Title

Regional characterization for the Arizona: potential of riparian areas for carbon sequestration

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REGIONAL CHARACTERIZATION FOR THE STATE OF ARIZONA OF RIPARIAN AREAS ARIZONA: POTENTIAL FOR CARBON SEQUESTRATION

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REGIONAL CHARACTERIZATION FOR THE STATE OF ARIZONA: POTENTIAL OF RIPARIAN AREAS FOR CARBON SEQUESTRATION

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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The PIER program strives to conduct the most promising public interest energy research by partnering with RD&D organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
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- Energy-Related Environmental Research
- Energy Systems Integration

Regional Characterization for the State of Arizona: Potential of Riparian Areas for Carbon Sequestration is a final report for the West Coast Regional Carbon Sequestration Partnership – Phase II (contract number 500-02-004, work authorization number MR-06-03L. The information from this project contributes to PIER's Energy-Related Environmental Research program.

For more information on the PIER Program, please visit the Energy Commission's Web site at www.energy.ca.gov/pier or contact the Energy Commission at (916) 654-5164.

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Abstract

In Arizona, riparian areas are important because of the limited amount of water and rapid population growth, that leads to the need for better management of riparian areas. We use PATHDISTANCE spatial model, incorporating rivers, water bodies, slope and elevation to model the extent of potential riparian areas in Arizona. We examined the geophysical potential of landform, rock formation and soil type factors for four native riparian woody vegetation types: cottonwood/willow, conifer/oak, mesquite and mixed broadleaf. To identify the suitable area for afforestation with these native riparian tree species, we analyzed the geophysical potential across the shrub/scrub land cover class (NLCD 2001) for three elevation strata. Total area identified for afforestation was estimated per native riparian tree species and potential carbon sequestration for 20, 40 and 80 year periods was estimated based on field carbon data collected along the Lower Colorado River. The analysis showed that area suitable for afforestation with conifer/oak could sequester more than 4 million t CO_2e after 80 years, while riparian areas suitable for growing cottonwood /willow, mesquite and mixed broadleaf species have greater sequestration capacity - 97 million, 98 million and 89 million CO_2e, respectively, after 80 years.

Keywords: Arizona, riparian areas, carbon, carbon sequestration

Executive Summary

Introduction

Riparian areas are a small portion of the Arizona landscape, but need proper management and restoration to provide their vital functions. Restoring the extent of the riparian forest could result not only in converting these areas into carbon sinks, but also improving the vital functions of riparian ecosystems. According to BIO-WEST (2006) approximately 400-450 thousand acres of riparian vegetation were historically estimated to exist in the Lower Colorado River between Fort Mohave and Fort Yuma, while currently riparian vegetation in this section of the river sums to approximately 89 thousand acres. In Arizona, riparian areas are important because of the limited amount of water and rapid population growth, which leads to the need for better management of riparian areas.

Purpose

The spatial analysis presented in this report aims to identify riparian areas that could reforested or afforested (termed in this report as forestation) and serve as potential carbon sequestration projects. For this purpose we model the potential riparian areas that could be used for forestation and estimate the potential carbon benefits from tree planting in identified riparian areas.

A spatial analysis of potential riparian area that could sequester carbon through forestation with native riparian woody species was conducted through the following steps:

- Modeling the extent of potential riparian areas.
- Defining geophysical potential for native woody riparian vegetation.
- Identifying opportunities for carbon sequestration through forestation with native woody vegetation within the potential riparian areas.

Project Outcomes

We used a modeling approach (PATHDISTANCE) incorporating river and water bodies as well as elevation and slope to model the extent of the riparian areas. This model resulted in predicting the potential riparian area in natural shapes rather than creating buffers around the rivers. The total modeled riparian area was estimated at 3 million acres (1.2 million ha), which is approximately 4% of the total area of Arizona. The results showed that Yuma, La Paz and Pinal County have the largest extent of potential riparian area as a percent of the total county area – 10%, 9% and 9%, respectively.

For this analysis, four riparian woody vegetation types were considered: cottonwood/willow, conifer/oak, mesquite and mixed broadleaf. We calculated the distribution of these four vegetation types across landform, rock formation and soil type classes. We created landform, geology and soil factor maps based on the percent distribution of each native woody vegetation type per landform, geology and soil class. Then we combined all factor maps using weighted averages to create a single geophysical potential map for each native woody vegetation type. We analyzed the geophysical potential scores for conifer/oak, cottonwood/willow, mesquite and mixed broadleaf on shrub/scrub land cover category across the tree elevation strata – (1) less than 3280 ft (1000 m), (2) between 3288 and 6560 ft (1000-2000 m) and (3) greater than 6560 ft (2000 m). We refined the area available for forestation on shrub/scrub riparian land by dividing the geophysical scores for each woody vegetation riparian type into four equal intervals to represent low, moderate, high and very high class of geophysical potential. The results showed that 88% of the total area was suitable for cottonwood/willow, 87% for mesquite, 33% for mixed broadleaf, and just 10% for conifer/oak located on very high geophysical potential class.

Data on carbon stocks in riparian areas in southwest of the US are very sparse, therefore applying standard forest growth rates will lead to overestimations of carbon stocks. Winrock International conducted measurements of mesquite, willow and cottonwood riparian areas along the Lower Colorado River in 2007 (Pearson et al., 2007). Due to the paucity of data at this time we are unable to provide separate carbon accumulation rates for the four proposed woody tree vegetation types: conifer/oak, cottonwood/willow, mesquite and mixed broadleaf.

The total amount of carbon that could be sequestered by forestation of riparian areas with high and very high geophysical potential after three time periods (20, 40, and 80 years) varies by native woody riparian vegetation type (Table ES-1). The analysis showed that areas defined as suitable for forestation with conifer/oak (69 thousand acres) on high and very high geophysical potential classes could sequester more than 4 million t CO_2e after 80 years. Riparian areas identified as suitable for growing cottonwood /willow, mesquite and mixed broadleaf species have a larger potential for carbon sequestration after 80 years, 97 million, 98 million and 89 million CO_2e, respectively.

Table ES-1. Potential riparian area for forestation, carbon accumulation rates, and total carbon sequestration for 20, 40 and 80 year projects.

Native woody riparian vegetation	Potential category	Potential area for forestation (acres)	Carbon sequestration rate (t CO_2e/acre) at age of:			Total carbon sequestration (t CO_2e) after project year (x 1 000)		
			20	40	80	20	40	80
Conifer/oak	High	62,130	46	57	60	2,858	3,541	3,728
	Very High	6,806				313	388	408
Cottonwood/ willow	High	191,864	46	57	60	8,826	10,936	11,512
	Very High	1,432,621				65,901	81,659	85,957
Mesquite	High	210,569	46	57	60	9,686	12,002	12,634
	Very High	1,430,920				65,822	81,562	85,855
Mixed broadleaf	High	1,004,446	46	57	60	46,205	57,253	60,267
	Very High	493,641				22,707	28,138	29,618

Conclusions

The approach used to map the extent of the riparian areas for the state of Arizona is robust because it allows calculating a surface of relative cost of moving from the stream or water source up into the stream valley, accounting for slope and elevation. This method resulted in mapping approximately 3 million acres (1.2 million ha) of riparian areas across the state of Arizona, which accounted for 4 % of the total state area. The result showed that Yuma, La Paz and Pinal County have the largest extent of potential riparian area as a percent of the total county area – 10%, 9% and 9%, respectively, while Greenlee and Gila County have the least extent of potential riparian area as a percent of the total county area - approximately 1%.

The analysis illustrated that approximately 59% of the mapped riparian area was occupied by shrub/scrub according to the NLCD 2001 across the whole range of the geophysical potential scores for the native woody riparian vegetation. Considering equal interval partition of the geophysical potential scores for each of the native woody vegetation, we selected riparian areas currently occupied by shrub/scrub in the high and very high geophysical potential class. The estimation of suitable riparian areas on very high geophysical potential accounted for approximately 1.4 million acres (566 thousand ha) for forestation with cottonwood/willow or mesquite, 500 thousand (202 thousand ha) for forestation with mixed broadleaf trees and only 7 thousand acres (3 thousand ha) for forestation with conifer oak.

Recommendations

The preliminary analysis presented in this report highlighted the needs of further research with an interest in restoration of riparian areas. Further research and analysis is needed particularly in the following areas:

1) Threshold selection of the relative cost surface

More in depth analysis and some empirical data collection are needed to select the correct threshold of the relative cost surface created through PATHDISTANCE. Aerial photographs or high resolution images can be used to develop a relationship between the value of the relative cost surface and the furthest and closest distance of riparian area edge per river class and/or elevation.

2) Collection of empirical data

Additional empirical data should be collected though field work and/or from aerial photographs or high resolution images to develop a relationship between the geophysical potential scores and location of existing native woody vegetation. This will allow for accurate determination of the interval of geophysical potential scores representative of each of the native woody vegetation.

3) Cross discipline analysis

The selection of sites that could be afforested within the identified riparian areas should consider additional functions of riparian forests such as water quality, stream integrity, wildlife habitat, and flood and storm water runoff. Information and data produced for the Arizona statewide freshwater assessment by the Nature Conservancy could be considered when selecting sites for forestation.

