***Report Series**: Assessment of Ecosystem Service Value and Program Delivery Options: Establishment of a Scalable Model for Understanding Landowner Engagement opportunities.*

MAPPING ECOSYSTEM SERVICES FOR THE GULF COASTAL PLAINS & OZARKS LANDSCAPE CONSERVATION COOPERATIVE

A method for targeting opportunities

January 2017

Series Description

This report is one in a series developed in a collaboration between Mississippi State University and Duke University to identify opportunities to engage private landowners in the GCPOLCC in conservation and restoration activities by focusing on ecosystem service outcomes that are important to them. There are three main pieces of interrelated work: 1) a survey of landowners to identify what services are important to them and how willing they are to participate in conservation or restoration activities; 2) coarse resolution maps of the provision and where possible demand for ecosystem services in the region; and 3) a social network analysis to understand how best to engage private landowners across the region. The work focused on three primary habitats of the GCPOLCC; bottomland hardwoods, open pine stands, and grasslands.

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Introduction

Incorporating ecosystem services into decision making is of growing interest to businesses (Natural Capital Declaration), the US (EOP 2015) and other governments (Intergovernmental Platform on Biodiversity and Ecosystem Services), as well as conservation and development organizations (Wealth Accounting and Valuation of Ecosystem Services). Incorporating ecosystem services into decision making is expected to improve how decisions are made and communicated to the public (NRC 2005; PCAST 2011; NESP 2016). Assessing ecosystem services requires measuring how much a change in ecological conditions due to management affects social benefit, or value to society (Olander et al 2015). The goal of this analysis is to identify the potential supply and, where possible, demand for ecosystem services within three subgeographies of the Gulf Coast Plains and Ozarks LCC (East Gulf Coastal Plain, West Gulf Coastal Plain, and Mississippi Alluvial Valley) (Figure 1). The purpose for selecting these geographies was to focus on three habitats of interest to the LCC; bottomland hardwoods, open pine stands, and grasslands. This is an exploratory analysis where we will assess the ecosystem services provided by conserving, managing or restoring these three ecosystems.

What are Ecosystem Services?

Ecosystem services are the benefits people receive from nature. Nature provides humans with many things of value. Not only the water we drink and the air we breathe, but also the crop pollination accomplished by bees, the flood protection afforded by wetlands, and the sense of peace we might find standing in a quiet forest. To be clear, nature's benefits include environmental commodities that are consumed as well as places within which people live, recreate, and work. They even include the knowledge that other species, wilderness, and natural beauty will exist for future generations. Ecosystem services is shorthand for all of these aspects of nature that contribute to our health, wealth, and well-being.

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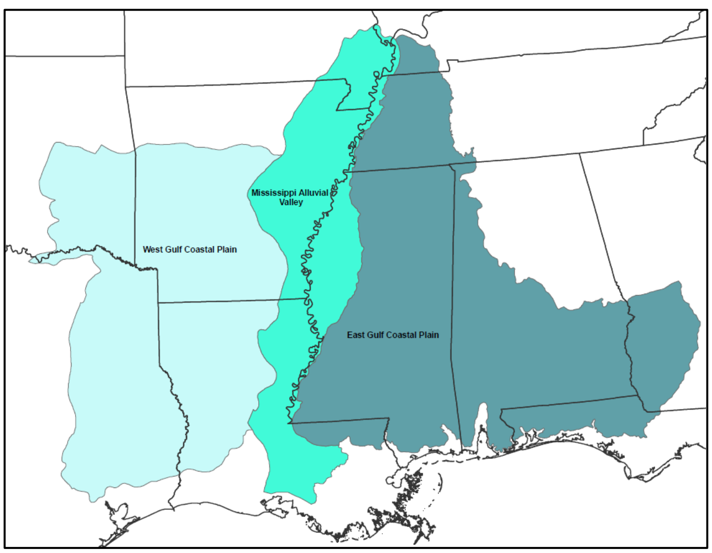


Figure 1. The study area for the ecosystem service analysis which includes three subgeographies of the GCPO LCC: the West Gulf Coastal Plain, the Mississippi Alluvial Valley, and the East Gulf Coastal Plain.

The study was designed to determine which ecosystem services provided by these ecosystems can be mapped at large scales using readily available data, and what type of information is available about each service. In describing the type of information we will explore questions about whether we can map only supply or whether we also have information about beneficiaries or demand and whether the resolution of the data is useful for conservation planning and management targeted to private landowners. The scale of the study limited our ability to determine detailed information on accessibility and substitutability, but where applicable we have included this information as it is important in determining the relevance and importance of services. The road network across the GCPO study area was found to be extensive, so general accessibility was not considered a limiting factor. By focusing on readily available data in the US, we hope this analysis could be used to guide future efforts for large-scale conservation and restoration in the country, or at least the lower 48. We estimate that the cost for another organization aiming to complete a similar analysis of the same set of services examined here would be between $5,000-$10,000. If the analyses were for a very different system, for example a coastal ecosystem, the cost would increase to roughly $15,000-$20,000 due to the time and effort involved in finding new data sources and working out a methodology for processing the data so that it effectively represents a new suite of services.

Using this readily available data we generated maps for the three geographies of interest for all potentially important ecosystem services for which we could find data. Some of these are incomplete or very uncertain due to data limitations. All details of the analyses are included in the appendix. The ecosystem services layers are then provided in a form in which they can be used in targeted assessment of conservation or restoration opportunities as shown in the use case section of this report.

The ecosystem services supply and demand maps developed in this part of our project can be overlaid with the results from the MSU led survey on landowner willingness to participate in conservation or restoration activities or programs, which is a piece of the larger project and is described in more detail in a separate report (Grala et al. 2016). Overlaying the survey and ecosystem services data can answer questions about how the potential provision of ecosystem services overlaps with landowner interest in these services and willingness to participate in conservation and management programs.

Overview of ecosystem services data assessment and mapping

We identified ecosystem services that might be enhanced or reduced by conserving, altering management, and restoring habitats in the three selected subgographies of the GCPOLCC using conceptual models depicted in Figures 2a-c below. We then collected data to assess and map the relative level of provision across the landscape for as many of these ecosystem services as possible. In this section we identify which services we were able to asses at least in some manner and those where data were insufficient. The conceptual model and ecosystem service mapping focus on services in relation to private landowners, as it is private lands that the LCC aims to target for restoration, conservation, and management.

The conceptual model depicts the effects that conservation and restoration of these three subgeographies may have on a suite of ecosystem services. The effects start with expected ecological changes that would eventually lead to a change in ecosystem services production and thus a change in benefits to people. Due to the scale of the conceptual causal chain diagrams we have broken the picture into three pieces (Figure 2 a,b, and c). Green boxes are the changes to ecological stocks and flows, orange boxes depict a linking point between ecological production and social benefit (what we call the benefit relevant indicators, or BRIs), and blue boxes indicate social benefit or value to people (which can sometimes be a monetary or monetized value). The boxes with bolded outlines are the best measures of the ecosystem service we were able to assess and map given existing data. While we stop at the bolded box in our analysis (the best we could do with data, time and resources available), the better measures of ecosystem services are further to the right on these chains as they better describe the magnitude of the benefits to people. A more final measure can capture information on both ecological production (things like the magnitude, timing, and location of the provision of services) as well as how important it is to people (how much it is valued by how many people and if they are critical populations (e.g. vulnerable populations or tribes)) (Olander et al. 2015). Where there is no bolded box, we did not have sufficient data to develop a measure of the service, and maps of this ecosystem service are not provided.

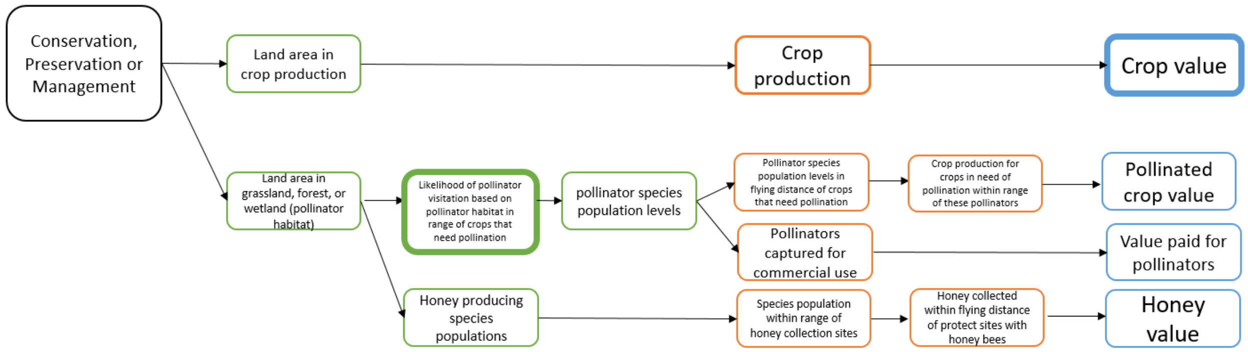


Figure 2a. Causal chain conceptual map showing how conservation, restoration (and management) of natural habitats in the GCPO LCC could change crop production and value, natural pollination of local crops, pollinators available for transport or honey production.

