study aims to identify portions of the state which could be prioritized for riparian protection in order to promote the resiliency of protected areas through increased ecological connectivity and improved water quality. This goal was addressed in three parts:

1. How much of a RCN already exists in Texas at the HUC-8 watershed level?
2. Which HUC-8 watersheds are most susceptible to development and fragmentation pressures?
3. Using the RCN framework and priority watersheds from the previous questions, which stream reaches should be prioritized for riparian conservation improve water quality and increase the connectivity of protected areas?

Using this RCN framework, I developed a new methodology to prioritize watersheds (and then river reaches) within Texas for riparian conservation, such that limited conservation funds can be most effectively spent. This methodology also identifies portions of the state that are likely to see an increase in anthropogenic disturbances, and which areas will likely be targeted to help mitigate the effects of these disturbances on already stressed ecosystems.

3.1 Study Area and Scales of Analyses

Because Texas is largely held in private ownership (~95 percent), implementation of an RCN will necessitate extensive use of protection measures other than public land acquisition, namely conservation easements and mitigation banks. My research first determined how much of an RCN already exists within the state. More importantly, I determined which watersheds (at the HUC-8 level) represent watersheds of consideration for the development of an RCN in light of existing protection and projected developmental pressures. I used HUC-8 watersheds because it is the unit of analysis used for mitigation banks operating in Texas (USACE 2011). River reaches were then selected within the identified watershed by the creation of a prioritization scheme based on the Texas Rapid Assessment Method (TXRAM) document provided by the USACE Fort Worth District (USACE 2015). The TXRAM document was created by the Fort Worth District to provide a rapid, repeatable methodology for determining stream integrity and health to guide mitigation actions required under section 404 of the CWA. Reaches were prioritized to favor headwaters, due to the high amount of disturbances to these streams, as well as more degraded landscapes, due to their greatest potential for improvement, allowing a bank to receive more credits from the USACE based on improvements in water quality.

3.2 Data

Data for my analyses included hydrography databases, land use data, protected areas databases, conservation easement data, and mitigation bank data. Hydrography data was obtained from the National Hydrography Dataset (NHD v2.2, USGS 2017). From this dataset, I extracted high resolution (1:24,000) flowline data. This stream network was used with an additional lateral buffer to determine the percentage of riparian habitat that was protected. The NHD also provided HUC-8 watershed boundaries, which was the primary unit of analysis. The flowline data was also used to isolate connectivity networks from the existing stream network within individual watersheds creating a simplified RCN.

Data pertaining to protected areas was obtained from the Protected Areas Database (PAD) of the U.S. (USGS 2017). The PAD is an inventory managed by the U.S. Geological Survey that tracks protected lands around the country. These protected areas are designated with GAP Status Codes corresponding to the level of protection afforded to each parcel. Information on the GAP Status Codes can be found in Table 1. Conservation easement data was obtained from the National Conservation Easement Database (NCED 2016). This is a national database which collects easement data from public agencies and land trusts. Mitigation bank information was obtained from the Regulatory In-lieu Fee and Bank Information Tracking System (RIBITS) through the U.S. Army Corps of Engineers (USACE 2016). This database has information on all mitigation banks filed with the USACE, and includes information about banking entities, bank status, bank type, and available credits. Land use data was obtained from the National Land Cover Database, for the year 2011 (USGS 2016). Data used to determine the amount of development expected to occur in each watershed was provided by the Integrate Climate and Land Use Scenarios (ICLUS) project (USEPA 2010). This project explores future projections for human population, housing density, and impervious surface for the U.S. For this project, the base case scenario was chosen as it most accurately described the study area.

Table 1: GAP Status Code Descriptions (after USGS 2017).

GAP Status	Description
1	Areas having permanent protection from conversion of natural land cover and mandated management plan in operation to maintain a natural state where disturbance events)of natural type, frequency, intensity, and legacy) are allowed to proceed without interference or are mimicked through management.
2	Areas having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a primarily natural state, but which may receive uses or management practices that degrade the quality of existing natural communities, including suppression of natural disturbances.
3	Areas having permanent protection from conversion of natural land cover for the majority of the area, but subject to extractive uses of either a broad, low intensity type (e.g., logging) or localized intense type (e.g. mining). This also confers protection to federally listed endangered and threatened species throughout the area may be conferred.
4	Areas with no known public or private institutional mandates or legally recognized easements or deed restrictions held by the managing entity to prevent conversion of natural habitats to anthropogenic habitat types. Conversion to unnatural land cover throughout is generally allowed and management intent is unknown.

3.3 Watershed-Scale Analyses

Borrowing from the methods outlined in Fremier et al. (2015) and informed by MacArthur and Wilson's theory of island biogeography (1967), my analysis began by focusing on protected areas that were designated with the conservation status code (GAP codes) of GAP-1 and GAP-2, as well as riparian portions of GAP-3 lands. These lands are protected from conversion of natural land cover to other uses and represent habitat that can be used to comprise an RCN. Conservation easements were also included in the analysis. Although many of these easements allow for private landowners to still use the land under easement, there are often restrictions placed on development and destruction of riparian habitat.

I also included the relatively new conservation mechanism of mitigation banks. These are areas where stream and riparian areas have been restored and protected as mitigation offsets under the CWA. These lands are often overlooked in other analyses but represent the conservation of important riparian habitat. Particularly in watersheds projected to experience large increases in development, mitigation banking has the potential to conserve key riparian habitat and serve important functions in connecting protected areas.

The shapefiles for each of these datasets were imported into ESRI's ArcMap 10.4 and duplicates between datasets were removed before analyses. The amount of habitat protected was determined by calculating the percentage of each watershed found within the borders of lands meeting the definition of protected (i.e., lands within the PAD with GAP codes 1 and 2, the riparian zone of lands within the PAD with GAP code 3, conservation easements, and mitigation banks). The percentage of a RCN that is already in place was assessed by determining the percentage of the stream network which lies within protected areas . I determined this by the amount of stream length that lies within a protected area, easement, or mitigation bank, with a 30 m buffer to allow for mapping errors of processed data (sensu Julian, Elmore, and Guinn 2012).

Watersheds with higher percentages of riparian areas that are protected have a larger framework from which a more suitable RCN can be developed. Watersheds with lower percentages of protected riparian habitats indicate areas in which more intensive conservation efforts should be focused if an effective RCN is to emerge. Watersheds to be considered for increased riparian conservation were determined by assessing which watersheds face the greatest threat from development, measured by the greatest increase in projected impervious surface from 2010 to 2050 using ICLUS data (USEPA 2010). Of those facing the highest threat (top 20%, Item A from Figure 1), those with the largest amount of protected lands (top 20%, Item B from Figure 1) represent those watersheds which have a large amount of protected land facing future developmental threats and likely to benefit from increased connectivity. Of these watersheds, the three with the lowest percentage of riparian habitat protected (Item C from Figure 1) were chosen as they have the greatest potential to increase connectivity via riparian conservation.

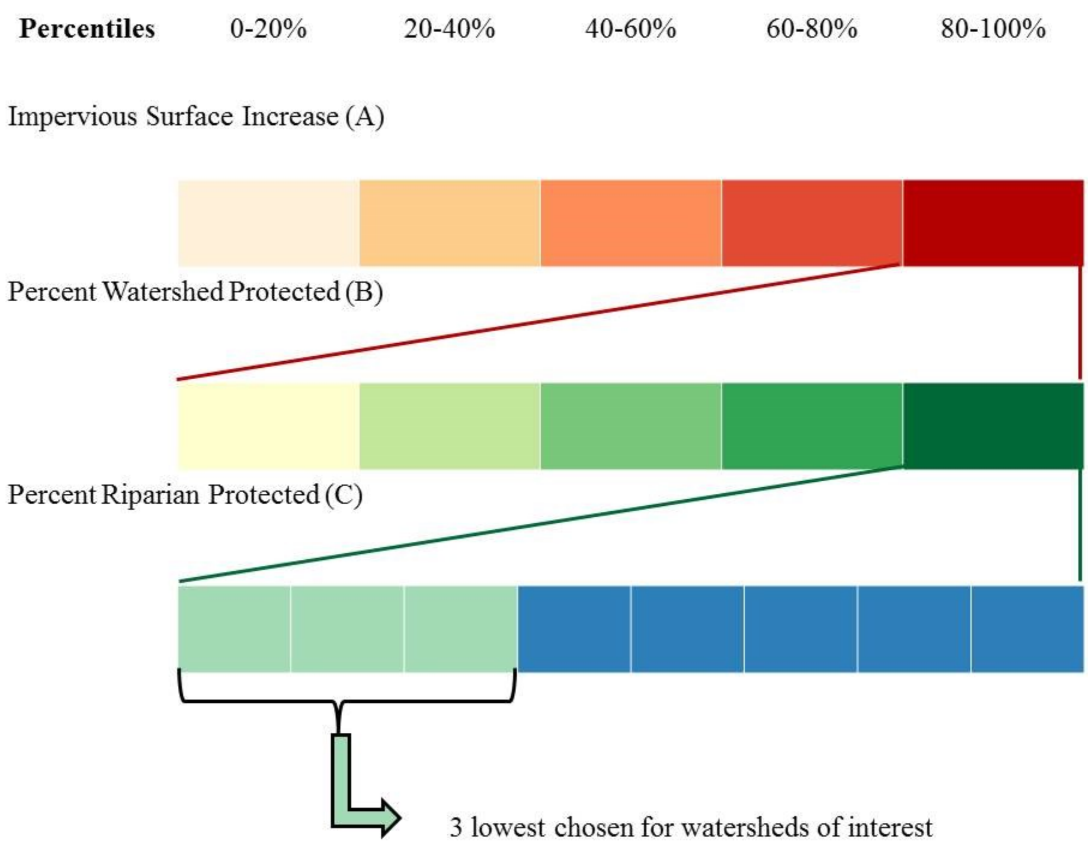

Figure 1: Methodology Diagram. Visual representation of the methodology used to identify the three watersheds of interest.

3.4 Reach-Scale Analyses

Within each of these watersheds, a prioritization of stream segments for the establishment of a mitigation bank was developed. The prioritization scheme created for the establishment of mitigation banks prioritizes headwater streams, those in the NHDplus as having a stream order of 0 or 1. These headwater streams are prioritized by the Army Corps in mitigation permitting due to their large influence on water quality as well as the prevalence of disturbances occurring in these streams (Alexander et al. 2007, USACE 2013). These headwater streams were reclassified with a value of 10, second order streams were given a value of 5 (due to the disturbances in these streams still being common occurrence) and the remaining streams given a value of 1 (as disturbances to streams of higher orders are avoided by most developers where possible). Note that within the USACE Fort Worth District, preferred mitigation for impacts to small intermittent streams is similar sized intermittent streams (USACE 2013).

Land cover data was also included in the prioritization, and the dataset was simplified into three categories by reclassifying data from the NLCD into the following three classes based on their classifications: Urban and intense agriculture (Developed, Barren, and Cropland categories; NLCD values of 21-31, 82); Low intensity agriculture (Pasture/Hay category; NLCD value of 81); and Undeveloped (Forest, Shrubland, Herbaceous, or Wetlands; NLCD values of 41-72, 90-95). These categories were reclassified for the prioritization scheme based on their priority for the improvement of water quality, following the general guidelines outlined in the Army Corps' Texas Rapid Assessment Module (TXRAM) for the Fort Worth District. Urban and intense agricultural land cover was given a value of 10, low intensity agricultural land cover given a value of 5, and Undeveloped land cover given a value of 1 (USACE 2015). Undeveloped land cover was given lower priority due to the Army Corps regulations giving preference to restoration over protection in most cases (USACE 2012). Table 2 describes the prioritization multipliers assigned to different land cover uses and stream orders.