It is recommended that these further analysis and data collection are carried out at the county level. As indicated from this analysis, Pima, Navajo and Yavapai counties have the largest estimated areas suitable for forestation cottonwood/willow and mesquite, mixed broadleaf and conifer/oak, respectively and could be good candidates for further analysis.

1.0 Introduction

1.1 Background and Overview

Despite of their small percentage of the landscape, riparian areas provide resources for many ecological functions and multiple land uses. Riparian areas are often productive ecosystems providing resources for wildlife and people.

According to BIO-WEST (2006) approximately 400-450 thousand acres of riparian vegetation were historically estimated to exist in the Lower Colorado River between Fort Mohave and Fort Yuma, while current riparian vegetation in this section of the river sums to approximately 89 thousand acres. In Arizona, riparian areas are important because of the limited amount of water and rapid population growth, which leads to the need for better management of riparian areas.

Some riparian areas are covered by forests; others are covered by brush and grassland, while some are dominated by agriculture and development. In the last few decades many native riparian areas have been destroyed or degraded. Agriculture contributes to the degradation of riparian zones through the building of channels, levee construction and other means of diverting water from reaching the riparian zones.

Riparian areas are a small portion of the landscape, but need proper management and restoration to provide their vital functions. Restoring the extent of the riparian forest could result not only in converting these areas into carbon sinks, but also improving the vital functions of riparian ecosystems.

The high variability of riparian areas through the United States and the many different disciplines (geology, fisheries, hydrology, plant ecology, etc) involved in studying these areas make it difficult for there to be a single unified definition of riparian areas (Zaimes, 2007). Despite the different definitions of riparian areas by various state, national agencies and organizations, Zaines (2007) determined the following common points:

(1) adjacency to a water body and dependency on perennial and intermittent water flow
(2) transitional zone between terrestrial and aquatic ecosystems
(3) linear in nature
(4) lacking clearly defined boundaries

For this report, riparian zones, riparian areas, and riparian buffers are terms used synonymously. However these terms may be defined differently in the literature depending on the applications or agencies in question.

1.2 Project Objectives

The spatial analysis aims to identify riparian areas that could become potential carbon sequestration projects. For this purpose two objectives were identified:

- To identify the potential riparian areas that could be used for forestation

- To estimate the potential carbon benefits from tree planting in identified riparian areas

1.3 Report Organization

Methods or steps taken to date for identifying suitable riparian areas for forestation in Arizona are provided in section 2, and results of this research are summarized in section 3. Section 4 provides conclusions and recommendations for next steps.

2.0 Project Approach, or Methods

Analysis of potential riparian areas for forestation was conducted through the following steps:

- Modeling the extent of potential riparian areas.
- Defining geophysical potential for native woody riparian vegetation.
- Identifying opportunities for carbon sequestration through forestation with native woody vegetation within the potential riparian areas.

2.1 Modeling the extent of potential riparian areas

In this section we examine how to define the area around rivers, streams and lakes that could support riparian vegetation in Arizona.

The majority of literature identified as part of this study referred to establishing a minimum buffer width on either side of rivers and streams in order to facilitate different conservation practices:

- According to the National Resources Conservation Service (NRCS), a minimum width of 15 feet (4.5 m) is needed on either side of streams (Riparian Forest Buffer (Ac.) Code 391.2006). No guidance of maximum width of buffers is provided by this standard, but for increasing carbon storage in biomass and soils maximizing the width and length of the riparian forest buffer is recommended.
- Different regulations for establishing riparian buffers differ not only by state but also by the different riparian use properties and vegetation requirements. According to Wenger (1999), hydrological, soil, topographic and climate factors were considered in assessment of the width of the riparian buffer in Georgia. According to this source, a minimum of 100 feet (30 m) of buffer width is required for effectively catching the sediments and protection of water quality, 50 feet (15 m) buffers are sufficient to provide nitrogen control through plant uptake. Furthermore, riparian forest buffers between 35 and 100 feet (10 and 30 m) are required to protect an aquatic habitat and riparian forest buffers with a width of 300 feet (90 m) are necessary to provide habitat for diverse terrestrial riparian wildlife.
- Based on wildlife habitat protection, the desired width of riparian buffers range from 40 to 600 feet (12 to 180 m) for wildlife and bird species in Connecticut (CRJC,

2001).Mayer et al. 2005 reviewed a number of peer-reviewed studies concerned with the relationship between riparian buffer width and nitrogen removal capacity effectiveness. He reported mean forest buffers of 240 feet (73 m) from the reviewed studies, with minimum of 35 feet (10 m) and maximum of 720 feet (220 m). Federally recommended buffer widths vary from 23 to 328feet (7 to 100 m), which covers the expected width of a buffer for significantly removing nitrogen (Mayes et al. 2006).

- Lee at al. 2004 reviewed provincial, territorial and state guidelines for establishing riparian forest buffer zones in Canada and United States and reported a mean buffer from 50 to 95 feet (15 to 29 m) for different water body types when both countries were combined. Arizona was not included in the results of this paper, because no riparian management guidelines were provided to the authors (Lee et al. 2004).

Instead of rigid buffer widths, an approach of mapping potential riparian areas based on a combination of stream network and topology, used by the Wyoming Gap Analysis Project (Merrill et al. 1996) and by the West Virginia Gap Analysis Project (Stranger et al. 2000), was adopted for this part of the regional characterization of Arizona. This approach was considered more appropriate than the approach of creating buffers with different widths, because it incorporates the topology and results in realistic shapes of riparian areas. The inputs used in this spatial model included (Figure 1):

1. 1:100,000 perennial streams network and lake databases obtained from the Arizona State Land Department, Arizona Land Sources Information System, both published in 1993
2. Digital Elevation Model (DEM) at 30 m resolution , obtained from U.S. Geological Survey DEM data , with filled sinks
3. Percent slope, derived from the DEM data

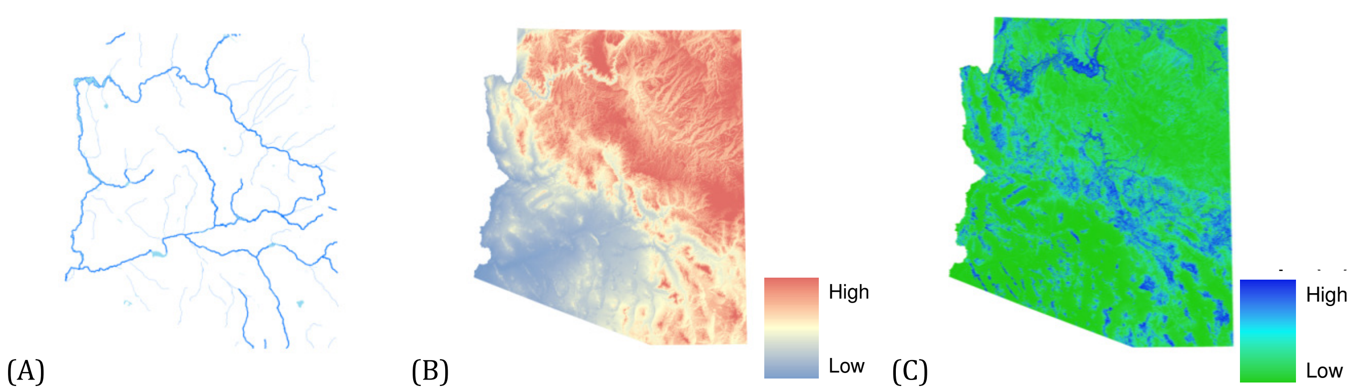

Figure 1. Input datasets for PATHDISTANCE modeling approach of riparian areas: (A) hydrology – rivers and water bodies; (B) elevation data; (C) percent slope.

-*First*, the major rivers and main basin rivers were selected from the statewide dataset of perennial streams. Polygons classified as ephemeral, inundation, lake, reservoir, streams and marsh/swamp in the lake database were separated to represent the water bodies in Arizona.

-*Then*, the PATHDISTANCE module in ArcInfo (ARCGIS 9.3.1) was used separately for each river and water body category to create a surface of the relative cost of traveling upslope from the stream. Elevation data were used in the PATHDISTANCE modeling to calculate more accurately cell–to cell distance.

-The result of the PATHDISTANCE module was a continuous surface with abruptly increasing relative cost for steeper slopes indicating that the higher cost associated with areas further away from river and water bodies and at higher elevation. The areas with high PATHDISTANCE values are less likely to support riparian vegetation and wildlife.

-To determine the extent of potential riparian areas we examined different thresholds for the PATHDISTANCE values and decided on threshold of 1000 for all river and water body categories. Areas with values below the threshold were considered to be reasonable approximations of riparian areas.

-*Finally*, we excluded all water bodies (lakes, reservoirs, etc.) from the delineated areas from the PATHDISTANCE module to determine the final extent of potential riparian areas surrounding perennial rivers and water bodies in Arizona.

2.2 Geophysical potential for riparian woody vegetation

In this section we examine which areas within the identified riparian zones have the potential to support riparian vegetation based on geology, landform and soil type.

In this part of the analysis we used a riparian vegetation dataset obtained from the Arizona State Land Department, Arizona Land Resources Information System (1994). The riparian vegetation types defined by the spatial datasets are reported in Table 1 and shown in Figure 2. Cottonwood/willow, conifer/oak, mesquite and mixed broadleaf were considered to have current native woody tree vegetation cover and were the primary focus of this analysis.