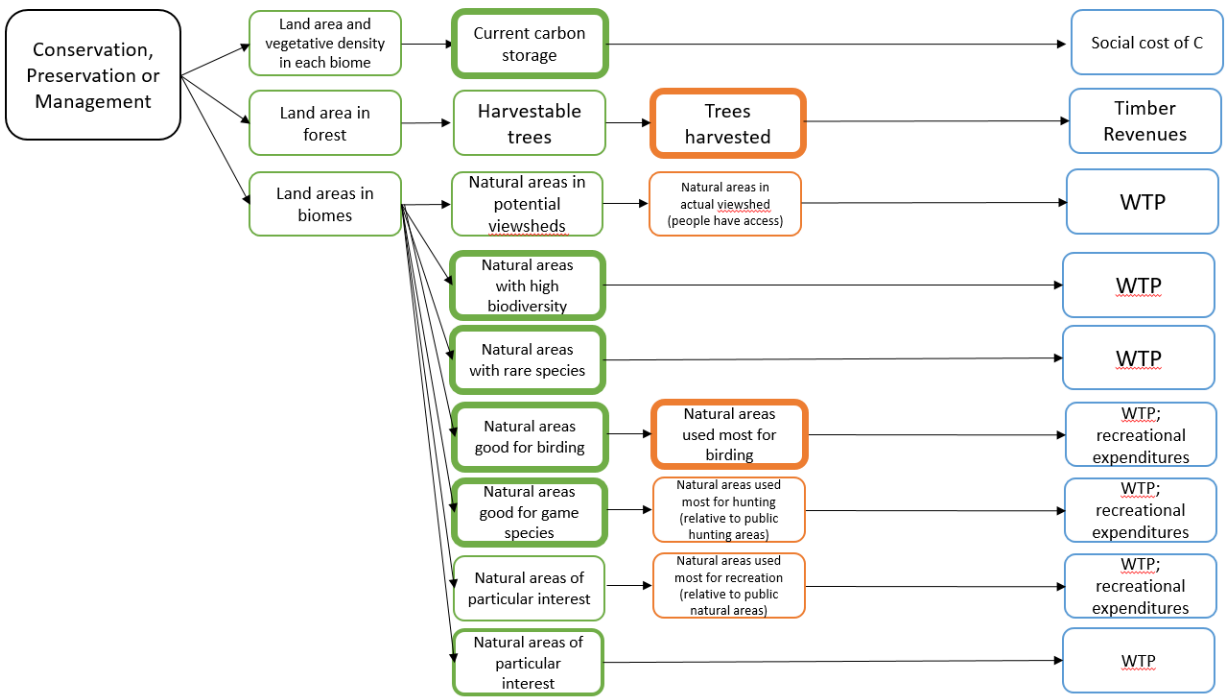


Figure 2b. Causal chain conceptual map showing how conservation, restoration (and management) of natural habitats in the GCPOLCC could change climate stabilization (carbon storage), timber production, and a diverse array of habitat, species, and recreation benefits. *WTP = Willingness to Pay.

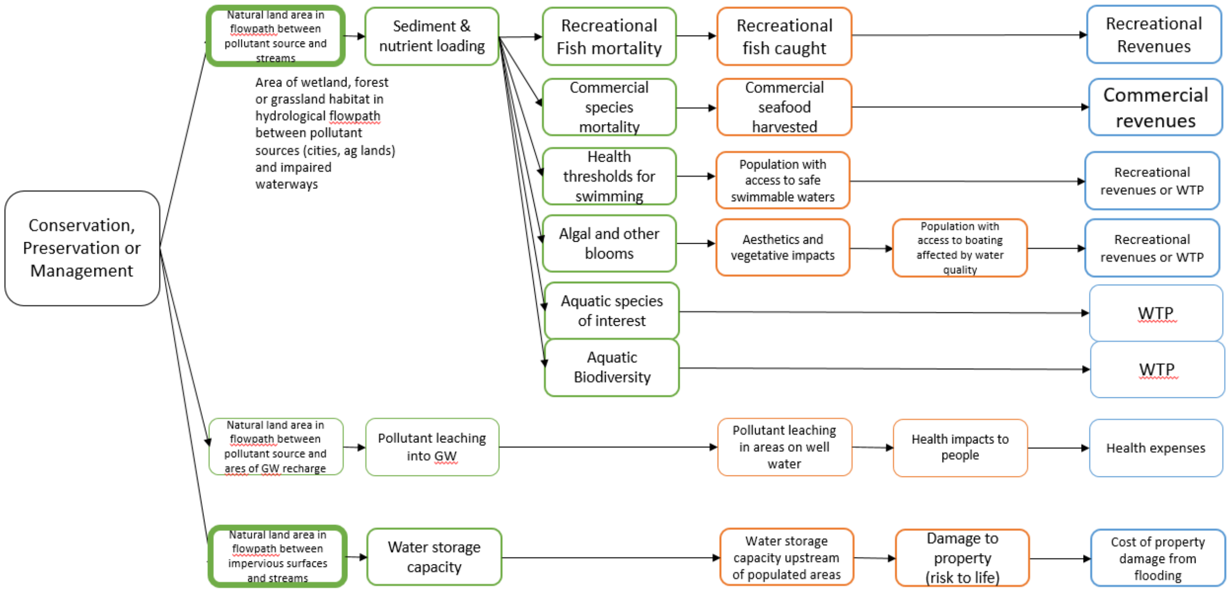


Figure 2c. Causal chain conceptual map showing how conservation, restoration (and management) of natural habitats in the GCPOLCC could change water filtration that may impact water quality and a variety of related services and water quantity effects on needed supply and flooding. *WTP = Willingness to Pay.

Figure 2a shows causal chains for how conservation and restoration of habitats can affect crop production, pollination for crops on site, pollination for offsite crops (trucking bees), and pollinator production of honey.

- ***Crop value*** per acre (final GIS layer 1b) can be used to determine the loss of crop value expected if an area is transitioned from cropland to natural habitat or the opportunity cost (lost net revenue) of preserving natural habitat rather than growing crops in the area.
- ***Likelihood of pollinator visitation based on pollinator habitat in range of crops that need pollination*** (final GIS layers 3a-d) can be used to estimate areas with sufficient levels of pollinator visitation that should be targeted for conservation of pollinator habitat and alternatively, areas lacking pollinator visitation that should be targeted for pollinator habitat creation. It should be noted that pollinator habitat is used as a proxy for presence of pollinators in this analysis. Data on pollinator species presence/ absence and/ or populations levels could not be obtained at the scale necessary for this project.
- We were not able to find data to assess **honey production** or commercial **pollinator production.**

Figure 2b shows causal chains on how the conservation, management, and restoration of natural habitats in the GCPO LCC could change climate stabilization (carbon storage), timber production, and a diverse array of habitat, species, and recreation benefits.

- ***Climate stabilization benefits*** are mapped using the biophysical measure tonnes of current carbon storage by displaying ***carbon stock in standing forest habitats*** (final GIS layer 7a). We also estimate areas most important for ***potential additional carbon that can be sequestered in forests through restoration*** (final GIS layer 7b) by looking at areas with high carbon storage but relatively few forests. We measure ***potential additional carbon that can be sequestered in these forests through management*** by looking at the difference in carbon storage between fully stocked and poorly stocked forests, and the areas of poorly stocked forests that could be managed to reach a fully stocked level and thus store more carbon (see appendix for full explanation and calculations). Carbon stabilization benefit can be valued using the social cost of carbon, a measure generated by experts and used as a rough estimate of avoided costs provided by each ton of carbon dioxide equivalents not emitted into the atmosphere (Interagency working group on social cost of carbon 2013).