Table 2: Prioritization Multiplier. Description of prioritization multipliers used in the creation of the prioritization scheme. The prioritization network was created using the following equation in raster calculator after the following reclassifications were made (Stream Network x Land Cover).

Prioritization Multiplier	Stream Network	Land Cover
10	Headwater streams, those with stream orders of 0 or 1 in the NHDplus.	Urban and Intense Agriculture, pixels with values of 21-31, 82 in the NLCD.
5	Smaller perennial streams, those with a stream order of 2 in the NHDplus.	Low Intensity Agriculture, pixels with a value of 81.
1	The remainder of the stream network was placed into this category	Undeveloped, pixels with values of 41-72, 90-95.

Within these watersheds, the shortest path to connect the protected areas were identified as a simplified, baseline RCN. These paths were created by rasterizing the stream network and running the Cost Connectivity tool in ArcMap to determine the shortest path along the stream network to connect the protected places. This represents the shortest distance and is a simplified RCN which does not take into account other factors which would need to be considered in the establishment of the most effective

RCN possible within the watershed. This shortest path was then isolated from the prioritization scheme developed for the establishment of mitigation banks, in order to identify where the priorities of wildlife conservation and water quality (through mitigation banking) could be integrated in the establishment of an RCN in order to increase habitat connectivity.

4. RESULTS

4.1 Current Extent of Riparian Connectivity Networks in Texas

There are a total of 211 HUC-8 watersheds, either fully or partially within Texas. These watersheds have varying amounts of area protected, ranging from 0-92% (Figure 2). Using the NHD high resolution flowline data, there are 817,734 km of streams in Texas. Of this, 32,337 km are within protected lands (3.95 percent of the stream network). At the HUC-8 level, varying degrees of the stream network are protected, ranging from 0-90% (Figure 3). The amount of the stream network protected represents the percentage of an RCN already in place within each watershed. This shows a few watersheds (those in the Big Bend region dominated by large tracts of public land) have a large percentage of their riparian habitat protected, representing a well-developed RCN in those watersheds. The majority of watersheds have a much lower percentage of their watershed protected, indicating that there is need of further riparian protection for the development of an RCN.

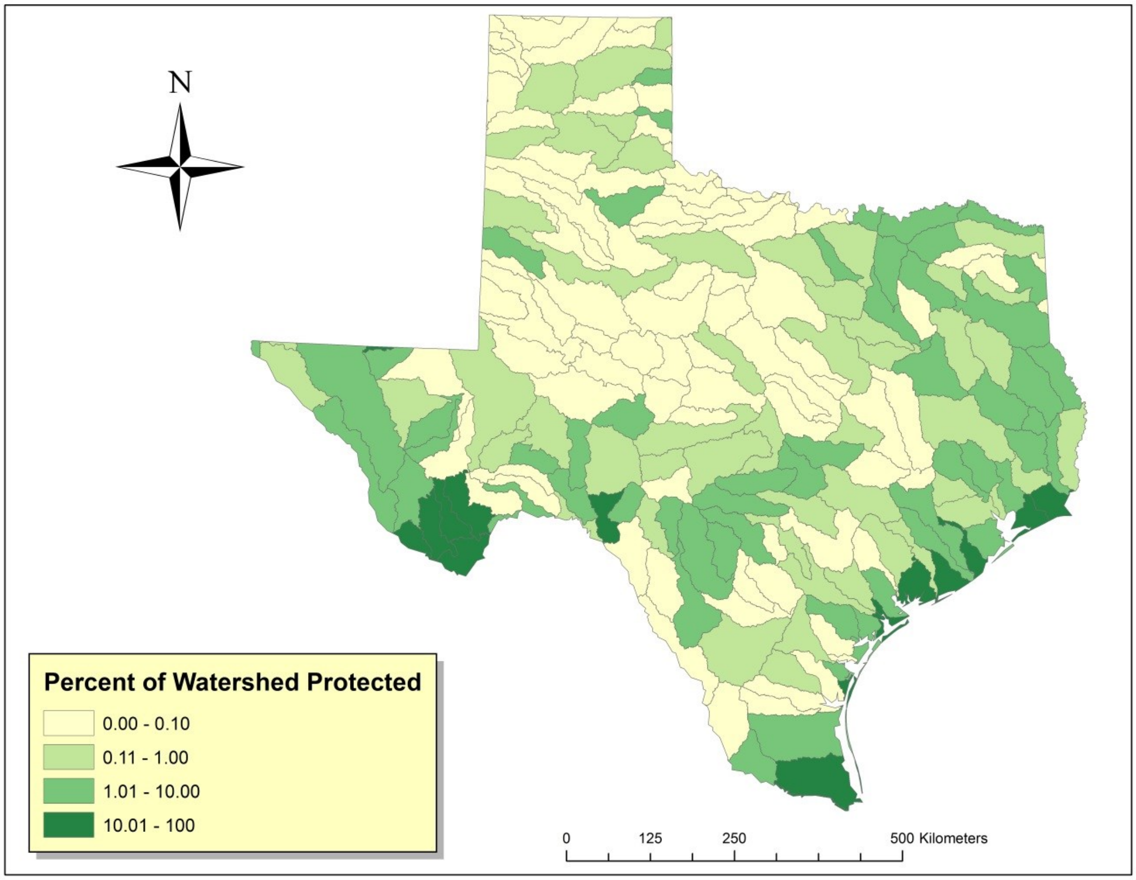

Figure 2: Percent of Watershed Protected. The percent of the area of each HUC-8 that falls within protected lands.

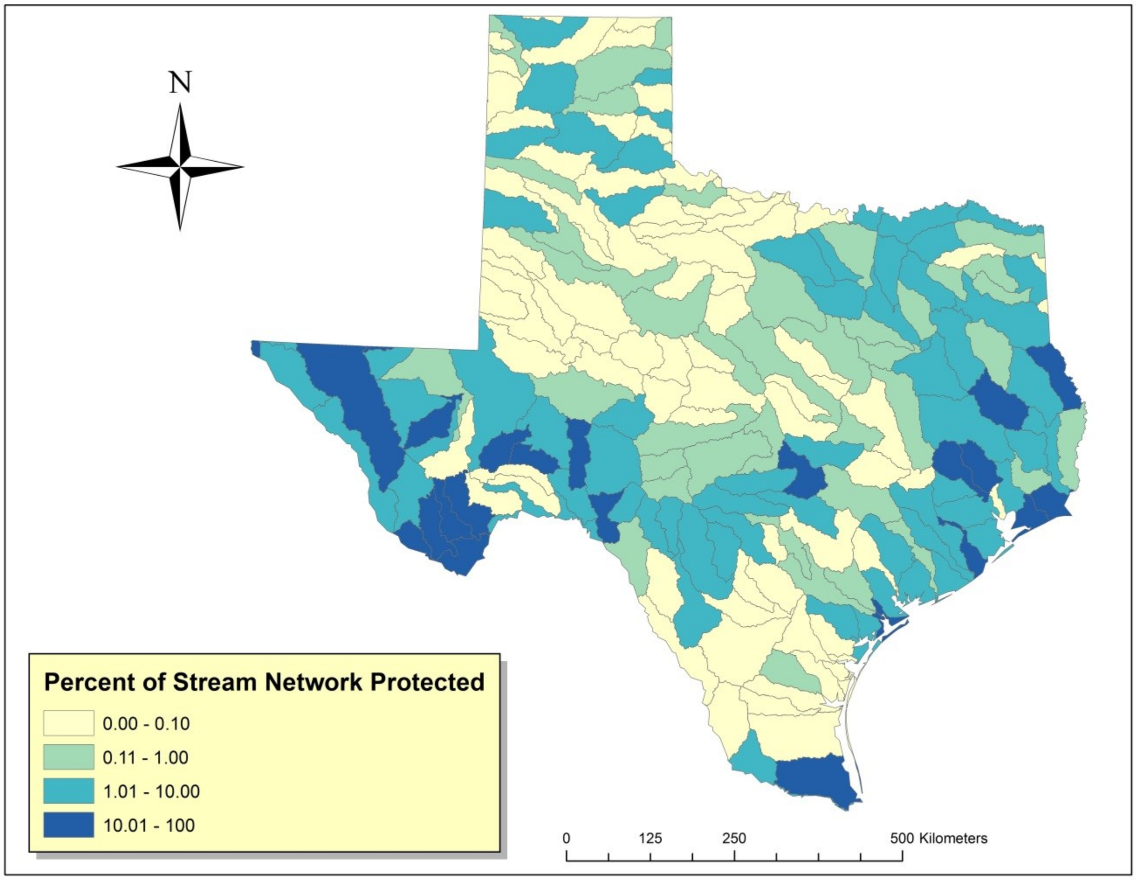

Figure 3: Percent of Stream Network Protected. Percentage of the stream network within each HUC-8 that falls within the boundaries of protected areas, this represents the amount of an RCN already in place within the watershed.

4.2 Watershed-Scale Development and Impacts

There was a total of 7,313 km^2 of impervious cover across Texas in 2010, with most of this development along the I-35 interstate corridor and along the Dallas-Houston-San Antonio triangle (Figure 4). This area of impervious cover was projected to increase to 9,974 km^2 by 2050, mostly expanding from the major cities (Figure 5). In order to determine which watersheds are expected to experience large amounts of development, the change in the amount of impervious surface was calculated by subtracting the 2010 values from the 2050 values (Figure 6). This shows large expected increases in the areas surrounding urban centers, resulting in environmental impacts that will require mitigation. These percentages were then converted into area of projected impervious surface increase and then summed for each watershed to show which watersheds are expected to experience the largest increase in area of impervious surfaces (Figure 7). This analysis showed which watersheds are most at risk of development pressures and will likely experience the highest amount of required mitigation. Due to the focus of this study on stream mitigation banks, the top quintile (20 percent) of watersheds with the largest expected amount of impervious surface increase were isolated from the remaining watersheds, which again showed that most of impervious surface increase is expected to occur in watersheds that contain or are near urban centers. The Trinity Basin, which covers much of the Houston and Dallas metro areas, is expected to experience a large amount of development, with all but four of its watersheds being in the top 20 percent. Large amounts of development are also expected in Central Texas from San Antonio north to Georgetown, with many of these watershed also being in the top quintile. From these watersheds, the percentage of land protected within each watershed was calculated and the top 20 percent were again isolated (Figure 8).