Table 1. Riparian vegetation types in Arizona and their area (acres) and percent of the total area.

Vegetation Class	Riparian veg. type	Area (acres)	Percent (%) of the total
Riparian Tree Cover	Cottonwood/Willow	29,979	18
	Mixed Broadleaf	14,624	9
	Conifer/Oak	4,923	3
	Mesquite	1,108	1
Other Woody Vegetation Cover	Mountain Scrub	58,689	35
	Russian Olive	3,240	2
	Tamarisk	1,204	1
	Strand	54	0
Agriculture	Agriculture	10,368	6
Other Wetland	Wet Meadow	632	0
	Marsh	630	0
Other	Flood Scoured	18,028	11
	Areas not Ground Verified	13,041	6
	Total area of riparian vegetation	**166,521**	**100**

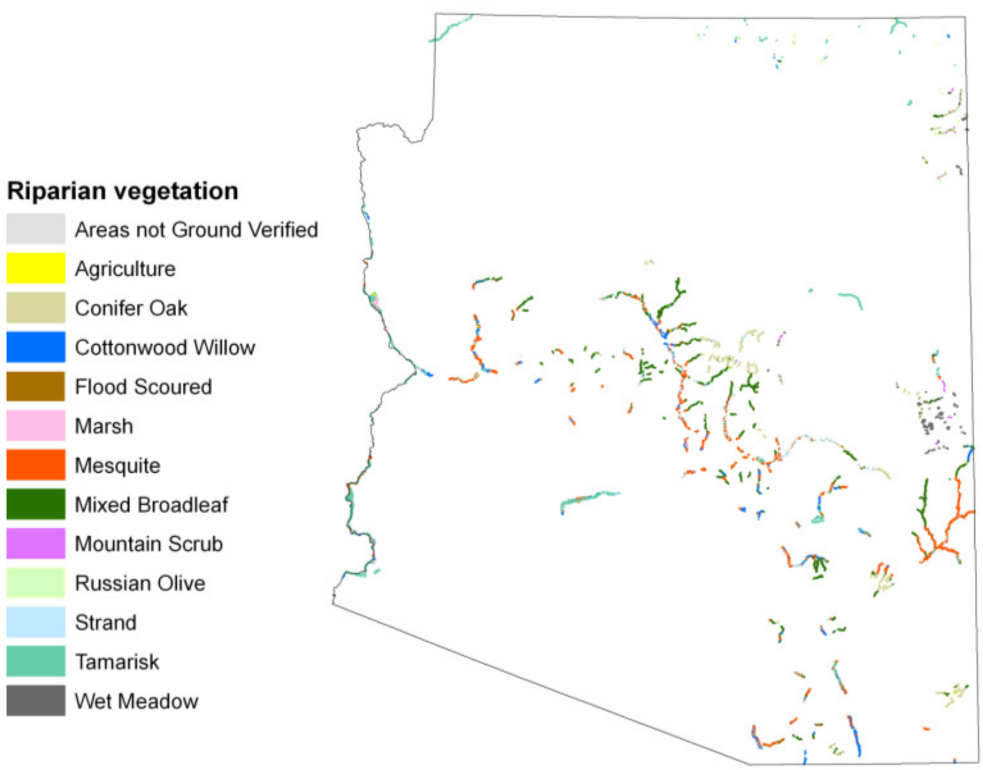

Figure 2. Distribution of riparian vegetation across Arizona according to a dataset obtained from the Arizona State Land Department.

The following databases were used to determine geophysical potential:

1. A digital database of geology for Arizona developed by Hirschberg and Pitts, 2000 (Figure 3) with information on geological formations, i.e. unconsolidated sediments, sedimentary rocks, metasedimentary rocks, intrusive rocks, extrusive rocks, metamorphic rocks, water or ice.
2. A digital dataset of landforms developed by Manis et al. (2001) for Arizona (Figure 4). The landforms dataset defines different landform types based on slope angles and aspects, landform positions, hydrological relationships and microclimatic parameters. Parameters influencing the surface and sub-surface water movement, and evaporative water loss versus water retention within local watershed were considered in the modeling of the landform types.
3. Soil type classes were obtained from the STATSGO2 database developed by the National Cooperative Soil Survey and distributed by the Natural Resources Conservation Service (formerly Soil Conservation Service) of the U.S. Department of Agriculture (Figure 5).

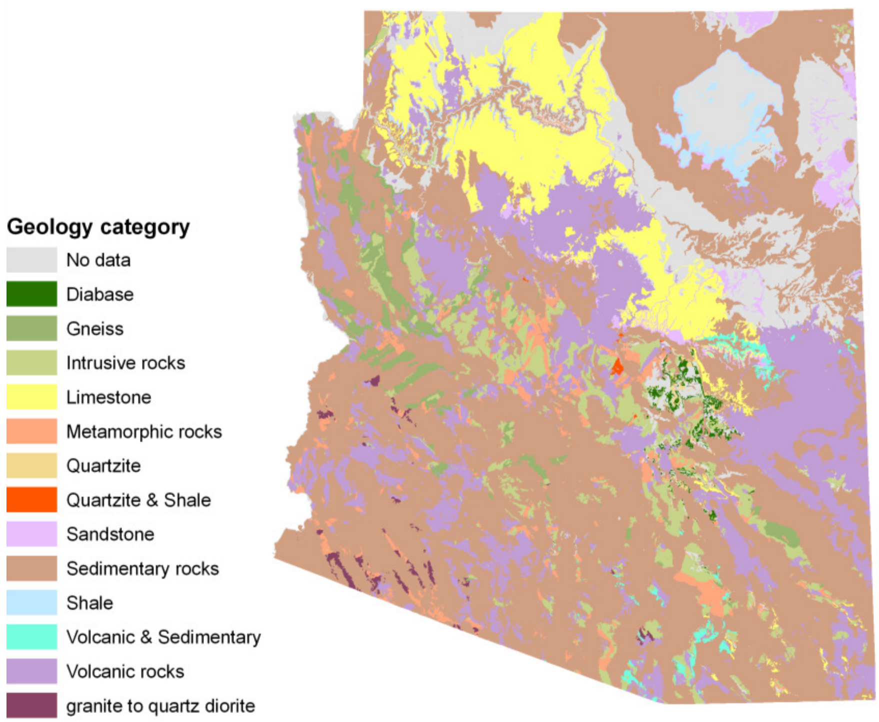

Figure 3. Geological formations across Arizona.

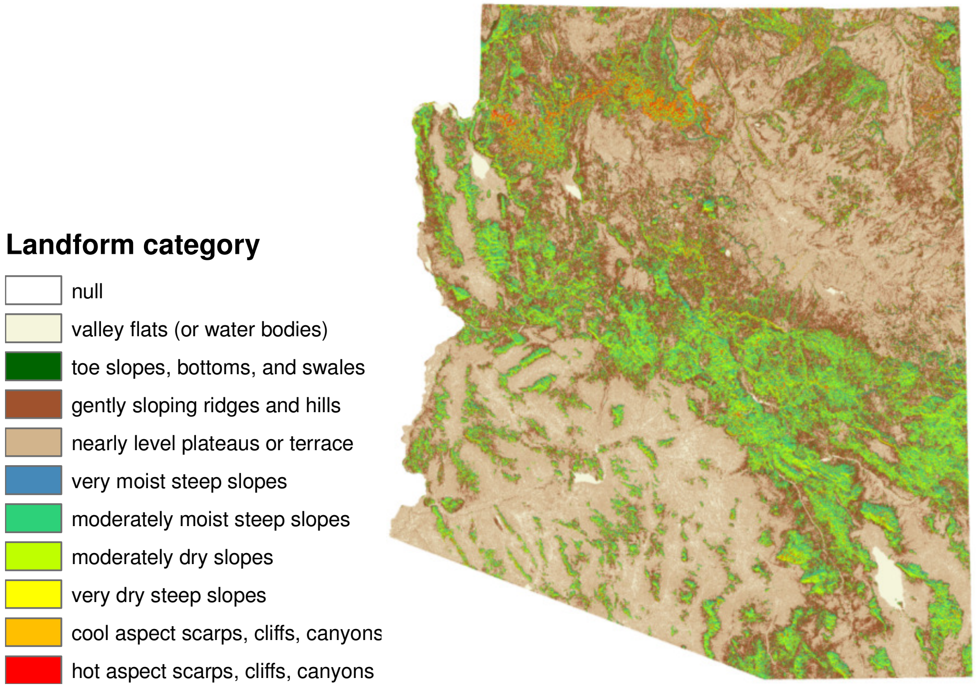

Figure 4. Landform categories across Arizona.