- ***Merchantable timber production*** (final GIS layer 2b) on private lands can be used to determine where timber production is valuable and should be combined with other synergistic services because the opportunity costs of shifting to conservation or other purposes may be high. It also identifies where production may be lower making other uses of the land more viable. For example, where production is high there may be benefits from working forest lands management rather than preservation models to account for opportunity costs. Public lands merchantable timber information (found in the appendix) tells us how big a role private lands are playing relative to public lands in producing timber in the region. This provides an indication of how much demand there may be for timber from private lands relative to public lands, which is an indication of substitutability of supply. Public land production in this region is significantly lower than private land production.
- We were not able to assess **viewsheds** in a useful manner at such a large scale and did not find data on people's interest in accessing them, which would be a measure of demand.
- ***High biodiversity areas*** (final GIS layer 4a) were measured by average species richness based on species distribution models. These layers indicate the number of different species but do not indicate anything about abundance of those species. These richness values can help provide indications of where conservation for the preservation of biodiversity could have the most impact. Biodiversity can be broken down by vertebrate taxa, and individual taxa groups (mammals, bats, birds, reptiles, and amphibians) can be targeted for conservation if that is desirable.
- ***Rare species existence*** (final GIS layer 4b.1) was estimated by using at-risk species richness data from Nature Serve. These species are important to include as they may be regulated and therefore important to landowners as they try to reduce regulatory costs. ***Endangered species critical habitats*** (final GIS layer 4b.2) from the US Fish and Wildlife Service identifies areas most important for federally listed species.
- ***Birding habitats*** (final GIS layer 6a) were approximated using the Important Bird Areas identified by Bird Life International and the National Audubon Society. These are habitats identified as important for rare species, restricted range species, or species of conservation concern. These are the types of species that birders often seek out, and thus represent areas valuable to birders. ***Areas frequented by birders*** (final GIS layer 6b) were approximated using the number of eBird data collection points appearing in each HUC 12.
- ***Hunting*** (final GIS layer 5) was approximated by ***waterfowl harvest numbers*** from each county in the GCPO. Knowing where private hunting lands are in comparison to existing public hunting areas could be beneficial (Knoche et al 2015), and while we could not find data on private hunting lands, public hunting areas are shown in the appendix.
- We were not able to find consistent data to assess **natural areas of interest**. While natural heritage areas might be a good proxy for this ecosystem service, state reporting and designation of these areas is not consistent across the region. Data on people's interest in visiting these areas (an estimate of demand) is not available on a relevant scale for an analysis of this type. We considered using distance to public lands (state and federal parks) as a proxy for demand of natural areas of interest, however the mean distance any point on the landscape is from one of these parks is only 5.7 miles, and therefore this measure does not represent a limiting factor. The farthest that any point in the study area is from one of these state or federal parks is 33 miles.

Figure 2c shows causal chains on how the conservation, management, and restoration of natural habitats in the GCPOLCC could change water filtration that may impact water quality, water infiltration, and a variety of related services.

- How important different areas are for providing ***water filtration*** (final GIS layers 8a-d) was determined by measuring the length of wetland, grassland, and forest habitat in the flow path that each water quality impairment area (urban or agricultural lands) flows through to reach a stream. High demand for new filtering habitat (natural habitats) in a flow path is based on 1) the amount of source area feeding into the flow path and 2) the amount of other grassland, wetland and forest areas already providing filtration services in the area. An additional layer of information could be provided by assessing these filtration areas in relation to known impaired waters, however state designation of 303(d) impaired waters is not consistent so they were left out of this analysis. Information on 303(d) impaired waters in the GCPO region is provided in the appendix. The highest value parcels for *restoration* are then those in flowpaths downstream from significant source areas, with little other grassland, wetland, or forestland to provide filtration (estimated by final GIS layers 8c-d). Alternatively, high value parcels for *conservation* are represented by those areas downstream from significant source areas, but with relatively good existing natural habitats to provide filtration (estimated by final GIS layers 8a-b). However, it is important to keep in mind that this is a nonlinear relationship (Figure 3), so this only holds in the middle of the range. At very low coverages of filtering habitat (grasslands, wetland, and forests) additional habitat makes little difference in filtration, and the same is true at high coverages of filtration habitat. Water filtration is an intermediate service not explicitly tied to beneficiaries like commercial and recreational fisherman, swimmers, municipal or industrial water users, or pollutant impacted aquatic species of interest. However, we did not have data to go further in these analyses and discuss who would benefit from the filtration to determine where it would be more important to emphasize managing land for this service. While this analysis does not include data on existing water impairments that may drive demand for water quality services, the EPA 303(d) impaired waters for the region are highlighted in the appendix. These data were not included in this analysis because impaired water reporting varies by state.

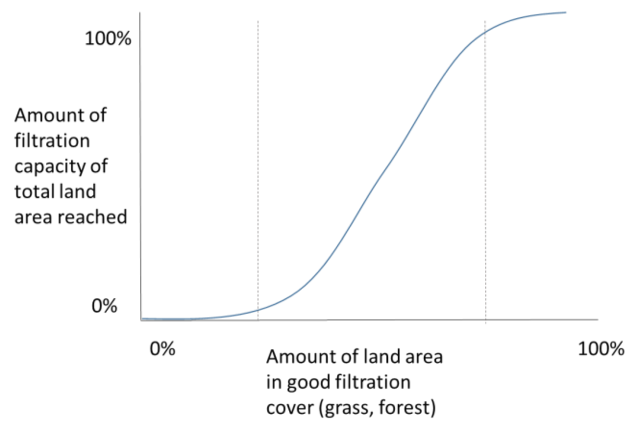


Figure 3. Relationship between natural habitat filtration area and filtration capacity of the land

- We were not able to find data to assess water filtration effects on ground water supplies and users. This kind of analysis would require more advanced hydrological modeling that includes data on how habitats impact groundwater and was not within the scope of this project.
- ***Water storage capacity and its effect on flooding*** (final GIS layers 9a-b) measured as infiltration capacity was roughly estimated by measuring the amount of grassland, forest, and wetland (natural habitat) in the flowpath between impervious surfaces and streams. Areas with high levels of impervious surface and relatively good natural habitat infiltration are important to target for conservation (final GIS layer 9a), while areas with high levels of impervious surface and relatively poor natural habitat infiltration are important to target for habitat restoration (final GIS layer 9b). Ideally we would like to incorporate flood plain data and existing man-made infrastructure at risk to flooding into this analysis to identify the areas where demand for infiltration capacity would be highest, but data at a large enough scale for the GCPO LCC study area was not found. Keep in mind, as for water filtration the relationship between land cover and water storage capacity is likely to be non-linear.
- We were not able to find data to assess **water storage capacity** and its effect on water supply. Though we were able to estimate infiltration, the model used to assess infiltration did not include

detailed information on water storage. To assess water storage a more advanced hydrological model that incorporates information on storage capacity of different habitats and/or soil types would be required.

Table 1. Ecosystem Services included in the assessment and indicators/measures used.

Service	Supply	Demand	Combined measure (BRI)
Food Provision (Crops)	Cropland	Market value of crops	Value per acre under production
Pollination Potential	Pollinator habitat within a threshold distance of pollinator benefitted crops	Pollinator benefitted crops	Areas that support pollinators within range of crops that need pollinators (estimated by pollinator visitation likelihood based on distance from pollinator habitat)
Forest Carbon Sequestration (Climate Stabilization)	Carbon stored in existing forests		
Timber Production	Merchantable timber extracted		
Biodiversity (Richness and At-risk Species)	Species richness, number of at-risk species		
Recreational Birding	Bird species richness, important bird areas, eBird observation locations	IBAs with no/ little public land access	
Recreational Hunting	Waterfowl harvests	Areas far from public hunting lands	
Water Filtration (Proxy for Water Quality Improvement)	Natural habitats available for water filtration	Areas with high levels of non-point source (NPS) pollution	Length of habitat in the hydrological flow path between NPSs and waterways where NPS coverage is high.
Infiltration Capacity (Proxy for Flood Mitigation Potential)	Natural habitats available for water infiltration	Areas of high impervious surface coverage	Length of natural habitats in the flow path between impervious surfaces and waterways where impervious surface coverage is high

Services that were not included due to insufficient data include:

- Production of honey
- Production of pollinators transported to pollinate in other regions
- Viewsheds
- Natural Areas of Interest
- Water filtration effects on ground water supply and users
- Water storage capacity and its effect on water supply

Assessment of EnviroAtlas Data

One objective of this project was to assess the value of the new EPA online EnviroAtlas which is intended to support ecosystem services assessment at national to regional scales (EnviroAtlas 2016). For the Gulf Coastal Plains and Ozarks LCC, it is possible to do some assessment of ecosystem services using the nationally available data, but many services are not well mapped using their data. For the most part, the source data used by the Atlas was more useful for the analysis rather than the data directly from the aggregated layers.