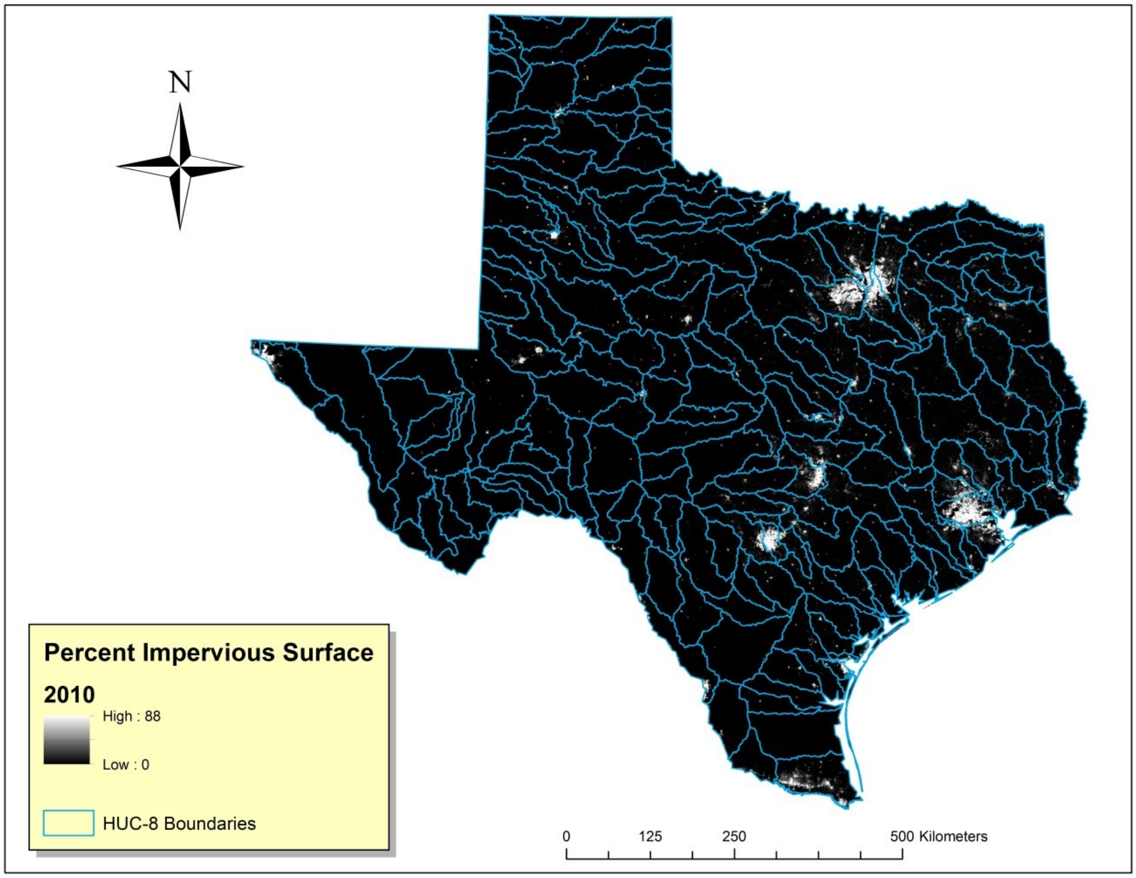

Figure 4:Percent Impervious Surface 2010. The percentage of each pixel that is covered by impervious surface in 2010, taken from the ICLUS program (USEPA 2010).

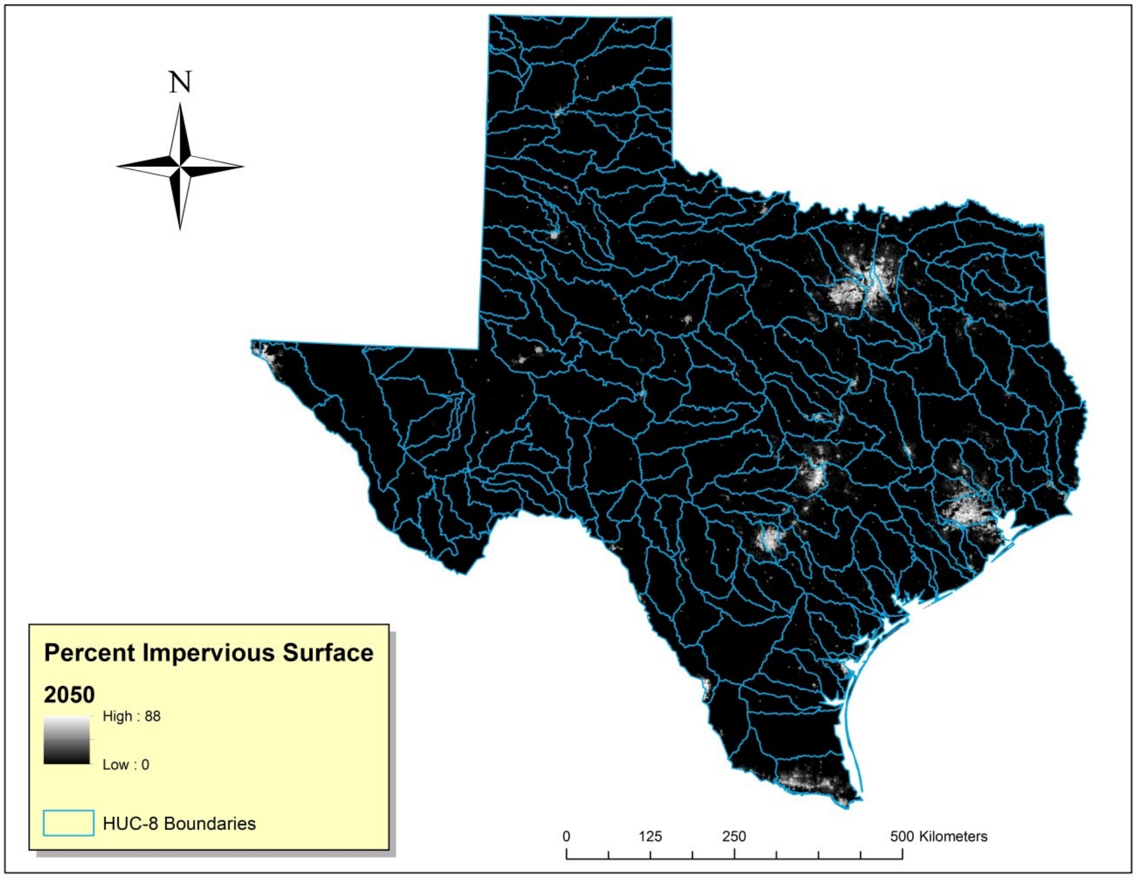

Figure 5: Percent Impervious Surface 2050. The percentage of each pixel that is projected to be covered by impervious surface in 2050, taken from the ICLUS program (USEPA 2010).

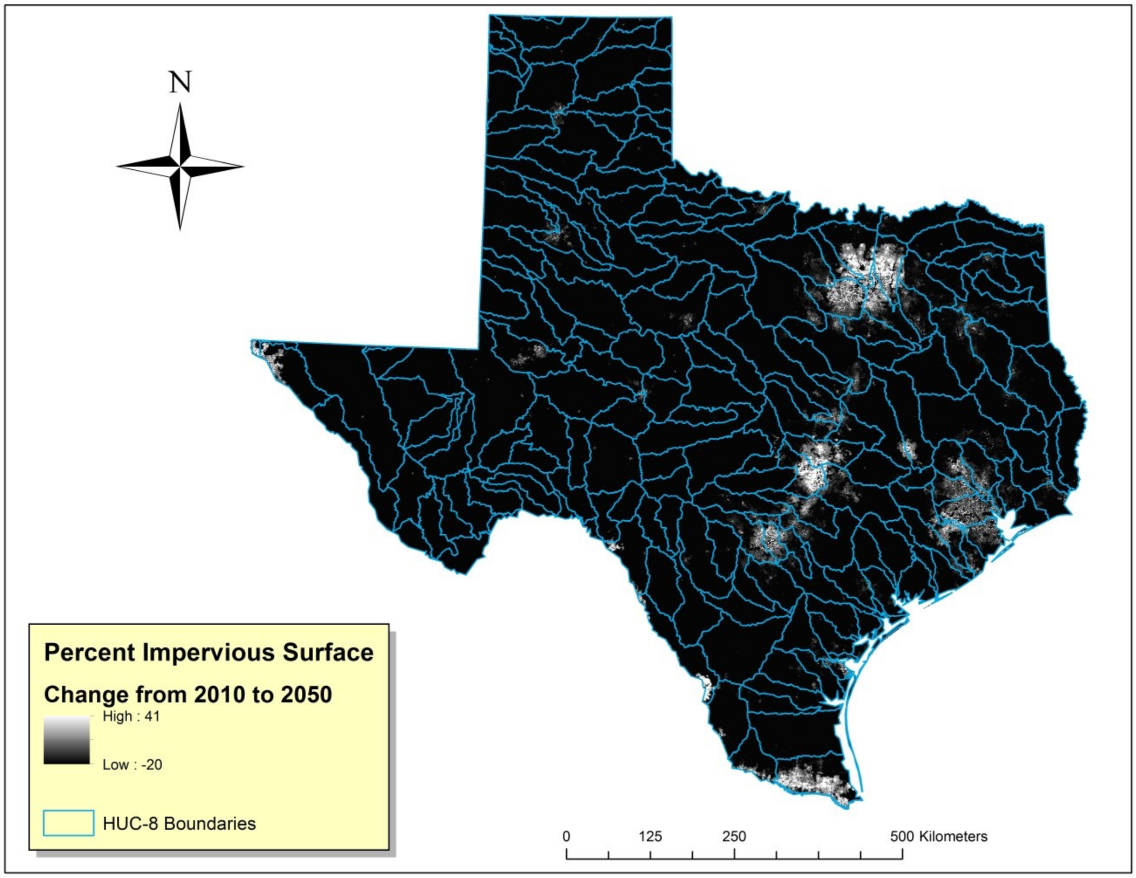

Figure 6: Percent Impervious Surface Change from 2010 to 2050. The change in impervious surface from 2010 to 2050, calculated by subtracting the 2010 values from the 2050 values using raster calculator in ArcMap.

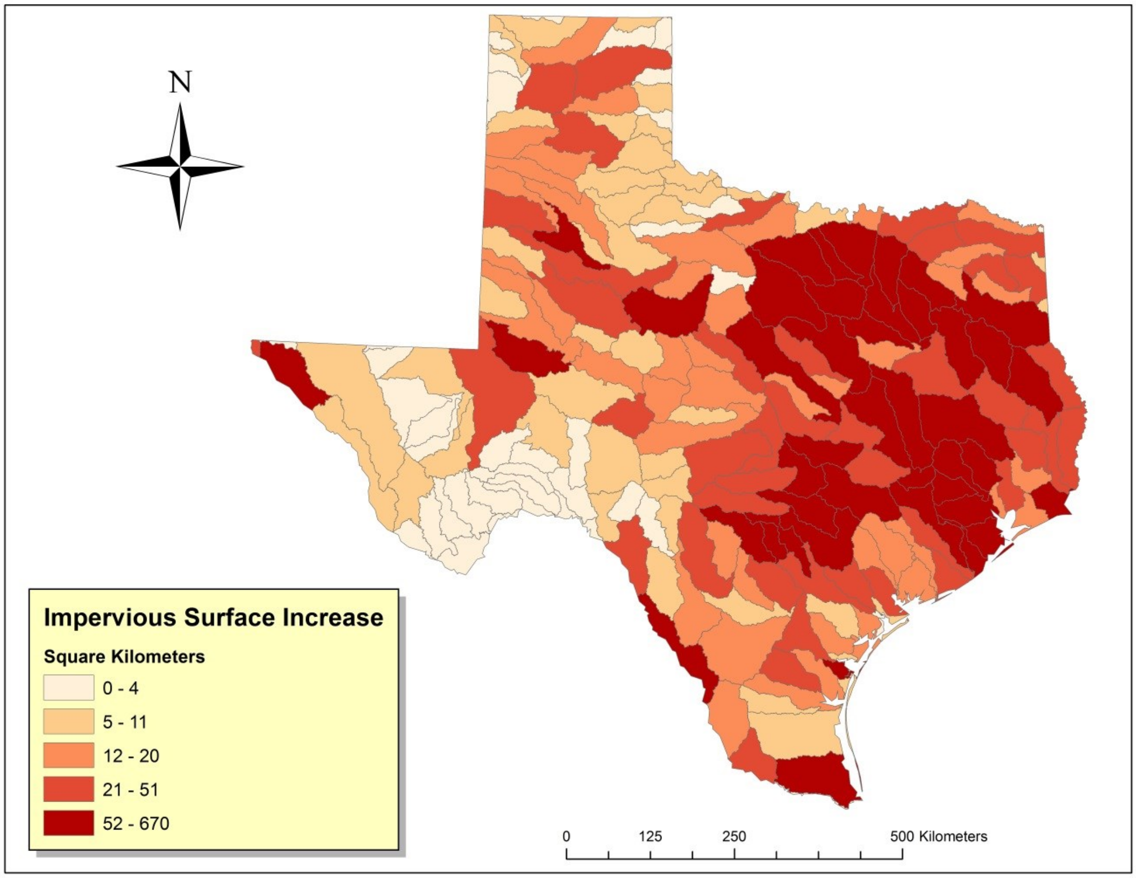

Figure 7: Impervious Surface Increase. Impervious surface increase of each HUC-8 watershed from 2010 to 2050.