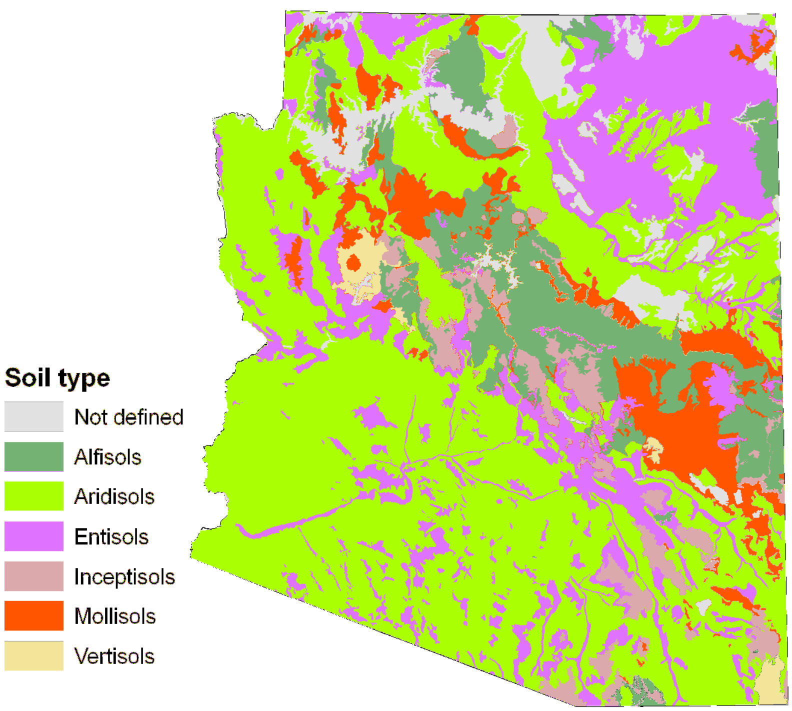

Figure 5. Soil types across Arizona according to STATSGO2 dataset.

For each database the percentage of the native woody tree riparian vegetation type per class/category was used to create a factor map for the modeled riparian areas.

Separate factor maps for geology, landforms and soil type were created for each of the riparian woody vegetation types (cottonwood/willow, conifer/oak, mesquite and mixed broadleaf); these factor maps were combined using a weighted average approach to create a single geophysical potential map for each of the riparian woody vegetation types.

2.3 Identifying opportunities for carbon sequestration through forestation

To identify the opportunities for carbon sequestration through forestation activities, we first identified areas suitable for forestation for each of the woody riparian types and then assigned the associated rates of carbon sequestration for 20, 40 and 80 years. Data on carbon stocks in riparian areas in southwest of the US are very sparse. Applying standard forest growth rates will lead to overestimations of carbon stocks. We used measurements of mesquite, willow and cottonwood riparian areas along the Lower Colorado River in 2007 collected by Winrock International to assign carbon sequestration rates for 20, 40 and 80 years (Pearson et al., 2007). This allowed us to estimate the potential carbon sequestration of a forestation project for these years.

To identify the areas that have potential for forestation we first overlaid the landcover categories from the National Landcover Dataset (NLCD) for 2001 with the potential riparian areas mapped under the first objective of this analysis. With this step we identified potential riparian areas that are occupied by the shrub/scrub category and could be used for forestation activities.

Then, we combined the riparian areas occupied by shrub/scrub with the geophysical potential map for each of the native woody vegetation types. According to Arizona's Riparian Areas web site[1], riparian vegetation can be characterized into three broad ecosystems based on the elevation for the southwestern United States. These three elevation categories are as follows: (1) less than 3280 ft (1000 m), (2) between 3288 and 6560 ft (1000-2000 m) and (3) greater than 6560 ft (2000 m). Therefore, we stratified the geophysical potential scores on shrub/scrubland cover category by elevation categories to refine the extent of areas suitable for sustaining riparian woody vegetation.

Carbon stocks were assigned for woody riparian tree and potential carbon sequestration from forestation of riparian areas was calculated for 20, 40 and 80 years.

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[1] Arizona's Riparian Areas is a module developed by University of Arizona to provide general information for riparian areas of Arizona. More information at http://ag.arizona.edu/extension/riparian/intro.html

3.0 Project Results

3.1. Modeling the extent of potential riparian areas

We used a modeling approach that incorporates river and water bodies as well as elevation and slope to model the extent of the riparian areas. This model resulted in predicting the potential riparian area in natural shapes rather than creating buffers around the rivers. Figure 6 shows the extent of the modeled potential riparian areas in Arizona. The total modeled area was estimated at 3 million acres (1.2 million ha), which is approximately 4% of the total area of Arizona (Figure 6).

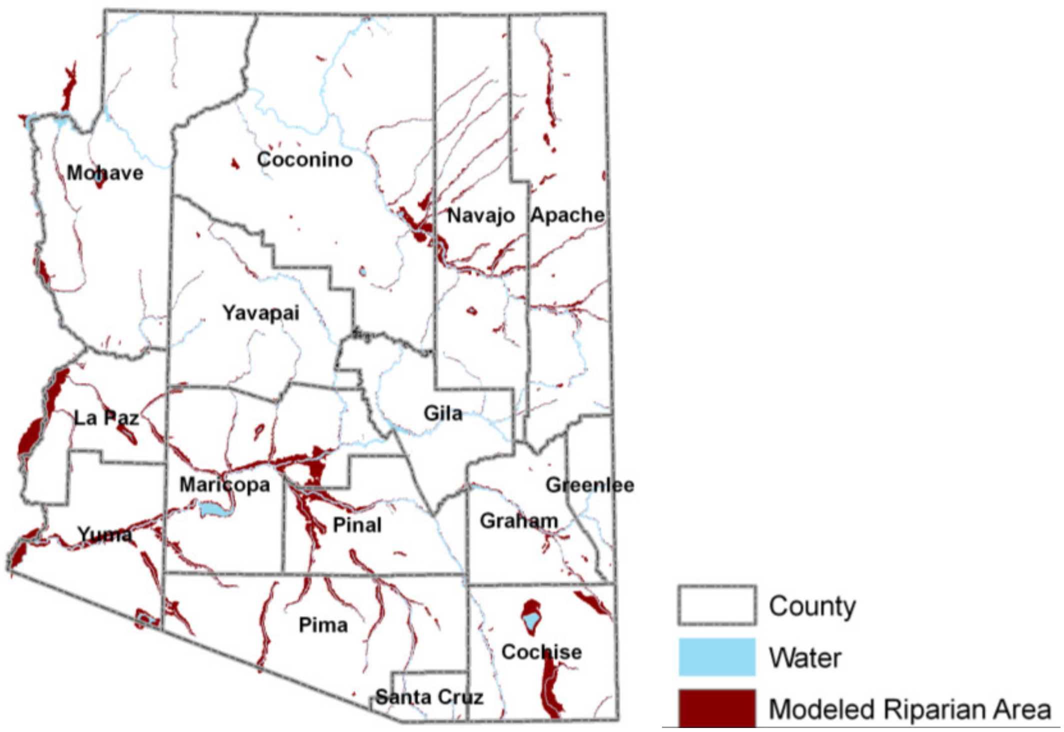


Figure 6. Extent of the potential riparian areas for Arizona modeled with PATHDISTANCE model.

The results showed that Yuma, La Paz and Pinal County have the largest extent of potential riparian area as a percent of the total county area – 10%, 9% and 9% respectively (Table 2). The county of Maricopa resulted in the largest area of potential riparian areas with approximately 450 thousand acres, which accounted for 8% of the total county area. Potential riparian areas for both Greenlee and Gila Counties, accounted for only about 1% of county area.

Table 2. Distribution of the potential riparian area per county and total county area (acres)

County name	County area	Potential riparian area	Percent of the area
	Acres		
Yuma	3,541,487	342,376	10%
La Paz	2,886,287	262,363	9%

Pinal	3,435,172	296,649	9%
Cochise	3,966,683	312,370	8%
Maricopa	5,902,022	448,549	8%
Pima	5,893,335	306,982	5%
Navajo	6,394,555	245,394	4%
Apache	7,161,887	194,347	3%
Graham	2,985,730	76,705	3%
Santa Cruz	796,230	19,140	2%
Mohave	8,634,681	157,628	2%
Coconino	11,932,379	202,261	2%
Yavapai	5,204,838	63,277	1%
Greenlee	1,178,381	11,352	1%
Gila	3,055,321	25,314	1%
Totals	72,968,987	2,964,706	4%

3.2. Geophysical potential for riparian woody vegetation

For this analysis the four riparian woody tree vegetation types were considered: cottonwood/willow, conifer/oak, mesquite and mixed broadleaf. We calculated the distribution of these four vegetation types across landform, rock formation and soil type classes.

3.2.1. Landform

Figure 7 shows the distribution of riparian vegetation types on different landform classes and Table 3 reports specific percentages of native woody vegetation classes within each landform class. For example, cottonwood/willow and mesquite are mostly spread on flat valleys, leveled plateaus or terraces and gently rolling slope ridges and hills, while mixed broadleaf and conifer/oak are common for gently sloping ridges as well as for moderately dry and moderately moist steep slopes.