EnviroAtlas data layers were useful in our assessment of existence value for biodiversity and at-risk species, provision of climate stability (carbon storage), and the provision of water quality. The Atlas does not have relevant data on flood protection or recreation such as hunting, fishing, hiking, and birding on private lands. Some Atlas data was used as a final output (the biodiversity layers), while others were used as comparisons or augmentations to other data sources (impaired waters and carbon layers). More detail on how these layers and data attributes were used in the final analysis can be found the appendix.

In addition to overall resolution being limiting, there were specific limitations for a few services. For example, the Atlas layer on pollination ecosystem services identifies crops without nearby pollinator habitat, but restricts pollinator habitat to only wooded areas and did not include grasslands or wetlands where insect pollinators are known to live (see appendix). Additionally, some of the Atlas layers of interest do not cover the entire GCPO LCC study area. The biodiversity richness layers, which were used in the biodiversity analyses, only extend over roughly ½ of the study region. Though these layers are useful, they can only be used for certain analyses due to their limited extent.

Final GIS Layers for Help with Decision-Making

Ecosystem services can provide guidance for policy-makers and land managers when they make decisions about how and where to conserve, restore, or manage natural resources. This analysis of the ecosystem services in the GCPO LCC landscape was meant to help create an adaptable set of map layers for scanning the region and locating areas where the LCC and their partners might target their actions to most effectively reach conservation goals. One of the primary objectives for this project was to create relatively simple geospatial layers depicting the relative provision (and where possible demand) of a wide range of relevant ecosystem services that could be combined and compared in ArcGIS to help answer specific questions about where co-benefits and tradeoffs might occur when prioritizing these different services.

Table 2 provides a list of the final GIS layers created and notes about how different ecosystem service layers can be combined. These layers were selected to avoid double-counting where intermediate services information (or the same data) may go into determining the maps for more than one service. For simplicity, which seems appropriate given the low resolution or certainty for most of the data, each layer must be transformed into a binary format before it is combined with other service layers for analysis. Some layers are already in this binary format, with binary cutoffs chosen most often by quartiles of the data. However, thresholds for creating these binary layers could be re-set if a specific query suggests a more meaningful threshold between high and low provision of a service. Binary cutoffs were provided for those final layers that were created based on the combination of two datasets, so as to show the user how these binary cutoffs might be made based on the data provided. Alternatively, other final layers are provided in a continuous data format and the user must threshold the input map before using it for analysis with the other layers provided here. Each layer's description indicates if and how a threshold is already set and why this threshold was used, or whether the user must apply his/ her own threshold. Choices about layer use may also be influenced by data availability; there are some data layers that do not cover the entire study area and therefore should not be used if a specific query focuses on a location outside of the data coverage. Following the table is a more detailed description of each of these layers and any considerations or critical information on their use. More detail on how these layers were developed – the underlying data used and assumptions and calculations made – can be found in the appendix.

When using these layers to prioritize locations with co-benefits or tradeoffs of ecosystem services, it is both helpful and important to know how landowners in these area value different sets of these services. The MSU landowner survey (described in detail in report by Grala et al 2016) provides data on landowner priorities and concerns regarding different ecosystem services, which have been spatially referenced by landowner zip-code. Some of these spatial layers could be helpful to managers when choosing locations to focus their efforts (Table 3). An example of how this data can be used is provided in Use-Case 3.

Table 2. List of final GIS layers for answering management questions

Service Category	Layer # and Title	Layer combo possibilities	Description
Food Provision (Crops)	1a. Crop value	Select either 1a or 1b	Crop value, measured in dollars/ county
	1b. Area-weighted crop value	Select either 1a or 1b	Crop value, measured in dollars/ acre of cropland/ county
Timber Production	2a. Merchantable timber extractions	Any layers	Timber extractions, measured in cubic feet/ county
Pollinator Potential	3a. Conservation priority pollinator HUC 12s for the analysis including cotton	Select one from 3a-b and/or 3c-d	Areas with high amounts of pollinator crops and high probability of pollinator visitation
	3b. Conservation priority pollinator HUC 12s for the analysis excluding cotton	Select one from 3a-b and/or 3c-d	Areas with high amounts of pollinator crops and high probability of pollinator visitation
	3c. Restoration priority pollinator HUC 12s for the analysis including cotton	Select one from 3a-b and/or 3c-d	Areas with high amounts of pollinator crops and low probability of pollinator visitation
	3d. Restoration priority pollinator HUC 12s for the analysis excluding cotton	Select one from 3a-b and/or 3c-d	Areas with high amounts of pollinator crops and low probability of pollinator visitation
Biodiversity-Richness	4a. Vertebrate species richness	Select non-overlapping layers	Vertebrate species richness, measured in the average number of species per HUC 12 for all vertebrates, mammals, bats, birds, reptiles and amphibians
Biodiversity-Rare and at-risk species	4b.1 At-risk species richness	Select one from 4b.1-2	At-risk species richness, measured in the number of observed species per HUC 12
	4b.2 Critical habitat areas	Select one from 4b.1-2	Critical habitat areas, as designated by the USFWS
Recreational Hunting	5a. Waterfowl harvests	Any layers	Duck and goose harvest numbers per county
Recreational Birding	6a. Important Bird Areas	Any layers	Areas important for endangered, rare, or vulnerable bird species
	6b. High birding areas	Any layers	Areas frequented by birders, measured by the number of eBird observations per HUC 12
Forest Carbon Sequestration (Climate Regulation)	7a. Conservation priority carbon storage areas	Any layers	Areas with high amounts of forest carbon and high area of existing forests
	7b. Restoration priority carbon storage areas	Any layers	Areas with high amounts of forest carbon and low area of existing forests
	7c. Potential additional carbon storage on private lands	Any layers	Potential additional tonnes of carbon that could be stored on private lands in each county with proper forest management
Water Filtration	8a. Conservation priority water quality HUC 12s for the analysis of all natural habitat filters	Select one from 8a-b and/or 8c-d	Areas with high NPS coverage and relatively good existing natural habitat filters
	8b. Conservation priority water quality HUC 12s for the analysis of riparian buffers	Select one from 8a-b and/or 8c-d	Areas with high NPS coverage and relatively good existing riparian buffers
	8c. Restoration priority water quality HUC 12s for the analysis of all natural habitat filters	Select one from 8a-b and/or 8c-d	Areas with high NPS coverage and relatively poor existing natural habitat filters

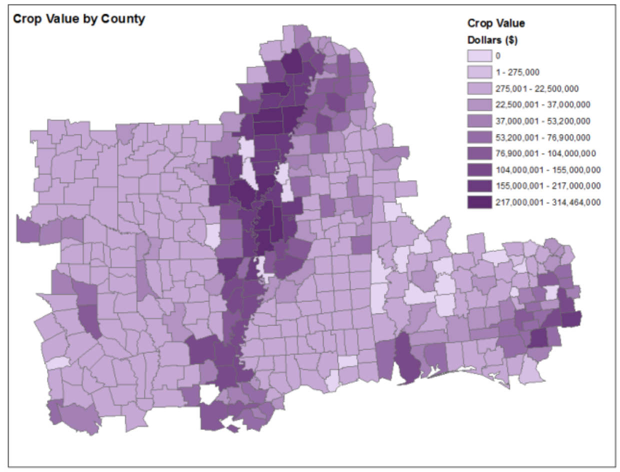
	8d. Restoration priority water quality HUC 12s for the analysis of riparian buffers	Select one from 8a-b and/or 8c-d	Areas with high NPS coverage and relatively poor existing riparian buffers
Infiltration Capacity	9a. Conservation priority infiltration capacity HUC 12s	Select one from 9a-b	areas with high impervious surface coverage and relatively good existing infiltration capacity
	9b. Restoration priority infiltration capacity HUC 12s	Select one from 9a-b	areas with high impervious surface coverage and relatively poor existing infiltration capacity