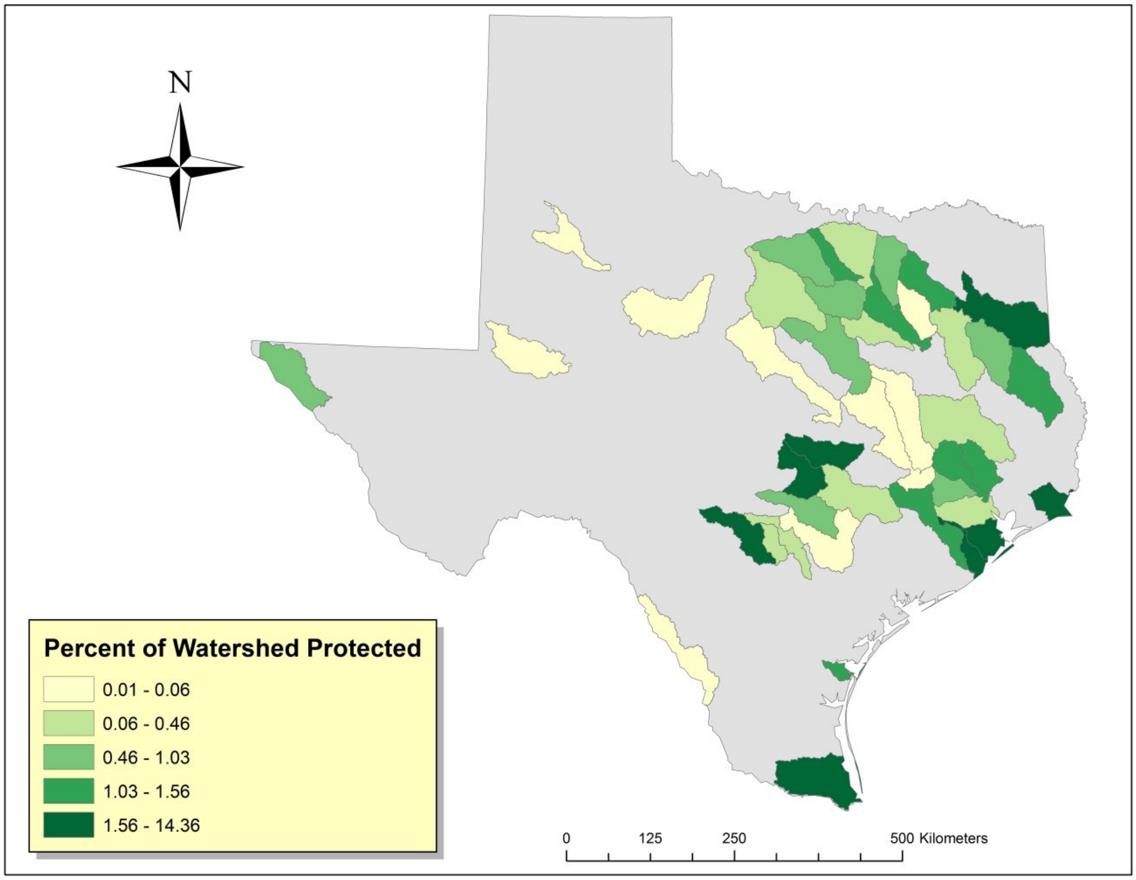

Figure 8: Percent of Watershed Protected via Figure 7. Percentage of each watershed that is protected for the top 20% of watersheds expected to experience the greatest amount of impervious surface increase (via Figure 7 above).

The percentage of the stream network protected in each watershed shows the current extent of an RCN already in place. The three watersheds with the lowest percentage of streams protected were isolated to provide three watersheds of interest in which riparian conservation could be a focus in promoting habitat resiliency (Figure 9). These three watersheds identified as those facing the largest threat of development, having large portions of protected land, yet little riparian connections. This methodology highlighted the Middle Sabine (HUC8 12010002), San Gabriel (HUC8 12070205), and Medina (HUC8 12100302) watersheds.

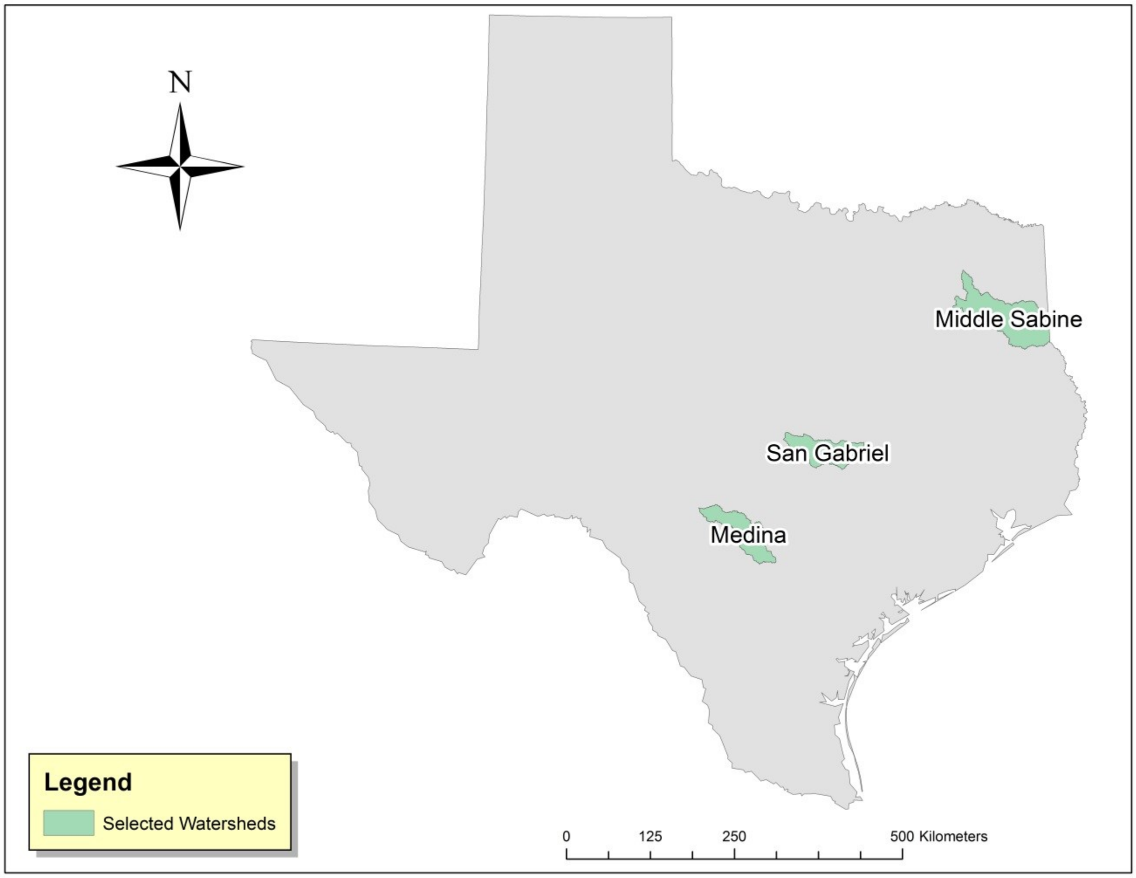

Figure 9: Selected Watersheds. The three focus watersheds with the lowest amount of riparian habitat protected, chosen from the top 20% of watersheds with the greatest percentage protected from Figure 8.

The analysis of the three watersheds shows a variety of differences among them. The Middle Sabine stands out due to being a rural watershed rather than an urban/suburban watershed like the San Gabriel and Medina. While it is largely rural, it is a large HUC-8 with several small urban centers resulting in higher areas of increased impervious surface compared to other rural watersheds, ranking 18^th^ overall for increased impervious surface area. The San Gabriel (10^th^) and Medina (12^th^) both encompass portions of large, and expanding, urban areas (Figure 6).

The pattern of development within each watershed also differs. The Middle Sabine watershed has several small urban centers expected to expand in the upstream portions of the watershed. The San Gabriel contains a large portion of the City of Georgetown, which is a growing urban area in the middle of the watershed growing outward to both the upstream and downstream portions of the watershed. The Medina encompasses the western edge of the San Antonio metro area, which is expanding to the upstream, rural areas to the west of the city (Figure 6).

The distribution of protected places between these three again show differences between the three watersheds of interest. The Medina watershed has protected areas evenly distributed across the watershed (Figure 10, Figure 11), while the Middle Sabine has protected areas distributed into two main clusters: one in the upstream and one in the downstream portion of the watershed (Figure 12, Figure 13). The San Gabriel's protected areas are located mostly within the upper to middle portion of the watershed, with the largest protected area being located in the lower portion of the watershed (Figure 14, Figure 15).

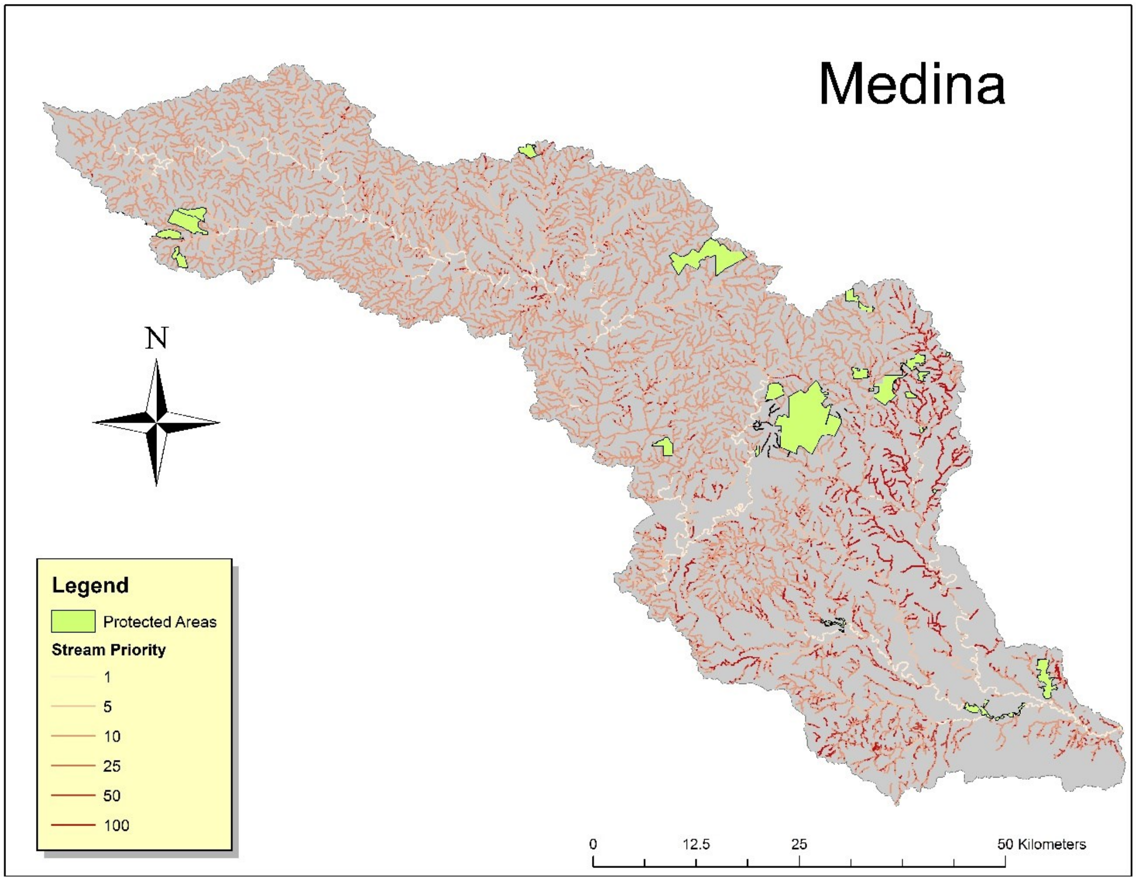

Figure 10: Stream Priority (Medina). Stream priorities, based on water quality improvement, are assigned to each segment in the Medina HUC-8, with 100 being the highest priority.