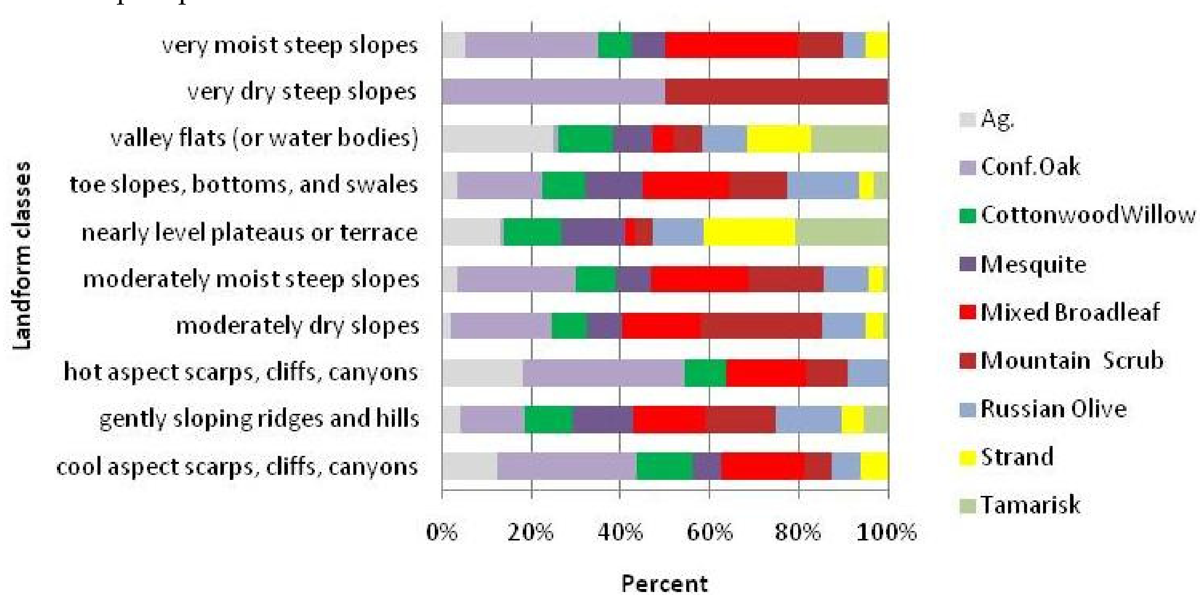


Figure 7. Distribution of riparian vegetation types per landform positional class.

Table 3. Percent of native woody riparian vegetation types per landform class.

Landform positional classes	Confer Oak	Cottonwood/ willow	Mesquite	Mixed Broadleaf
Cool aspect scarps, cliffs, canyons	5%	2%	1%	3%
Gently sloping ridges and hills	22%	16%	21%	24%
Hot aspect scarps, cliffs, canyons	4%	1%	0%	2%
Moderately dry slopes	23%	8%	8%	18%
Moderately moist steep slopes	24%	8%	7%	20%
Nearly level plateaus or terrace	1%	34%	37%	5%
Toe slopes, bottoms, and swales	6%	3%	4%	6%
Valley flats (or water bodies)	2%	24%	18%	9%
Very dry steep slopes	1%	0%	0%	0%
Very moist steep slopes	12%	3%	3%	12%

3.2.2. Rock Formation

The distribution of each vegetation class per rock formation class is shown in Figure 8 and the specific percent of native woody vegetation classes within each landform class is reported in Table 4.

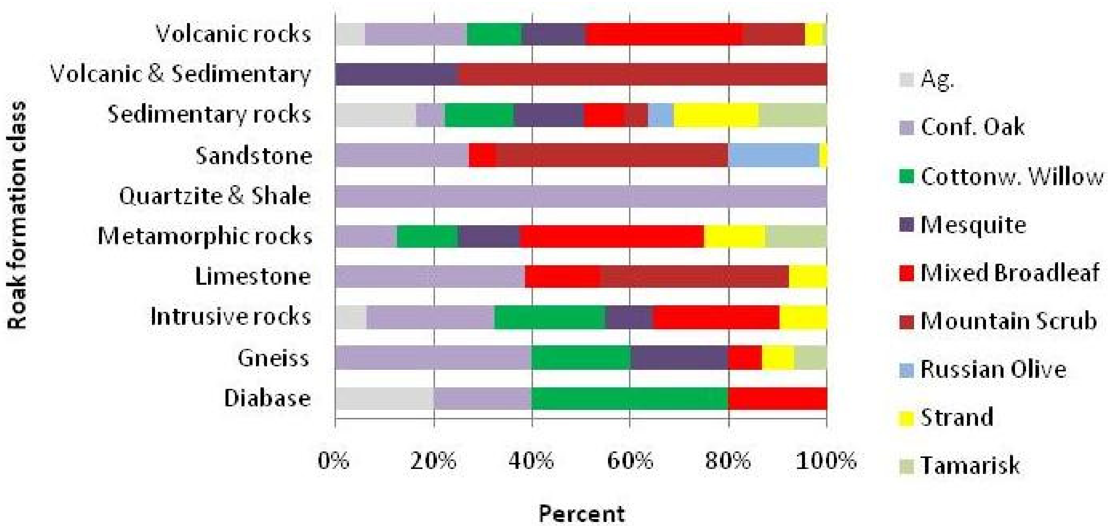


Figure 8. Distribution of riparian vegetation types per rock formation class.

Table 4. Percent of native woody riparian vegetation type per landform (rock formation) class.

Landform class	Confer Oak	Cottonwood Willow	Mesquite	Mixed Broadleaf
Diabase	1%	2%	0%	1%
Gneiss	6%	3%	3%	1%
Intrusive rocks	8%	7%	3%	8%
Limestone	5%	0%	0%	2%
Metamorphic rocks	1%	1%	1%	3%

Quartzite	0%	0%	0%	0%
Quartzite & Shale	1%	0%	0%	0%
Sandstone	19%	0%	0%	4%
Sedimentary rocks	30%	72%	73%	42%
Shale	0%	0%	0%	0%
Volcanic & Sedimentary	0%	0%	1%	0%
Volcanic rocks	24%	13%	15%	37%

3.2.3. Soil Type

The distribution of each vegetation class per soil class is shown in Figure 9 and the specific percent of the native woody vegetation types within each soil type class is reported in Table 5.

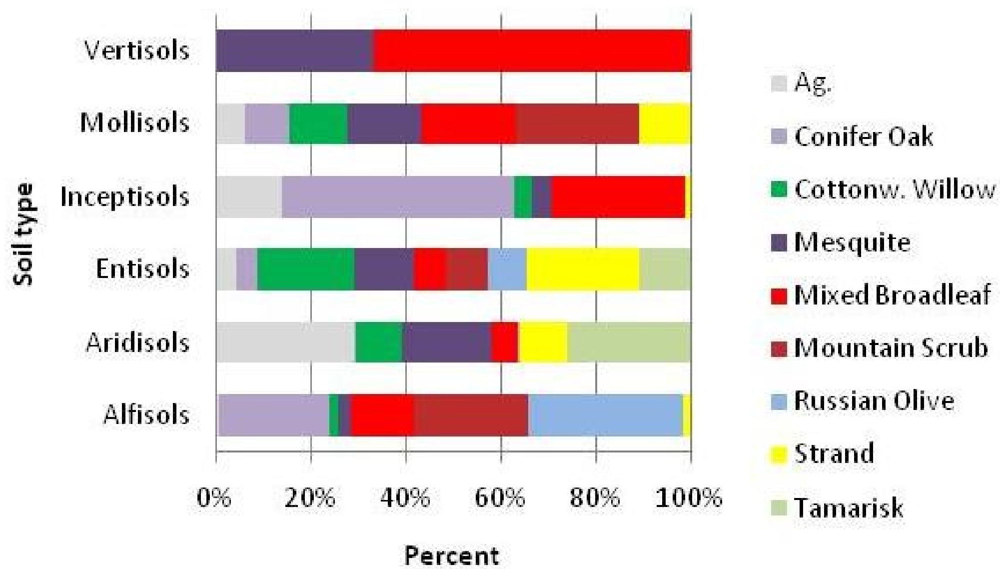


Figure 9. Distribution of riparian vegetation type per soil type.

Table 5. Percent of native woody riparian vegetation per soil type.

Soil Order	Conifer /oak	Cottonwood Willow	Mesquite	Mixed Broadleaf
Alfisols	40%	**3%**	4%	23%
Aridisols	1%	**22%**	44%	13%
Entisols	12%	**57%**	35%	19%
Inceptisols	38%	**3%**	3%	22%
Mollisols	6%	**8%**	10%	13%
Vertisols	0%	**0%**	1%	2%

3.2.4. Geophysical Potential Maps

Percentage information from Table 3, 4 and 5 were used to create landform, geology and soil factor maps, which were combined using weighted averages to create a single geophysical potential map for each native woody vegetation type. Figure 10 shows the geophysical potential map for conifer/oak, cottonwood/willow, mesquite and mixed broadleaf vegetation for area south of Scottsdale, AZ.