Table 3. Survey data layers that provide information on landowner priorities and concerns for a range of ecosystem services may be useful for different management scenarios where landowner priorities are being considered or targeted:

Survey Question	Zip-code spatial layers ranking importance of:		
Question 4: How important to you are the following reasons for owning your land?	Clean water	Legacy for heirs	Carbon sequestration
	Endangered species	Personal recreation	Non-Traditional Forest Products
	Family tradition	Healthy soils	Traditional forest products
	Fee-based recreation	Land appearance	Wildlife habitat
	Zip-code spatial layers ranking concern about:		
Question 5: Which services/ issues are you most concerned about?	Drinking water quality	Soil erosion	Loss of forests
	Drinking water quantity	Overgrazing	Loss of farmland
	Wildfire	Insect or animal pests	Loss of wildlife habitat
	Chemical drift	Invasive species	Loss of pollinators

1. Food Provision (Crops): (choose one from 1a-b)

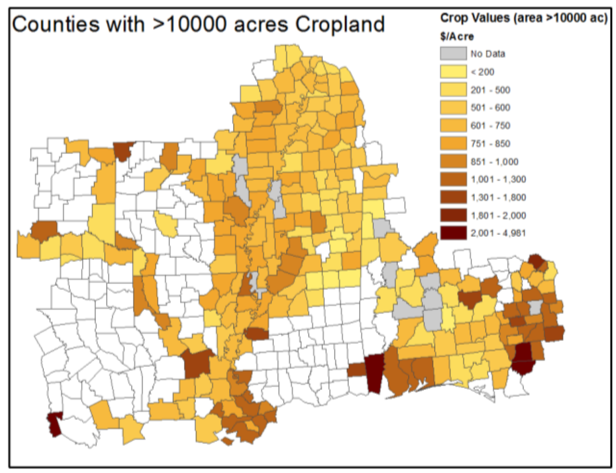
1a. Crop Value: Crop value, measured in dollars per county. Those counties with more agriculture have more overall value. A threshold will have to be applied to this layer based on the specifications of each query to provide a map with binary high and low areas.



Final Layer 1a. Crop value by county.

1b. Area Weighted Crop Value: Crop value, measured in dollars per acre of cropland per county. By measuring crop value per acre we can see that while there is more agriculture in Mississippi Alluvial Valley counties, the value per acre of agriculture shows a more distributed pattern. A threshold will have to be applied to this layer based on the specifications of each query to provide a map with binary high and low areas.

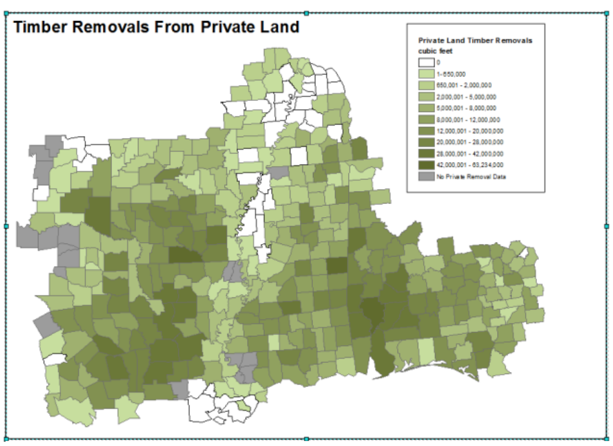
Note: Counties with <10,000 acres of cropland are filtered out of the map shown here. This was done to reduce bias (see appendix for details).



Final Layer 1b. Crop values, measured in dollars/ acre by county. Only counties with >= 10,000 acres of cropland are shown here.

2. Timber Production:

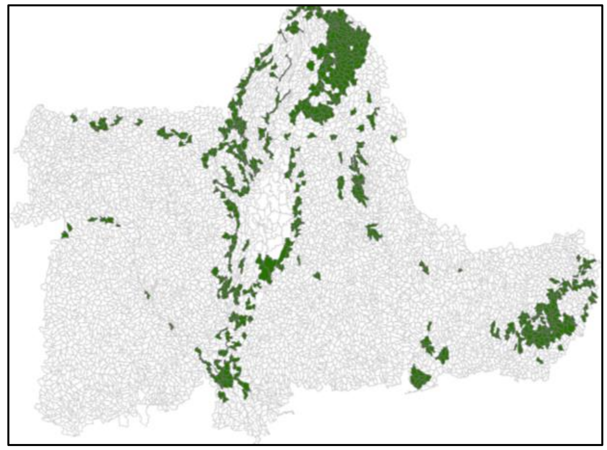
2a. Merchantable timber removals from private lands, measured in cubic feet per county. This shows which counties have more merchantable timber extractions. Merchantable timber value per acre of forest shows a very similar pattern but may introduce a bit more error so we suggest this data layer be used in the final analysis (see appendix). A threshold will have to be applied to this layer based on the specifications of each query to provide a map with binary high and low areas.



Final Layer 2a. Merchantable timber removals from private land, measured in cubic feet, per county.

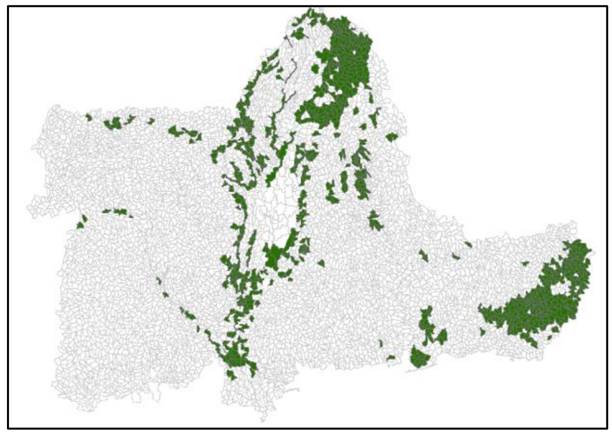
3. Pollinator Potential: (choose one from 3a-b and/ or one from 3c-d)

3a. Conservation priority HUC 12s for pollinators: this analysis *excludes* cotton. (see appendix for explanation of cotton) The HUC 12s highlighted on this map layer have ≥10% coverage by pollinator benefitted crops and ≥90% mean probability of pollinator visitation. In other words, these are HUCs with a large area of pollinator benefitted crops and a relatively large probability of pollinator visitation, based on the presence of pollinator habitat.



Final Layer 3a. HUC 12s targeted for conservation of pollinator habitat near pollinator benefitted crops, excluding cotton.

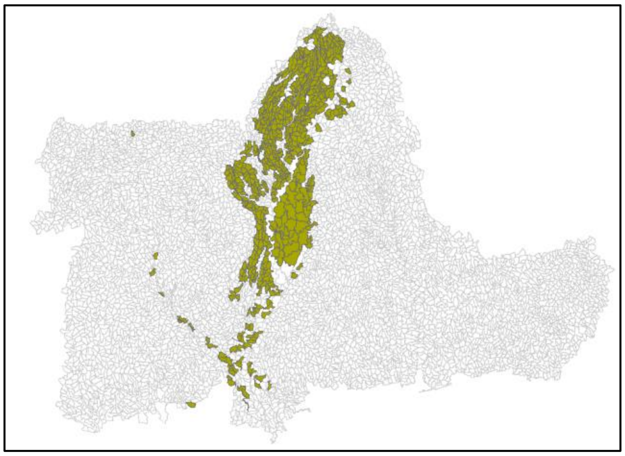
3b. Conservation priority HUC 12s for pollinators: this analysis *includes* cotton. The HUC 12s highlighted on this map layer have ≥10% coverage by pollinator benefitted crops and ≥90% mean probability of pollinator visitation. In other words, these are HUCs with a large area of pollinator benefitted crops and a relatively large probability of pollinator visitation, based on the presence of pollinator habitat.



Final Layer 3b. HUC 12s targeted for conservation of pollinator habitat near pollinator benefitted crops, including cotton.

Final Layer 3c. HUC 12s targeted for restoration of pollinator habitat near pollinator benefitted crops, excluding cotton.

3c. Restoration priority HUC 12s for pollinators: this analysis *excludes* cotton. The HUC 12s highlighted on this map layer have ≥10% coverage by pollinator benefitted crops and <90% mean probability of pollinator visitation. In other words, these are HUCs with a large area of pollinator benefitted crops and a relatively small probability of pollinator visitation, based on the presence of pollinator habitat.