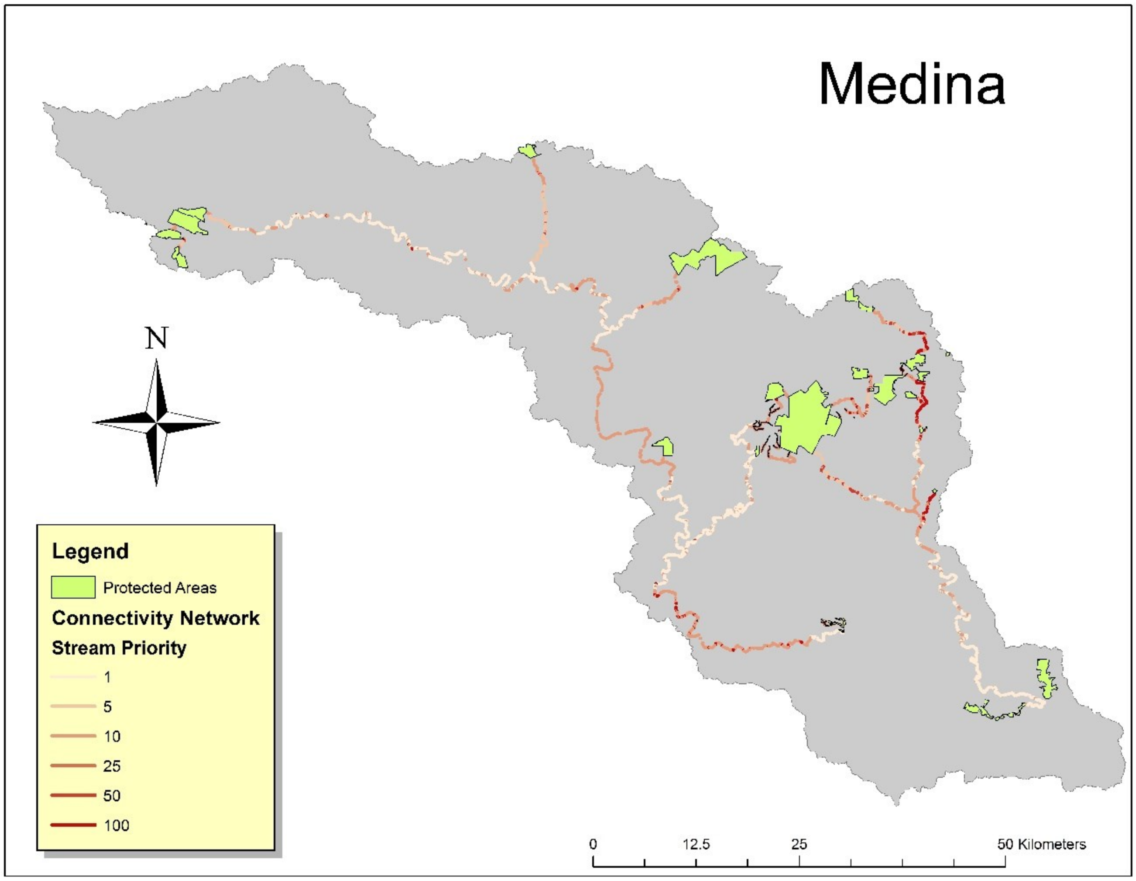

Figure 11: Connectivity Network (Medina). A connectivity network to increase connectedness of protected areas, and improve water quality, was created by isolating the shortest path along the stream network to connect the protected places within the Medina HUC-8. The stream priorities assigned to these segments have also been included.

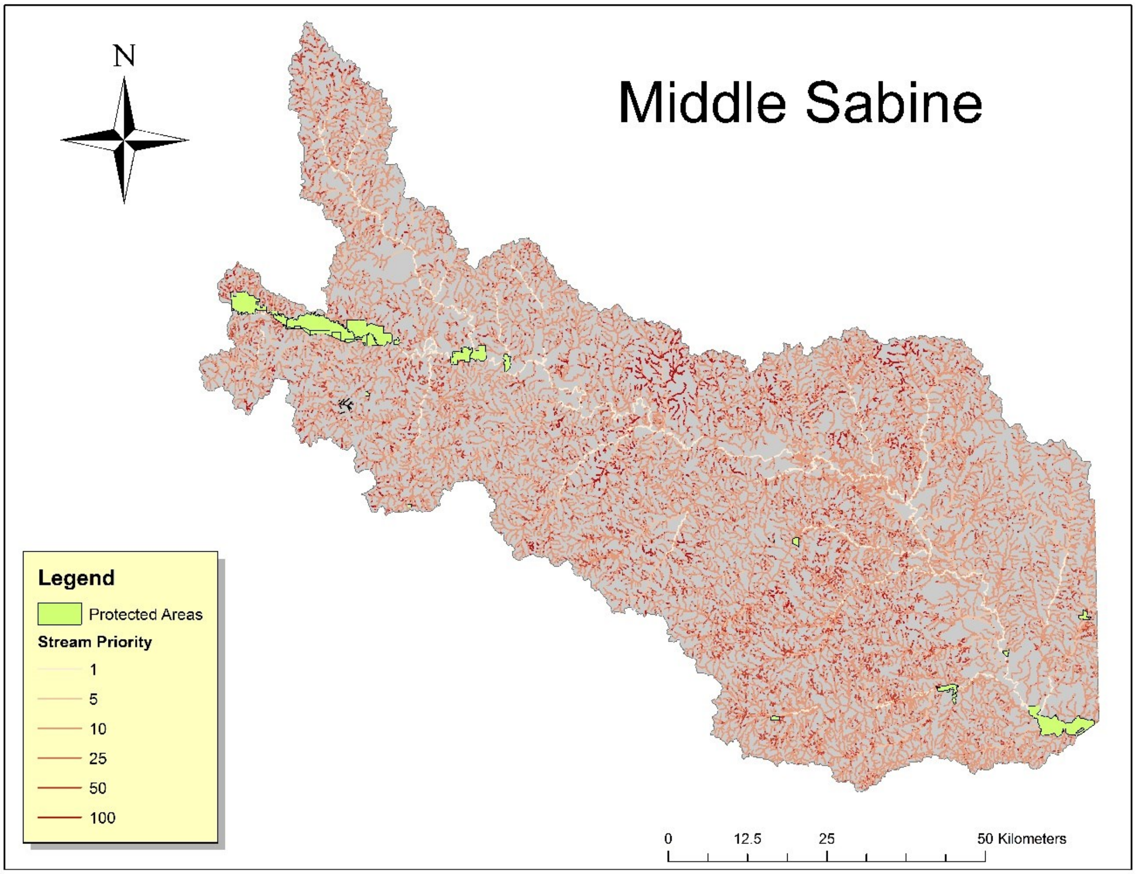

Figure 12: Stream Priority (Middle Sabine). Stream priorities, based on water quality improvement, are assigned to each segment in the Middle Sabine HUC-8, with 100 being the highest priority.

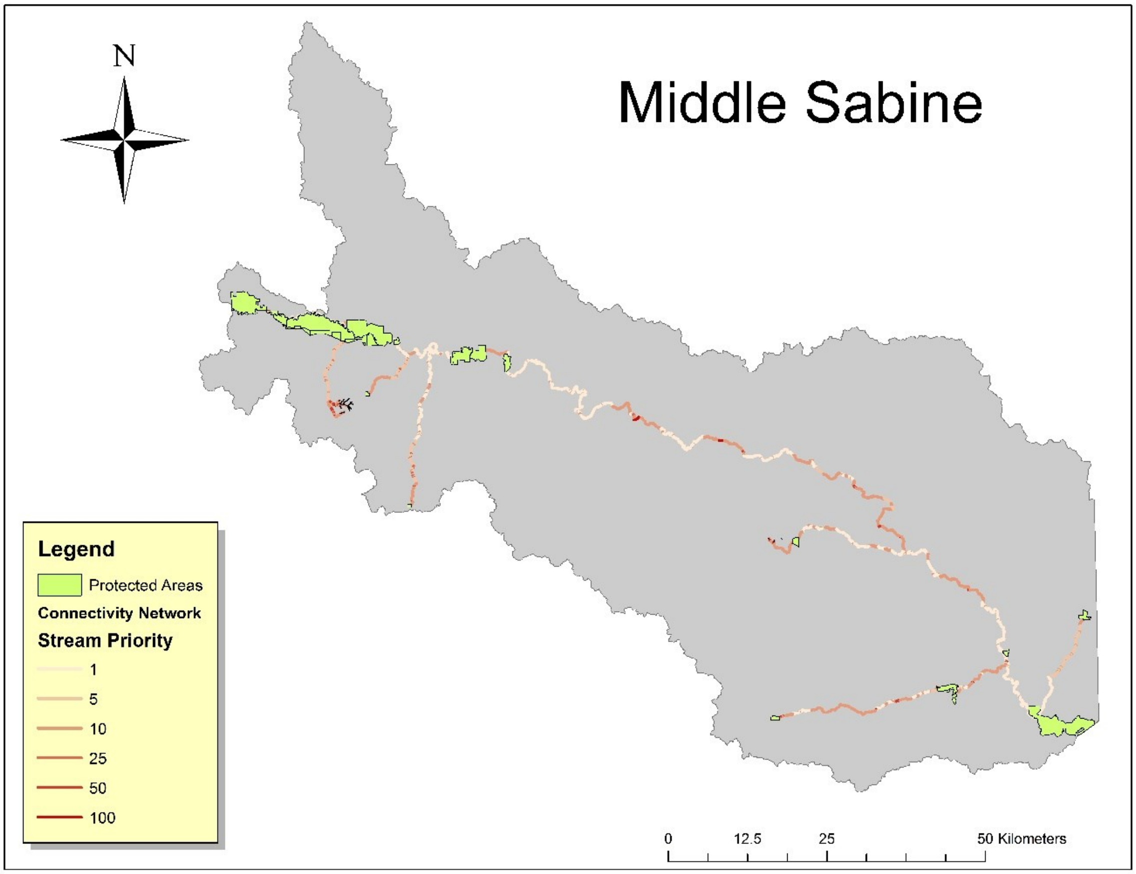

Figure 13: Connectivity Network (Middle Sabine). A connectivity network to increase connectedness of protected areas, and improve water quality, was created by isolating the shortest path along the stream network to connect the protected places within the Middle Sabine HUC-8. The stream priorities assigned to these segments have also been included.