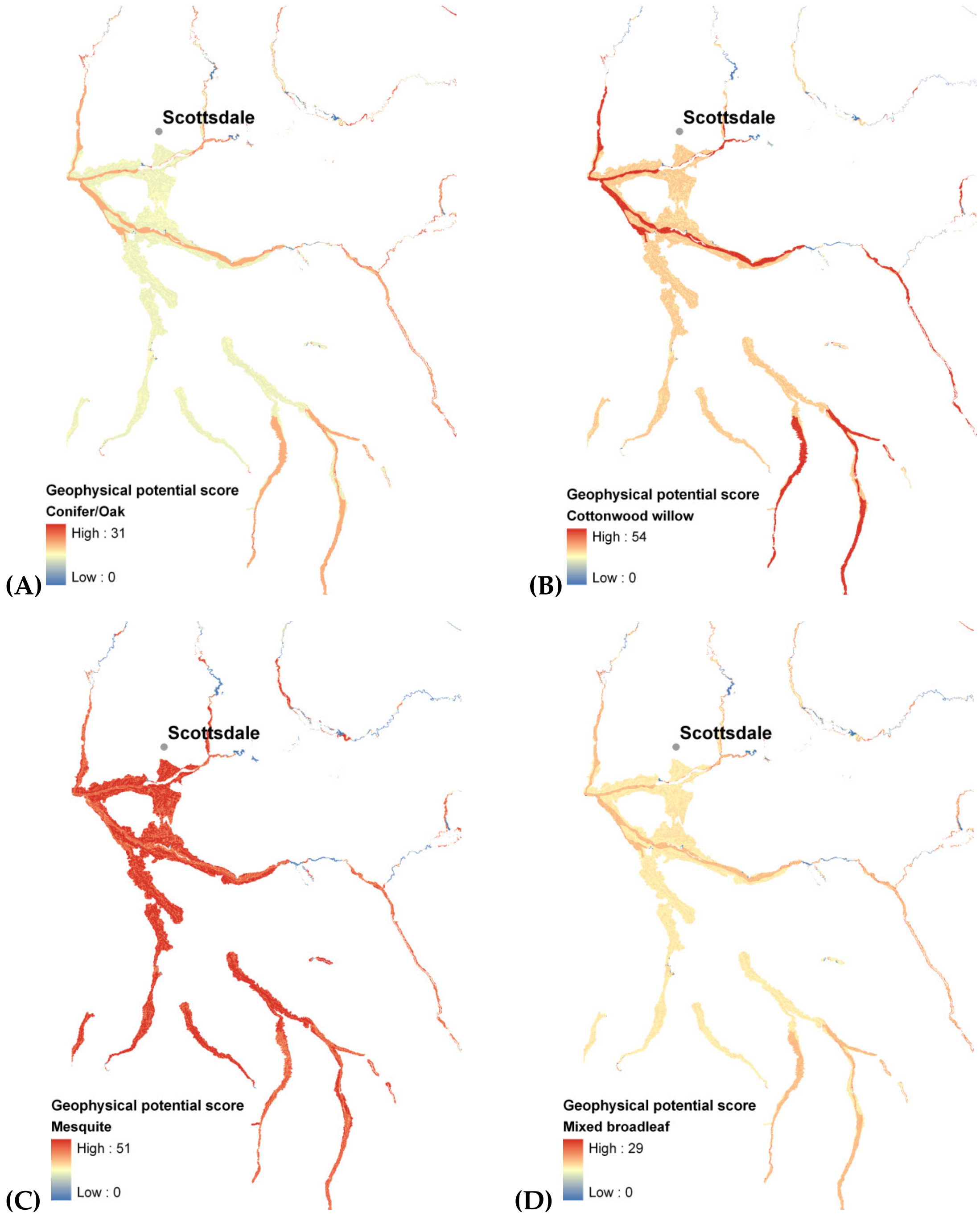


Figure 10. Example of geophysical potential map for (A) conifer/oak, (B) cottonwood/willow, (C) mesquite, and (D) mixed broadleaf vegetation.

3.3. Identifying opportunities for carbon sequestration through forestation

The National Land Cover Dataset (NLCD) for 2001 has a total of 15 categories for the state of Arizona. We aggregated the four developed classes, three forest classes and two wetland classes into developed area, forest and wetland classes, respectively. The distribution of the nine aggregated land cover classes across the modeled potential riparian areas is shown in Figure 11.

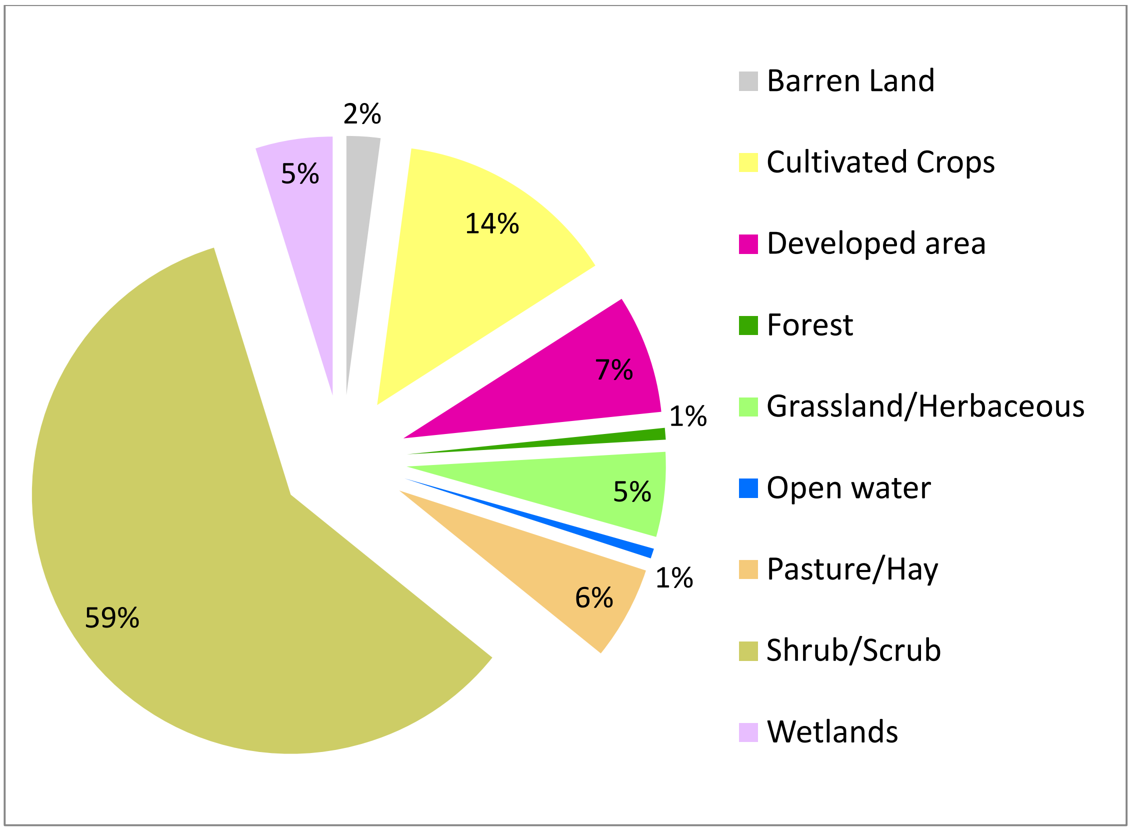
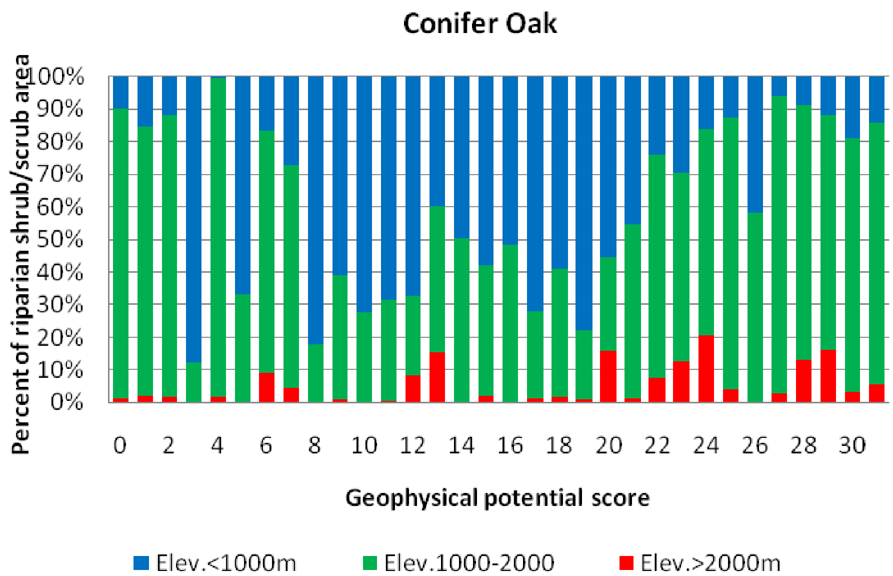
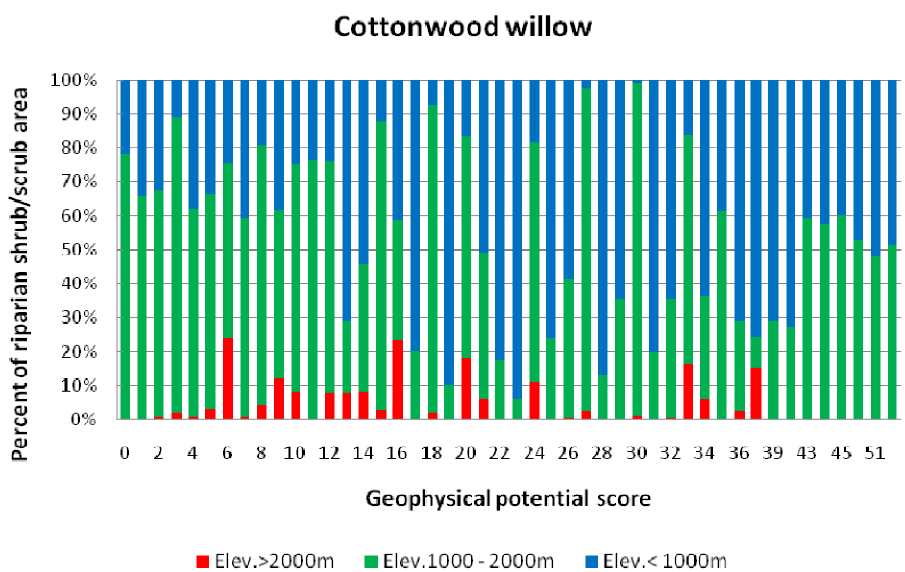