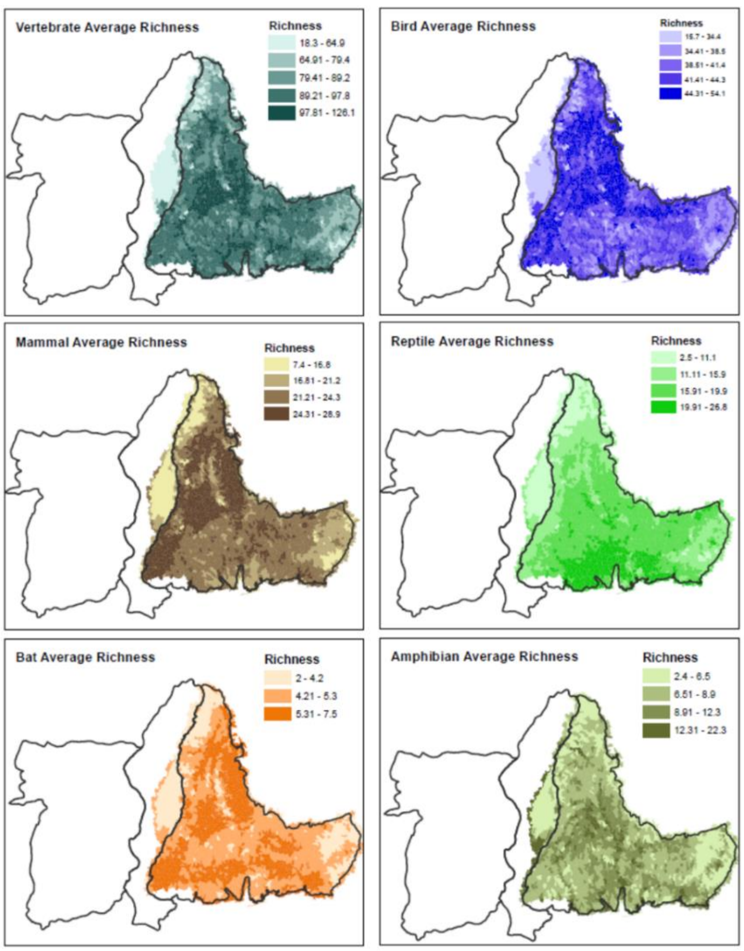


Final Layer 3d. HUC 12s targeted for restoration of pollinator habitat near pollinator benefitted crops, including cotton.

3d. Restoration priority HUC 12s for pollinators: this analysis *including* cotton. The HUC 12s highlighted on this map layer have ≥10% coverage by pollinator benefitted crops and <90% mean probability of pollinator visitation. In other words, these are HUCs with a large area of pollinator benefitted crops and a relatively small probability of pollinator visitation, based on the presence of pollinator habitat.

Thresholds and maps set here can be revised by analysts using the initial data map layers provided by this project. See appendix for more detail on the thresholds used here.

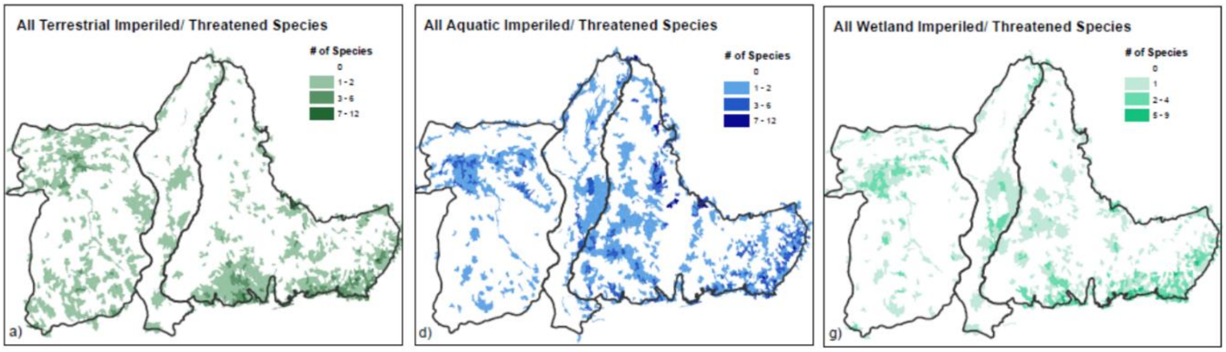
4. Biodiversity-Richness: (choose non-overlapping layers)
4a. All vertebrate, mammal, bat, bird, reptile, and amphibian species richness measured in average number of species per HUC 12. Values are based from GAP species distribution model estimates. Available model data only covers ~1/2 of the GCPO study area. The average represents the average number of overlapping distribution models for each pixel in a particular HUC. A threshold will have to be applied to these layers based on the specifications of each query to provide a map with binary high and low areas. To avoid double counting species only select non-overlapping layers. Vertebrate richness cannot be used in combination with any other biodiversity richness layers. Amphibian or reptile richness can be used with other richness layers. Mammal and bat richness can be used with other richness layers but not with each other.



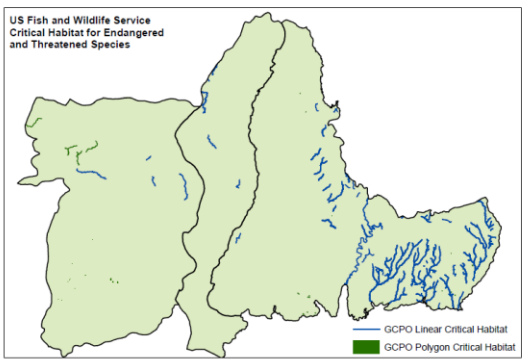
Final Layer 4a. Average vertebrate, mammal, bat, bird, reptile, and amphibian taxa richness, based on richnesses estimated by species distribution models.

4b. Biodiversity-Rare and at-risk species: (Choose one from 4b.1-2)

4b.1 (can use all three of the 4b.1 maps if desired but cannot use with 4b.2) Number of at-risk species, measured in number of observed at-risk species per HUC 12. The number represents observed occurrences, based on natural heritage datasets. A threshold will have to be applied to these layers based on the specifications of each query to provide a map with binary high and low areas. The threshold can be set at presence (≥1) versus absence (0).



Final Layer 4b.1. At-risk species richness, as determined by Nature Serve recorded element occurrences.

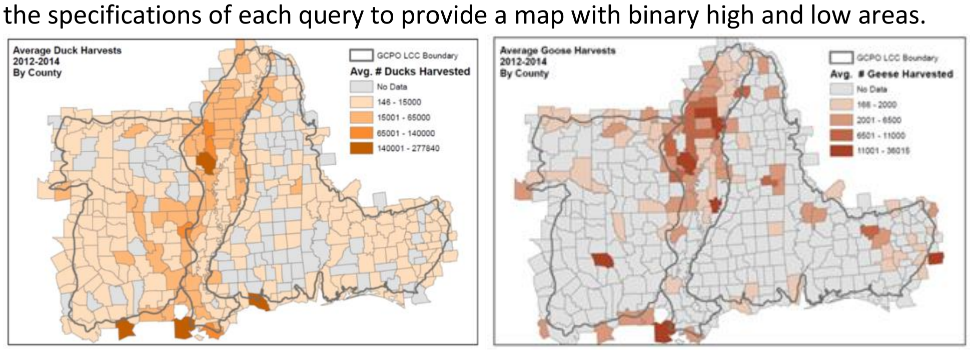


Final Layer 4b.2. Critical habitats for threatened and endangered species in the GCPO region.

4b.2 Critical habitats in the GCPO region, as designated by the US Fish and Wildlife Service for threatened and endangered species.

5. Hunting

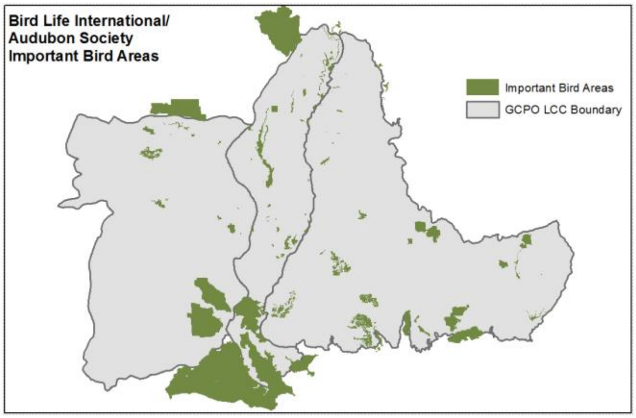
5a. Waterfowl harvests per county (layers can be used together, and with any other layer). These layers show average harvests for ducks and geese from 2012-2014. These data were collected by the USFWS using hunter surveys, and estimates of total waterfowl harvests have been extrapolated from the surveys. Gray areas represent counties where no data was collected. A threshold will have to be applied to this layer based on the specifications of each query to provide a map with binary high and low areas.