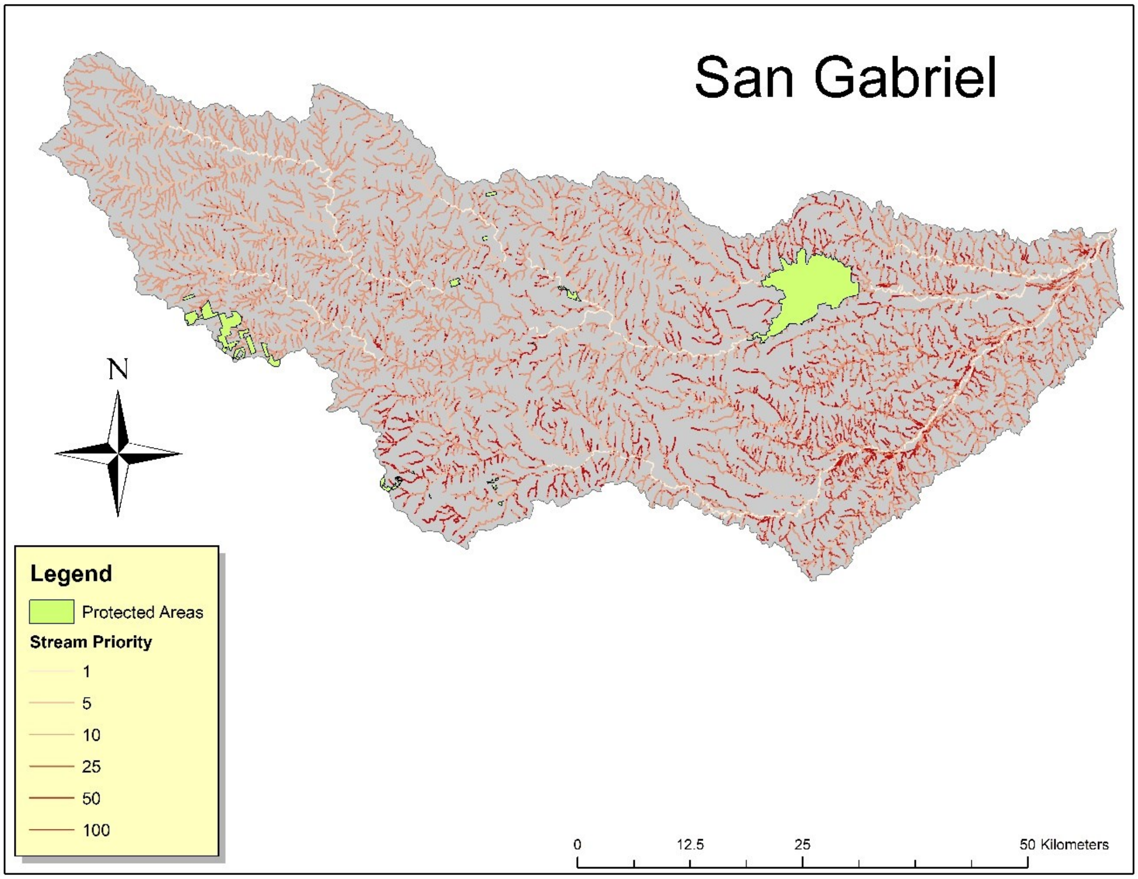

Figure 14: Stream Priority (San Gabriel). Stream priorities, based on water quality improvement, are assigned to each segment in the San Gabriel HUC-8, with 100 being the highest priority.

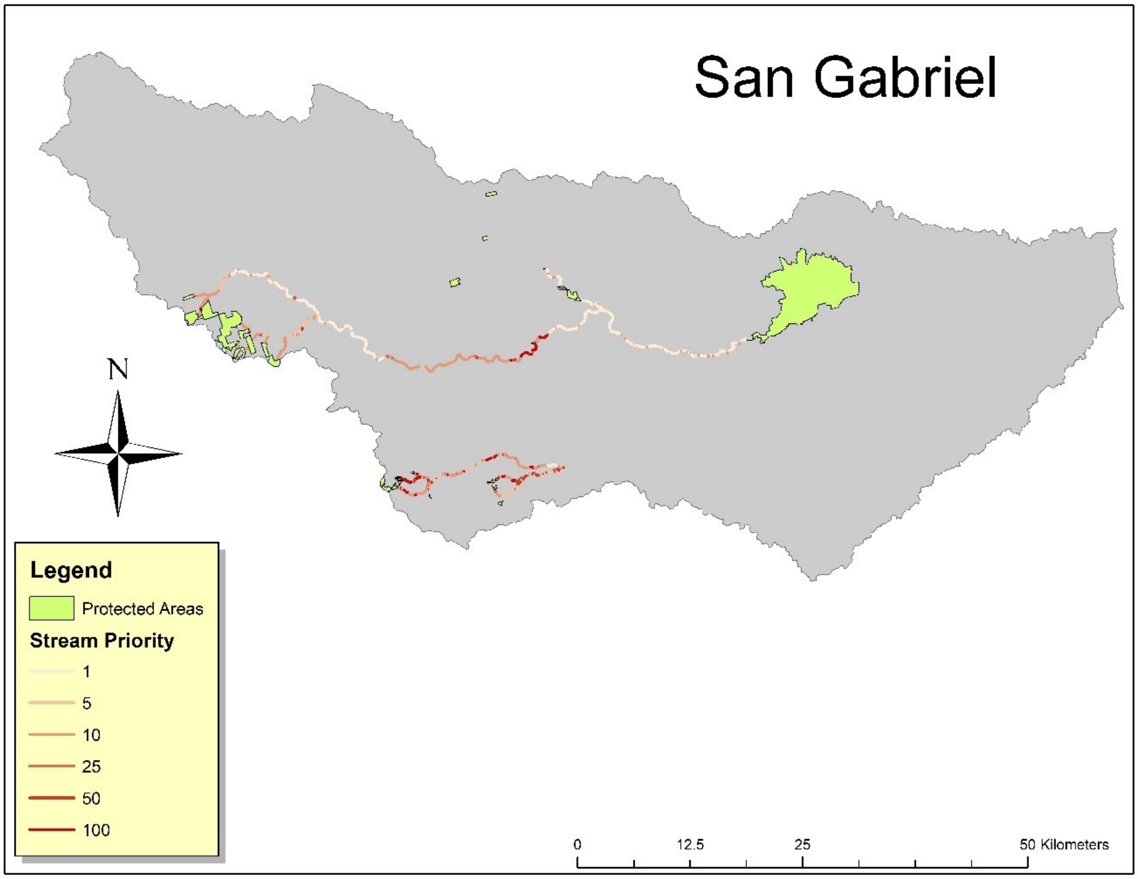

Figure 15: Connectivity Network (San Gabriel). A connectivity network to increase connectedness of protected areas, and improve water quality, was created by isolating the shortest path along the stream network to connect the protected places within the San Gabriel HUC-8. The stream priorities assigned to these segments have also been included.

4.3 Reach-Scale Prioritization for Protection

Using the three priority watersheds identified previously, I began a closer investigation, looking at the potential for stream mitigation banks to be established along the stream networks as well as identifying the shortest connectivity network that could connect the protected places in these watersheds along the stream network. Using the prioritization multipliers outlined in Table 2, the two prioritization rasters were then multiplied together using raster calculator to produce the resulting priority datasets (Figure 10, Figure 12, Figure 14). Thus, stream reaches with a priority of 1 are locations with the lowest priority for the establishment of a mitigation bank while reaches with a priority of 100 represent locations with the highest priority for the establishment of a mitigation bank. The shortest connectivity path within each stream network was isolated from the prioritized network result showing the priority of each segment of a simple RCN for the establishment of a mitigation bank (Figure 11,Figure 13,Figure 15). This shows potential locations where stream mitigation banks can increase connectivity within the watershed if they are established along the connectivity network.

Patterns within the prioritization of the stream network as well as the connectivity path to connect the protected places are observed within each watershed. The Medina watershed has the highest priority for the establishment of mitigation banks in the lower portion of the watershed where the highest amounts of urbanization are expected to occur, with low priorities for most of the upstream portion of the watershed. The protected areas within the Medina watershed all lie along the stream network, making the use of riparian corridors for connectivity a plausible means of increasing the connectivity of the watershed (Figure 10, Figure 11). The Middle Sabine has high priorities for the establishment of mitigation banks along much of the headwaters in the middle to upstream portions of the watershed, and also has most of its protected areas connected to the stream network (Figure 12, Figure 13). The San Gabriel has high levels of priority through much of the mid to lower watershed, but the protected areas in this watershed show the lowest degree of connectedness via the river network. In the San Gabriel, many smaller protected areas are not connected to the stream network, and disconnection within the stream network of the HUC-8 show the creation of two separate connectivity networks (Figure 14, Figure 15).

5. DISCUSSION

5.1 Summary of Findings

My analysis has shown that watersheds containing urban areas, as well as watersheds near urban areas, are expected to experience continued growth in the near future (Figure 6). This will result in further fragmentation of the landscape, isolating existing protected places, as well as reducing water quality due to disturbances from landuse changes. As such, prioritization schemes, like the one created in this study, can be valuable tools for prioritizing mitigation money to identify which stream reaches can provide the best improvements to water quality, allowing for the prioritization of limited funds (Figures 10, 12, 14). Connectivity networks can also be created to address the issue of habitat fragmentation, with the goal of increasing connectivity between protected areas. These two goals can be implemented simultaneously by identifying stream reaches which have a high priority for improving water quality intersect with the connectivity network (Figures 11, 13, 15).

The Middle Sabine is a largely rural watershed, interspersed with several small urban areas, and large amounts of pasture and forested area. These urban and pasture areas provide many areas within the watershed in which mitigation banks can be established in order to improve water quality, as urban runoff as well as nonpoint source pollution from livestock or erosion from grazed areas are likely to necessitate the need for improved water quality. The distribution of protected areas being split into two clusters has implications for the consideration of RCN and water quality planning. For the establishment of an RCN, a practical approach would likely be to connect the two clusters before joining them together into a watershed scale network. While the entire connectivity network identified is not ideal for the establishment of mitigation banks, there are key areas, particularly along the stretch connecting the upstream and downstream clusters that could be used as focal points for extending riparian conservation in the creation of a watershed-wide network. Most of the area protected within the watershed is found at the upstream portion of the watershed, which provides many benefits to water quality, however further protections along the urban waterways just downstream of these protected areas should be protected to improve water quality to the downstream portions of the watershed. Since this is largely a rural watershed, another important focus for the successful creation of an RCN and to improve water quality is to engage the rural landowners, farmers, and ranchers in order to mitigate pollutants originating from agricultural sources.

The Medina watershed has most of its development occurring along the western edge of San Antonio at the downstream portion of the watershed. Protection of land upstream will be important for the protection of water quality; this is especially important as many of the protected areas in the Medina are located in either the recharge or contributing zones of the Edwards Aquifer. The protected areas within the Medina are dispersed throughout the watershed. This results in upstream habitat that will provide benefits to water quality as well as likely serving as less disturbed habitat, benefiting from distance from the urbanizing downstream watershed. Protected areas closer to the urbanizing downstream portion of the watershed are likely to experience more disturbances due to their proximity to large amounts of development or intensive land use. These urban protected areas however can serve as small refugia for wildlife living in or passing through the urbanized portion of the watershed. There are also several fragmented protected areas that are close together in the urbanized area; these areas have connectivity paths with high priorities for the establishment of a mitigation bank which can improve connectedness between these isolated habitats. Stream prioritization along the connectivity network is high in the urban portion of the watershed, which would allow mitigation banks to create important corridors through the urban areas into less disturbed habitat upstream. However, much of the network outside of the urban area has low priority for the establishment of mitigation banks, which would necessitate the heavy inclusion of conservation easements or other methods of protection to connect downstream protected areas to those upstream.