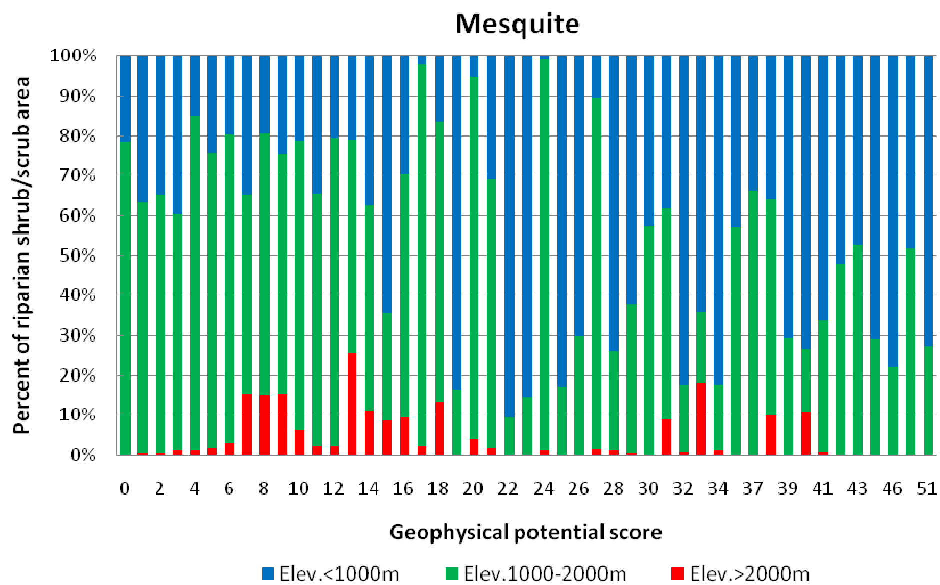
Figure 11. Percent distribution of the aggregated nine land cover classes from NLCD 2001 across modeled potential riparian areas.

The area occupied by shrub/scrub category, representing more than 59% of the modeled potential riparian areas, was extracted as the baseline cover with the greatest economic opportunity for forestation.

Geophysical potential scores for conifer/oak, cottonwood/willow, mesquite and mixed broadleaf on shrub/scrub land cover category were analyzed across the tree elevation strata – (1) less than 3280 ft (1000 m), (2) between 3288 and 6560 ft (1000-2000 m) and (3) greater than 6560 ft (2000 m). Figure 12 reports the percent of area occupied by shrub/scrub land cover category per geophysical likelihood score and per elevation stratum for each of the four native woody riparian vegetation types.


Conifer Oak
Percent of riparian shrub/scrub area
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Geophysical potential score
Elev.<1000m
Elev.1000-2000
Elev.>2000m


Cottonwood willow
Percent of riparian shrub/scrub area
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 39 43 45 51
Geophysical potential score
Elev.>2000m
Elev.1000 - 2000m
Elev.< 1000m



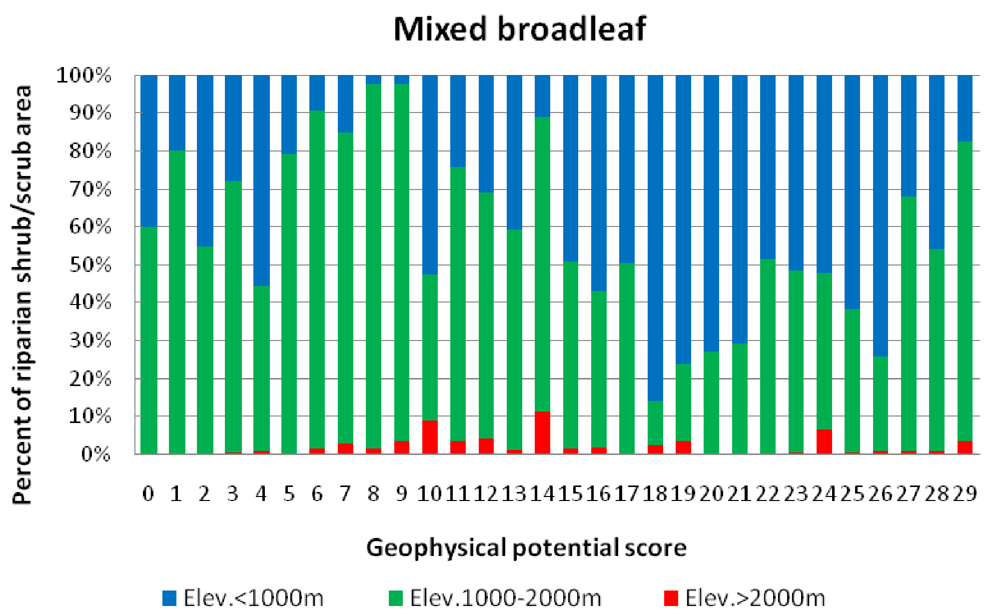


Figure 12. Percent distribution of area occupied by shrub/scrub land cover category across the geophysical likelihood score per elevation strata for (top to bottom) conifer/oak, cottonwood/willow, mesquite and mixed broadleaf.

We refined the area available for forestation on shrub/scrub riparian land by dividing the geophysical scores for each woody vegetation riparian type into four equal intervals to represent low, moderate, high and very high class of geophysical potential. We considered area suitable for forestation with the four woody vegetation riparian types only for the latter two geophysical potential classes (high and very high) per elevation stratum (Table 6).

Total area, on high and very high geophysical potential class, identified for forestation with cottonwood/willow and mesquite trees was estimated to be 1.6 million acres (647 thousand ha), with mixed broadleaf trees was estimated to1.5 million acres (607 thousand ha), and with conifer/oak trees was estimated to 69 thousand acres (27 thousand ha). The results show that 88% of the total area for cottonwood/willow, 87% for mesquite, 33% for mixed broadleaf, and just 10% for conifer/oak are located on very high geophysical potential class.

Table 6. Final riparian area (acres) identified as suitable for forestation with conifer/oak, cottonwood/willow, mesquite and mixed broadleaf woody riparian vegetation types on high and very high geophysical potential.

	Conifer/Oak		Cottonwood/Willow		Mesquite		Mixed broadleaf	
Elevation category	High Potential	Very High Potential	High Potential	Very High Potential	High Potential	Very High Potential	High Potential	Very High Potential
	Acres							
1000m	34,944	1,012	29,245	928,357	36,785	927,434	716,603	247,504
1000-2000	25,703	5,146	158,818	502,088	170,837	501,639	283,843	244,503
>2000m	1,483	648	3,801	2,176	2,947	1,847	4,000	1,633
Totals per class	62,130	6,806	191,864	1,432,621	210,569	1,430,920	1,004,446	493,641
Grand totals	**68,939**		**1,624,486**		**1,641,490**		**1,498,087**	

Table 7 reports the area identified as suitable for forestation for each of the woody riparian vegetation types per county. Pima County has the largest potential of 249 thousand acres (100 thousand ha) for planting either cottonwood/willow or mesquite, Navajo county has the largest potential of 99 thousand acres (40 thousand ha) for planting mixed broadleaf species, and Yavapai County has the largest potential of 2,000 acres (800 ha) for planting conifer/oak.

Table 7. Very high geophysical potential riparian area (acres) identified for forestation with conifer/oak, cottonwood/willow, mesquite and mixed broadleaf woody riparian vegetation types reported by county.

County Name	Conifer/oak	Cottonwood/willow	Mesquite	Mixed broadleaf
Apache	556	77,468	77,173	70,971
Cochise	63	212,856	212,893	27,262
Coconino	171	27,355	26,606	21,562
Gila	1,360	10,585	10,180	7,694
Graham	93	36,901	36,904	28,332
Greenlee	481	5,984	6,204	6,122
La Paz		99,019	99,031	5,142
Maricopa	54	185,561	184,884	67,617
Mohave		82,728	83,157	9,626
Navajo	1,629	134,637	134,561	**99,338**
Pima		**249,420**	**249,430**	50,496
Pinal		141,157	141,223	40,529
Santa Cruz	335	9,559	9,619	7,487
Yavapai	**2,062**	36,096	35,588	13,097
Yuma		123,225	123,337	38,362

3.4. Potential Carbon Stocks

Thirty-five measurement plots were recorded along the lower Colorado Rivers by the Winrock team (Pearson et al., 2007) and from the data collected for mesquite, willow and cottonwood riparian areas, the growth curve was developed (Figure 13 and Table 8).