Final Layer 5a. Average number of ducks and geese harvested in each county in the GCPO region. Harvest numbers were determined through hunter surveys.

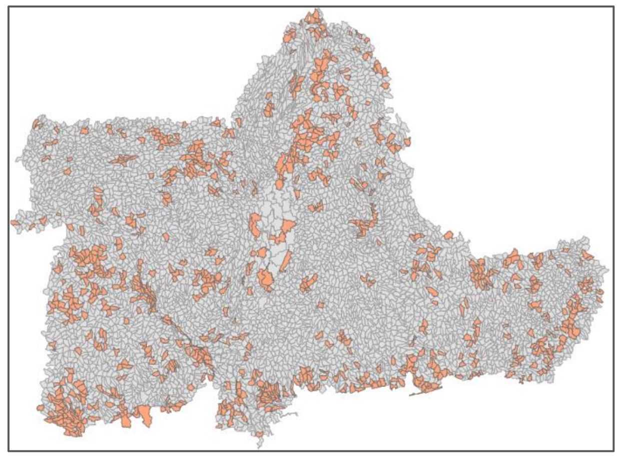
6. Recreational Birding:

6a. Important Bird Areas, as designated by Bird Life International. Important Bird Areas contain important habitats for species of conservation concern, vulnerable species, and/or rare species of birds. These species groups are often sought out by birders.



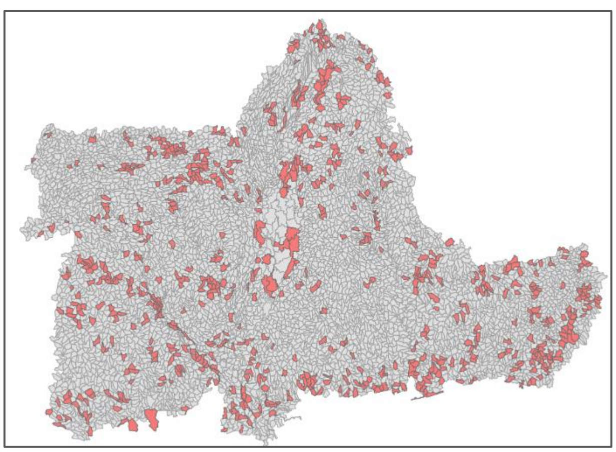
Final Layer 6a. Important bird Areas as designated by Bird Life International.

6b.1 (choose one from 6b.1 and 6b.2) eBird priority birding areas. These are the HUC 12s with the highest number of birding observations, using the entire downloaded eBird dataset from Jan 2015- Jan 2016. The top 25% of non-zero HUCs were included in the map; the threshold was 165 observations/ HUC.



Final Layer 6b.1 HUC 12s highlighted as the areas most used by birders who use eBird.

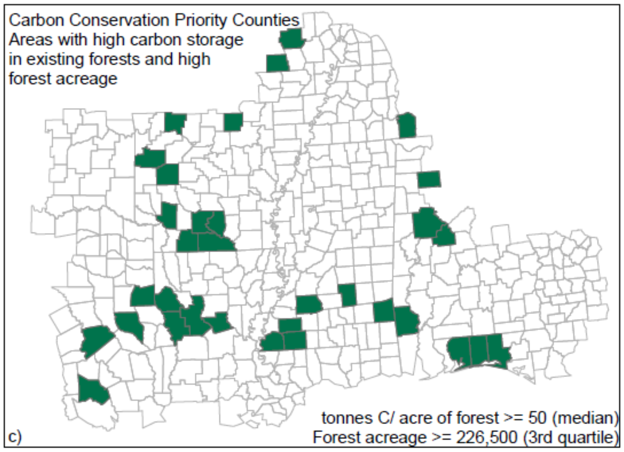
6b.2 (choose one from 6b.1 and 6b.2) eBird priority birding areas. These are the HUC 12s with the highest number of birding observations, using only eBird observations outside of highly developed areas from Jan 2015- Jan 2016 (see appendix for details on how eBird observations were filtered). The top 25% of non-zero HUCs were included in the map; the threshold was 102 observations/ HUC.



Final Layer 6b.2 HUC 12s highlighted as the areas most used by birders who use eBird outside of highly developed areas.

Thresholds and maps set here can be revised by analysts using the initial data map layers provided by this project. See appendix for more detail on the thresholds used here.

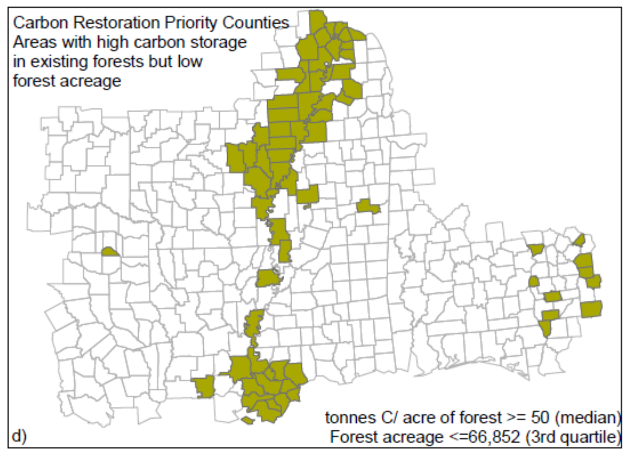
7. Forest Carbon Sequestration (to support climate regulation) (These maps can be combined in a single query with the correct logic)



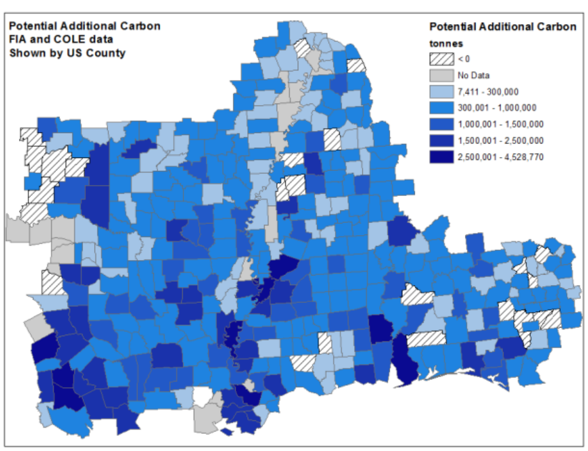
Final Layer 7a. Counties targeted for conservation of existing high carbon forests.

7a. Forest carbon conservation prioritiy areas. These counties have ≥50 tonnes carbon/ acre of forest (the median of the data) and ≥ 226,500 acres of forest (the 3rd quartile of the data). In other words, these counties have relatively high carbon forests, and relatively high forest acreages. These high carbon existing forests could be targeted for conservation of existing forest carbon.

7b. Forest carbon restoration priority areas. These counties have ≥50 tonnes carbon/ acre of forest (the median of the data) and ≤ 66,852 acres of forest (the 1st quartile of the data). In other words, these counties have relatively high carbon forests but relatively low forest acreages. These high carbon but low area forests could be targeted for expansion and restoration.



Final Layer 7b. Counties targeted for restoration of potential high carbon forests.

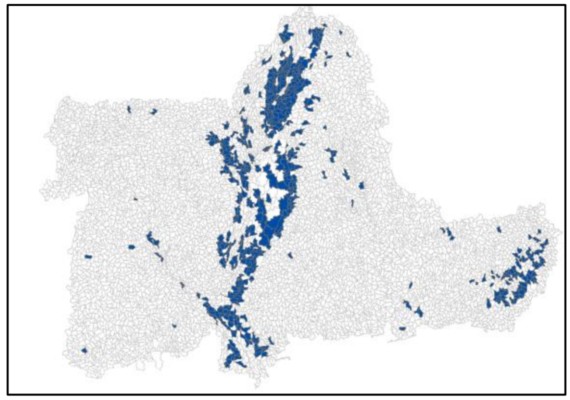


Final Layer 7c. Potential additional carbon, measured in tonnes, that could be stored on private lands in each county.