The San Gabriel Watershed encompasses a large portion of the city of Georgetown, situated in the middle of the watershed growing out in both upstream and downstream directions. Upstream protections would provide increased water quality; however, since the center of the watershed is largely urbanized, downstream water quality is likely to suffer. As such, riparian buffers in the headwaters as well as the urban core can greatly improve water quality and connectedness through the urbanized watershed, to the protected areas in the less developed areas of the watershed. This watershed also faces difficulties for the creation of an RCN. Several of the protected areas are not connected to the stream network, and would necessitate the use of land acquisition of easements to connect these protected areas in order to make an RCN possible. The creation of the connectivity network also resulted in two separate networks, indicating that not all of the protected areas can be connected via riparian corridors. This means that the creation of a terrestrial corridor would be needed in order to properly connect the two networks.

5.2 Limitations of Analysis

Connectivity is the central focus of the RCN concept, with the goal of creating links between protected areas. Connectivity is a functional feature of the landscape, a measure of active connection between two patches. However, at the level of analysis of this study, it is connectedness which is being measured, a structural feature of the landscape measuring simply the amount of physical (i.e., unfragmented land cover or land use) connection between two patches regardless of their functional use (Baudry and Merriam 1988). If serious consideration is to be made toward the planning and implementation of an RCN, careful attention must be paid to creating functional connections, rather than simply structural connections, in order to promote the resiliency of protected places. This will ensure that a proper connectivity network is created that can actually be utilized by the local biota, serve as a functional corridor, increase connectivity, and promote more resilient ecosystems within the watershed. This, however, lies outside the scope of this study. I instead used structural connections (i.e., connectedness) as a proxy for connectivity, not to imply the functional connections exist but that structural connections make functional connections possible.

It is also important to note that, due to the analysis being of broad scale, the connectivity and prioritization schemes created in this study are far more simplified than would likely be used in the actual planning and implementation of an RCN. Following the general guidelines outlined in the TXRAM document created by the USACE-Fort

Worth District, I created a simple scheme for the prioritization of headwaters and land cover that would indicate stream reaches that would feasibly be targeted by stream mitigation banks and could be integrated into a larger connectivity framework (USACE 2015). For actual application, much finer detail of classifications would likely need to be, considered in order to more appropriately choose stream reaches ideal for the establishment of a mitigation bank.

In riparian conservation and stream mitigation banking, the size of the riparian buffer is an important (and valuable) consideration (Meyer et al. 2007, USACE 2015). In this study, I simplified stream buffers to 30 m for all streams, undertaken simply for the ease of analysis. For this work to advance to real world applications, a more sophisticated approach would be needed to better prescribe 'functional' riparian networks. This is particularly important for water quality purposes (and hence mitigation banking) as the land use in these areas close to the stream network have large impacts on water quality, and can impact the effectiveness of a protected riparian corridor for both water quality and regulatory purposes (USACE 2015). Indeed, the USACE Fort Worth District has specific guidelines on the width of restored riparian buffers that take into account channel width, floodplain width, and flow conditions (USACE 2015).

The connectivity network created to connect the protected areas in each watershed was also simplified. This network was merely the shortest path required to connect all protected areas using the stream network. However, this does not take into consideration a variety of factors that should be considered when developing a connectivity network. Some factors that should be included are measures of habitat quality, barriers to usage of these riparian areas as corridors (e.g. dams, fences), species of concern, or anything else which must be carefully considered when choosing the best means of creating functional corridors to create resilient ecosystems (DiLeo et al. 2016, Li and Nigh 2011, Parker et al. 2016). It is important to note that the stream network and the associated riparian habitat often encounter fragmentation agents particularly problematic to riverine connectivity, such as waterfalls, canyons, lakes, dams, road structures, pollution, and invasive species (Fuller et al 2015). These must be considered carefully to ensure that any planned RCN will see usage by a wide variety of biota. Other studies have taken into account movement resistance through various types of habitats for an amphibian species of concern, taking note of features that may boost connectivity (floods) and those that hinder it (roads) in order to more accurately determine the connectivity of habitat patches for that particular organism (Bishop-Taylor and Tulbure 2015).

5.3 Riparian Connectivity Network Implementation

Stream mitigation banking is the primary means of creating connections in this study. While connections can be established by a variety of mechanisms, mitigation banking has rarely been taken into consideration for its potential in broader conservation goals outside their regulatory framework. Mitigation banks have potential to be an integral component of an RCN framework due to their increasing use, increasing demand, and focus on riparian environments (Lave 2008). Unlike fee simple purchase or conservation easements, which can occur on any parcel of land, mitigation banks instead are constrained to the riparian network making them ideal for integration into the creation of an RCN. This would allow mandatory mitigation the opportunity to become incorporated into a watershed-scale conservation plan that goes beyond their requirements for site-scale restoration. This allows otherwise isolated restoration efforts undertaken under clean water regulation to serve an important dual purpose of promoting habitat connectivity in addition to improving water quality. Indeed, this dual purpose highlights one of the biggest benefits of adopting an RCN framework, in that a single project has the potential to provide stacked benefits by providing increased connectivity, if it lies along the network, regardless of whether connectivity was an intended or required component of the project.

The watersheds of interest identified are all contained within the Fort Worth District of the USACE. Of the four Army Corps districts with jurisdiction in Texas, the Fort Worth District encompasses the most area within the state. The Fort Worth district has developed mitigation banking regulations that require a high degree of environmental compliance, requiring restoration of the same type of habitat disturbed whenever possible and outlining appropriate alternatives should these same habitat types be unavailable (USACE 2013). Other districts, however, have their own procedures regarding mitigation banking with varying degrees of development and requirements in mitigation banking regulations. These differences could limit the potential to utilize mitigation banks in districts with less developed regulations regarding their establishment and implementation. Difficulties could result should an RCN wish to be implemented on a basin wide scale, as the requirements, and likely the environmental quality, of mitigation banks will vary by district. The environmental and permitting regulations developed within each district must be closely examined to ensure they will provide proper riparian habitat if mitigation banks are used in the planning of RCNs in other USACE districts.

Mitigation banks, while having the potential to be integral to the implementation of an RCN, are not suitable for all locations. As shown in the connectivity network maps (Figure 11, Figure 13, Figure 15), the percentage of the network with the highest priorities for mitigation banks are relatively small. However, there are key portions of these networks that could be protected by a mitigation bank. Since stream mitigation banks are heavily skewed towards headwaters, due to their strong influence on water quality, alternative methods will be necessary to protect areas along larger rivers (i.e., higher stream orders) in the stream network (Alexander et al. 2007). This is an area in which conservation easements are likely to fill in the gaps, as easements have already been shown to be skewed toward riparian areas and are popular forms of protections within floodplains, which often have restrictions on development (Fremier et al. 2015). It is imperative, therefore, that mitigation banking be one of many different tools used in the conservation of riparian habitat for the creation of an RCN (Fremier et al. 2015). In areas where mitigation banks are not suitable, alternative methods, such as conservation easements, should be considered.

Voluntary programs can also serve a purpose in the creation of an RCN. Voluntary payments to adopt riparian buffers on riparian forest lands have been assessed as a means of protecting riparian forest lands in the Pacific Northwest (Kline et al. 2000). The difficulties of voluntary programs lie both in pricing and in enforcement. Even if funding for a voluntary program can be secured, the willingness of landowners to engage in conservation practices will vary, as will their required monetary compensation (Kline et al. 2000). Since these programs are voluntary, there is also no means of ensuring that the conservation practices are carried out, save for the removal of funds should a landowner not comply. Voluntary programs are also temporary, for as long as the landowner is willing and funding is available, making these lands susceptible to future disturbances. It is important to note that studies have shown that even informally protected habitats can serve as important habitat for species of concern (Bishop-Taylor and Tulbure 2015). Therefore, this method could be a solution incorporated into a larger plan in the creation of an RCN, either as a temporary measure, or in areas where landowners are unwilling to sell or funding is unavailable for purchase of the land. Such actions can be important short term measures of protection for water quality and connectedness particularly in rural areas such as much of the Middle Sabine and the upstream portion of the Medina.

While urban sprawl has been shown to greatly reduce landscape connectivity, there are some opportunities for connectivity in these areas (Dupras et al 2016). While people drive the demand for urbanization, many urban centers experience a demand for green space. In response, many cities, such as Barcelona, have undertaken plans to greatly increase their urban greenspace to improve quality of life for its human population, which will likely provide benefits to the wildlife as well (O'Sullivan 2017). While this particular example is not undertaken specifically to improve connectivity for wildlife, it serves as an example of how green corridors can be incorporated into the planning of dense urban centers and there is potential to incorporate the connectivity needs of the greater ecosystem if it is supported both politically and financially. Even without planning grand urban greenways, many cities increase ecological connectivity through the utilization of landscape architecture in addition to parks and greenway infrastructure (Wu et al. 2017). Such measures can be important for increasing the connectivity in urban areas, which could be utilized in the San Gabriel and lower Medina watersheds.

No single conservation mechanism is likely to be adequate to protect ecosystem resiliency due to limited funding, as such mitigation bankers could provide compounded environmental benefits if bank locations are chosen with respect to other environmental factors beyond the regulatory requirements (Li and Nigh 2011). Planning efforts undertaken for the establishment of an RCN must incorporate as many conservation entities as possible, establishing a connectivity network that meets the criteria of constituent environmental agents, adequately incorporates the concerns and input of landowners, and incentivizes the protection of identified riparian corridors.

Coordinating conservation efforts between various environmental agents is an incredibly difficult task. The RCN concept has the benefit, however, of establishing a common goal that can then be pursued independently by various environmental agents. Previous studies have already developed methodologies to prioritize the conservation of land parcels as well as riparian land (Li and Nigh 2011, Parker et al. 2016). These methodologies can be merged with methods similar to those developed in this study to devise a means to identifying the best connectivity corridors that can take advantage of land purchase, easements, mitigation, and voluntary land protections. If the conservation community of a particular watershed agrees on a connectivity network, each entity is then able to conserve portions of the network as they see fit, are able, and as they meet their needs. Due to the high degree of coordination necessary, creation and implementation of an RCN will necessitate strong leadership as well as coordination among the many stakeholders in the watershed. Nonprofits, or other organizations, with strong ties to landowners (such as the Hill Country Alliance, The Nature Conservancy, or the Texas Land Conservancy) can become important agents to fill such leadership roles. The RCN concept can also be incorporated into local watershed planning; which is concerned with water quality (per EPA compliance) but which can include important ecological considerations important to watershed stakeholders, such as connectivity and ecosystem resiliency.

Greater degrees of coordination are more likely to result in the effective establishment of an RCN, and the identification of priority parcels for protection will be a key component of strengthening the resilience of these habitats and prioritize conservation efforts within the reality of limited funding (Parker et al. 2016). Regardless of the difficulty, connectivity networks have shown success in past studies, and their further development will likely aid in increasing ecosystem resiliency at broad scales (DiLeo et al. 2017).

5.4 Additional Considerations

The methodology outlined in this study did not prioritize the "best" or most resilient habitat for the creation of the most resilient ecosystems. Instead this methodology targeted degraded riparian areas in watersheds expected to have increased development pressures. This was done with the idea that increasing amounts of required mitigation can be used to provide additional benefits (in the form of connectedness) to help promote resiliency of areas already protected in an attempt to mitigate the stresses on these areas caused by development and land use changes. The use of the HUC-8 for this analysis is important due to the HUC-8 being the unit of regulation for mitigation banking (USACE 2011). However, there have been concerns voiced about the use of the HUC system for resource planning, due to the face that HUCs are not all true watersheds, and therefore may not be the most appropriate division of planning in some cases (Omernik et al. 2016). A final note of concern for the planning of any conservation efforts in Texas, or other prior appropriation states, is the issue of water rights which are particularly important for the success of riparian habitat and which may be affected by the exercise of senior water rights (Fremier 2015).