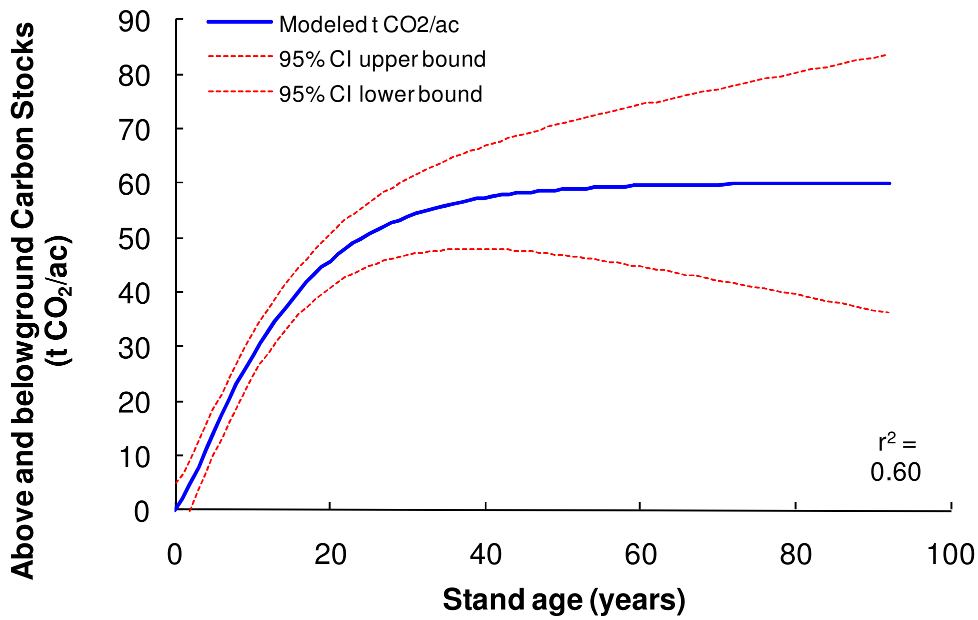


Figure 13. Estimated carbon sequestration for riparian areas in Arizona derived from field measurements along the Lower Colorado River

Table 8. Estimated carbon sequestration for riparian areas in Arizona derived from field measurements along the Lower Colorado River

Years	Expected Sequestration *t CO_2e/acre*		
0	0	+/-	*4.8*
5	14	+/-	*4.2*
10	28	+/-	*4.0*
15	39	+/-	*4.2*
20	46	+/-	*4.9*
25	51	+/-	*5.9*
30	54	+/-	*7.0*
35	56	+/-	*8.2*
40	57	+/-	*9.5*
45	58	+/-	*10.8*
50	59	+/-	*12.1*
55	59	+/-	*13.5*
60	60	+/-	*14.8*
65	60	+/-	*16.2*
70	60	+/-	*18.1*
75	60	+/-	*20.9*
80	60	+/-	*23.7*

Due to the paucity of data at this time we are unable to provide separate carbon accumulation rates for the four proposed woody tree vegetation types: conifer/oak, cottonwood/willow, mesquite and mixed broadleaf. It is likely that the curve used would be conservative for areas with high water availability and particularly for areas dominated by cottonwood.

3.5. Potential Carbon Sequestration Through Forestation of Riparian Areas

The total amount of carbon that could be sequestered by forestation of riparian areas with high and very high geophysical potential at all three time periods varies by native woody riparian vegetation type (Table 9). The analysis showed that areas defined as suitable for forestation with conifer/oak (69 thousand acres) on high and very high geophysical potential classes could sequester more than 4 million t CO_2e after 80 years. Riparian areas identified as suitable for growing cottonwood /willow, mesquite and mixed broadleaf species a higher potential to sequester carbon after 80 years, 97 million, 98 million and 89 million CO_2e, respectively.

Table 9. Potential riparian area for forestation, carbon accumulation rates, and total carbon sequestration for 20, 40 and 80 years forestation project activity.

Native woody riparian vegetation	Potential category	Potential area for forestation (acres)	Carbon sequestration rate (t CO_2e/acre) at age of:			Total carbon sequestration (t CO_2e) at project year (x 1 000)		
			20	40	80	20	40	80
Conifer/oak	High	62,130	46	57	60	2,858	3,541	3,728
	Very High	6,806				313	388	408
Cottonwood/ willow	High	191,864	46	57	60	8,826	10,936	11,512
	Very High	1,432,621				65,901	81,659	85,957
Mesquite	High	210,569	46	57	60	9,686	12,002	12,634
	Very High	1,430,920				65,822	81,562	85,855
Mixed broadleaf	High	1,004,446	46	57	60	46,205	57,253	60,267
	Very High	493,641				22,707	28,138	29,618

4.0 Conclusions and Recommendations

4.1 Conclusions

The approach used to map the extent of the riparian areas for the state of Arizona is robust because it allows calculating a spatial surface of relative cost of moving from the stream or water source up into the stream valley, accounting for slope and elevation. The relative cost increases abruptly with steeper slope as well as with areas located further from the water source by distance or elevation. These areas may be less likely to support riparian vegetation and wildlife. Using this method, the areas mapped as potential riparian areas have more natural shape. The area mapped as riparian areas is sensitive to selecting the threshold for the relative cost surface. In this analysis we used a threshold of 1000 units of the relative cost.

This method resulted in mapping approximately 3 million acres (1.2 million ha) of riparian areas across the state of Arizona, which accounted for 4% of the total state area. The result showed that Yuma, La Paz and Pinal County have the largest extent of potential riparian area as a percent of the total county area – 10%, 9% and 9% respectively while Greenlee and Gila County have the least extent of potential riparian area as a percent of the total county area - approximately 1%.

In this analysis we used geology, landform and soil type to evaluate the geophysical potential for growing native woody riparian trees such as conifer/oak, cottonwood/willow, mesquite and mixed broadleaf. The locations of these native woody riparian trees allowed us to calibrate the model and to predict the geophysical potential for the geology, landform and soil type classes across the remained riparian areas. The geophysical potential or likelihood maps in Figure 9 clearly indicate the areas with high values for landform, geology (rock formation) and soil factors.

The analysis illustrated that approximately 59% of the mapped riparian area was occupied by shrub/scrub according to the NLCD 2001 across the whole range of the geophysical potential scores for the native woody riparian vegetation. Considering equal interval class partition of the geophysical potential scores for each of the native woody vegetation, we selected riparian areas currently occupied by shrub/scrub in the high and very high geophysical potential class.
Due to the scarcity of carbon data for these native riparian tree species we used previously collected carbon data of mesquite, willow and cottonwood riparian areas along the Lower Colorado River in 2007 (Pearson et al., 2007) to estimate the carbon rate at 20 , 40 and 80 years. The analysis identified that approximately 1.4 million acres (566 thousand ha) are suitable for forestation with cottonwood/willow or mesquite, which potential for sequestering 97 and 98 million t CO_2e, respectively after 80 years. Area suitable for forestation with mixed broadleaf species was estimated at 500 thousand acres (202 thousand ha) with carbon sequestration potential of 89 million t CO_2e after 80 years, while the area suitable for forestation with conifer/oak was estimated at only 7 thousand acres (3 thousand ha), resulting in potential carbon sequestration of only 4 million t CO_2e after 80 years.

4.2 Recommendations

The preliminary analysis presented in this report highlighted the needs of further research with regarding restoration of riparian areas. Further research and analysis is needed particularly in the following areas:

4.2.1. Threshold selection of the relative cost surface

More in depth analysis and empirical data collection are needed to help select the correct threshold of the relative cost surface created through PATHDISTANCE. The current analysis considered only one value threshold for identifying the extent of the riparian areas, while in reality different values of threshold of the relative cost could be needed for mapping precisely the extent of the riparian areas. Aerial photographs or high resolution images can be used to develop a relationship between the value of the relative cost surface and the furthest and closest distance of riparian area edge per river class and/or elevation.

4.2.2. Collection of empirical data

The current analysis used equal interval to separate geophysical potential scores into low, moderate, high and very high classes. Additional empirical data should be collected though field work and/or from aerial photograph or high resolution images to develop a relationship between the geophysical potential scores and location of existing native woody vegetation. This will allow for accurate determination of the interval of geophysical potential scores representative for each of the native woody vegetation. The riparian vegetation data used in this analysis did not provided enough information to develop such relationship.

4.2.3. Cross discipline analysis

Forestation of the identified riparian areas will function not only as a carbon sink, but will be important in preserving water quality, maintaining stream integrity, providing wildlife habitat, and controlling flood and storm water runoff. Therefore, the selection of sites that could be afforested within the identified riparian areas should consider all these additional functions of riparian forest. For example, information and data produced by the Arizona statewide freshwater assessment by the Nature Conservancy could be considered when selecting sites for forestation.

Based on the funds available, it is recommended that these further analysis and data collection are carried out at county level. As indicated from this analysis Pima, Navajo and Yavapai counties have the largest estimated areas suitable for forestation with cottonwood/willow and mesquite, mixed broadleaf and conifer/oak, respectively and could be a good candidate for further analysis.

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