6. CONCLUSIONS

Connectivity and connectedness are important factors to consider when engaging in conservation planning and ensuring the resiliency of our protected places. The RCN concept has great potential to serve as a method to coordinate various environmental efforts undertaken by a variety of environmental agents for differing purposes, into a plan created to increase connectivity between protected places, improve water quality, and promote ecosystem resilience. This can then be used at watershed scales to create a connectivity plan, which identifies riparian habitat in an RCN that can then be targeted for conservation whenever possible by the various entities that engage in conservation, habitat protection/restoration, and stream mitigation.

Methods from this study will be useful in other areas of the country with high percentages of private land ownership. These portions of the country have less protected land, increasing the number of people required to engage in conservation efforts to create an effective connectivity network. Many of these areas also oppose government acquisition of land, increasing the popularity of conservation easements or market based conservation measures such as mitigation banks. Examining the potential for stream mitigation banks to increase connectivity within an RCN context is also useful for watersheds experiencing rapid development as these watersheds will have a large market for mitigation credits if banks are established to provide them.

The RCN framework is a valuable tool that can be used to coordinate conservation activities at a watershed scale to increase connectivity and improve water quality. Further promotion and adoption of the RCN framework would greatly increase the chances of protecting vital riparian habitat, increasing connectivity, improving water quality, and adding to the resiliency of the watershed. Due to the large number of conservation, restoration, protection, and mitigation activities that occur on riparian lands, the RCN has great potential to promote ecosystem resiliency (Bernhardt et al. 2005).

APPENDIX SECTION

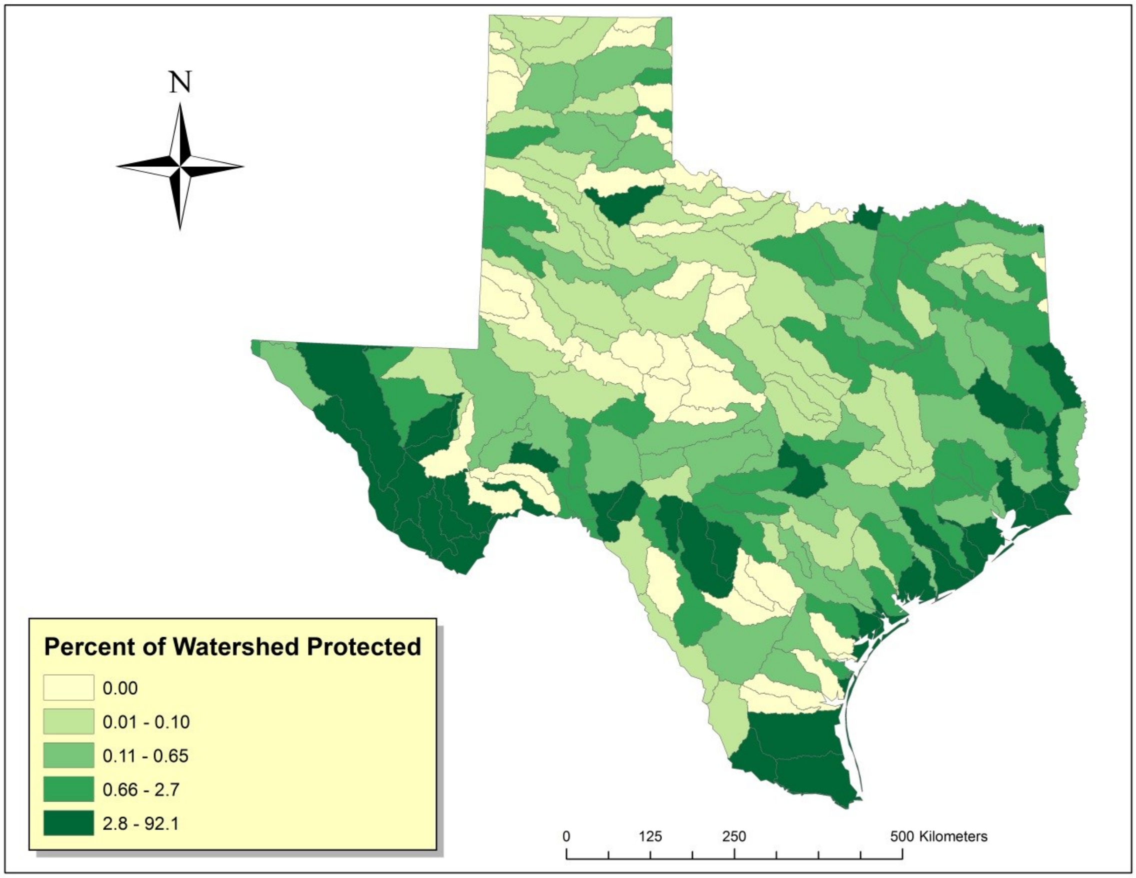

Figure A1: Percent of Watershed Protected (Quantile). The percent of the area of each HUC-8 that falls within protected lands. This additional figure was created using quintile classification.

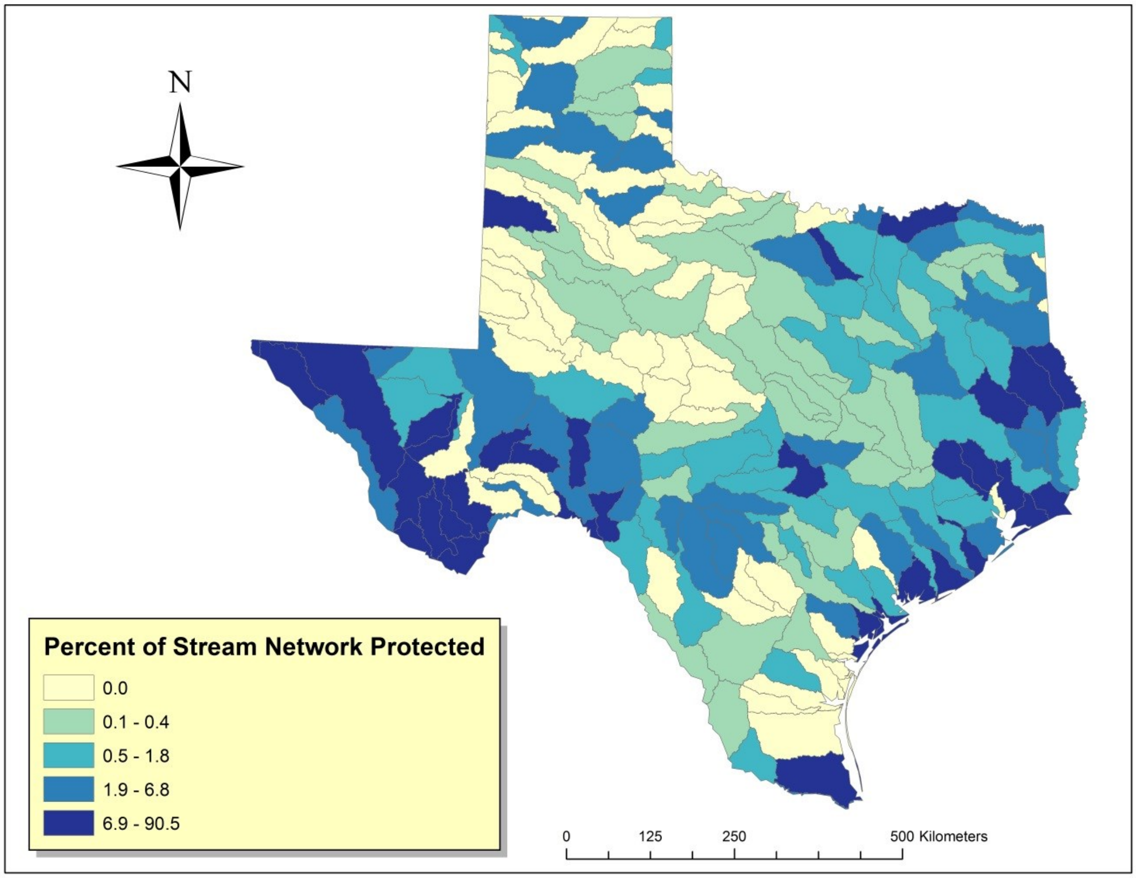

Figure A2: Percent of Stream Network Protected (Quantile). Percentage of the stream network within each HUC-8 that falls within the boundaries of protected areas, this represents the amount of an RCN already in place within the watershed. This additional figure was created using quintile classification.

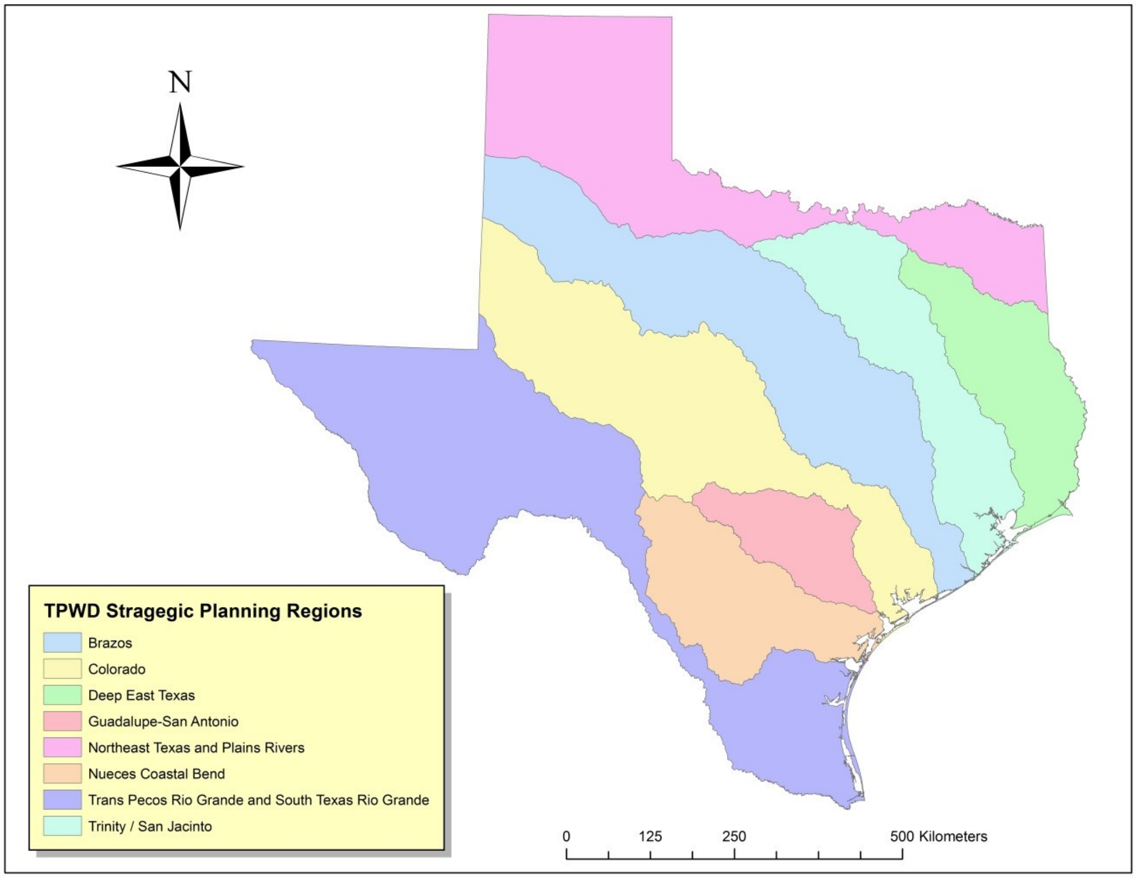

Figure A3: Major River Basins of Texas. Major River Basins used by the Texas Parks and Wildlife Department (TPWD) for their Strategic Planning Regions.

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