7c. Potential additional carbon that could be stored on private lands. This was calculated using the difference in carbon storage between fully stocked and poorly stocked forests and the area of private lands currently in a poorly stocked state (see appendix for details about potential carbon calculations). Those counties with high additional carbon values could be targeted for management to bring poorly stocked stands to a fully stocked state. A threshold will have to be applied to this layer based on the specifications of each query to provide a map with binary high and low areas. (A similar analysis to this was one performed to calculate potential changes in carbon storage if forest stocking levels were reduced from an overstocked level, see appendix for details).

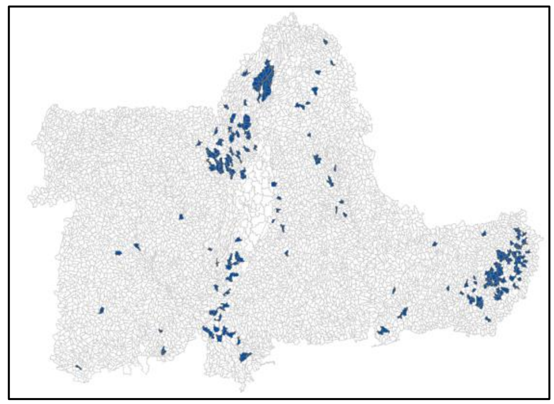
8. Water Filtration (Proxy for Water Quality Improvement)

8a. Conservation priority water quality HUC 12s for overall natural habitat filtration capacity. These are the HUCs with the top 25% highest coverage of non point source (NPS – agriculture and urban) cells and the top 25% mean length traveled by each NPS cell through natural habitat cells. In other words, these are the HUCs with high NPS coverage but with relatively good existing filtration capacity. The map layer indicates that it is important to conserve filtration capacity in these highlighted areas.

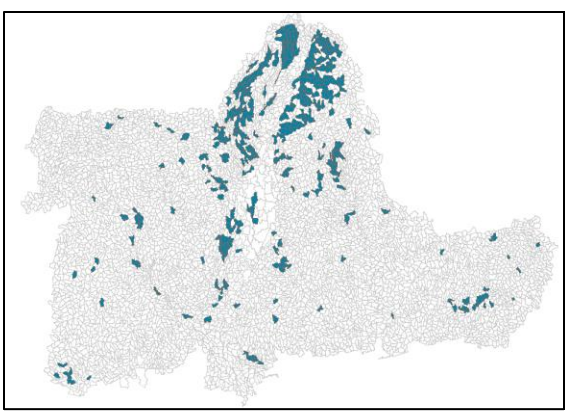


Final Layer 8a. HUC 12s targeted for conservation of forests, wetlands, and grasslands (natural habitat) that act in a water filtration capacity.

8b. Conservation priority water quality HUC 12s for natural habitat riparian buffer filtration capacity. These are the HUCs with the top 25% highest coverage of NPS cells and the top 25% mean length traveled by each NPS cell through riparian buffer cells. In other words, these are the HUCs with high NPS coverage but with relatively good existing riparian filtration capacity. The map layer indicates that it is important to conserve filtration capacity in these highlighted areas.

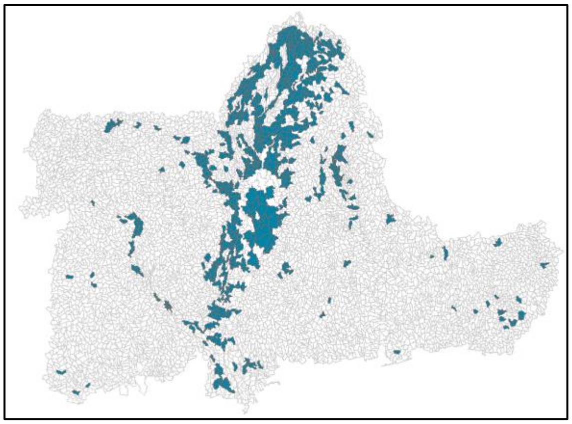


Final Layer 8b. HUC 12s targeted for conservation of forests, wetlands, and grasslands (natural habitat) in the riparian buffer.



Final Layer 8c. HUC 12s targeted for restoration of forests, wetlands, and grasslands (natural habitat) that could act in a water filtration capacity.

8c. Restoration priority water quality HUC 12s for overall natural habitat filteration capacity. These are the HUCs with the top 25% highest coverage of NPS cells and the bottom 25% mean length traveled by each NPS cell through filter cells. In other words, these are the HUCs with high NPS coverage and with relatively poor existing filtration capacity. The map layer indicates that it is important to create filtration capacity in these highlighted areas.



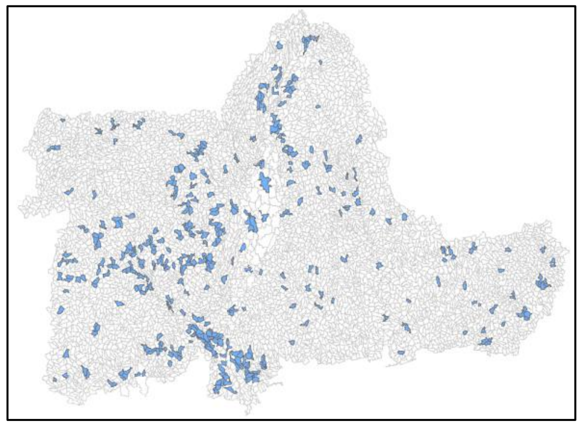
Final Layer 8d. HUC 12s targeted for restoration of forests, wetlands and grasslands in the riparian buffer.

8d. Restoration priority water quality HUC 12s for riparian buffers filtration capacity. These are the HUCs with the top 25% highest coverage of NPS cells and the bottom 25% mean length traveled by each NPS cell through riparian buffer cells. In other words, these are the HUCs with high NPS coverage and with relatively poor existing riparian filtration capacity. The map layer indicates that it is important to create filtration capacity in these highlighted areas.

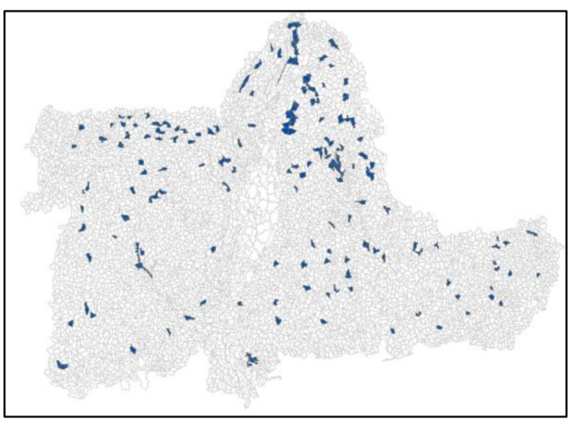
Thresholds and maps set here can be revised by analysts using the initial data map layers provided by this project. See appendix for more detail on threshold choices.

9. Infiltration Capacity (Proxy for Flood Mitigation Potential):

9a. Conservation priority infiltration capacity HUC 12s. These are the HUCs with the top 25% of impervious surface coverage but also with the top 25% mean length traveled by each impervious surface cell through natural habitat absorption cells. In other words, these are the HUCs with high impervious surface coverage but with relatively good existing infiltration capacity. The map layer indicates that it is important to conserve infiltration capacity in these highlighted areas.



Final Layer 9a. HUC 12s targeted for conservation of existing forests, wetlands and grasslands (natural habitat) that act in an infiltration capacity for excess water storage.



Final Layer 9b. HUC 12s targeted for restoration of forests, wetlands, and grasslands that could potentially act in an infiltration capacity to store excess water.

9b. Restoration priority infiltration capacity HUC 12s. These are the HUCs with the top 25% of impervious surface coverage and the bottom 25% mean length traveled by each impervious surface cell through natural habitat absorption cells. In other words, these are the HUCs with high impervious surface coverage and relatively poor existing infiltration capacity. The map layer indicates that it is important to create infiltration capacity in these highlighted areas if flooding is a problem. If data becomes easily available, it would be helpful to combine this layer with flood zone and property data.

Thresholds and maps set here can be revised by analysts using the initial data map layers provided by this project. See appendix for more details on these thresholds.

Example Use-Cases

These example uses of the final GCPO LCC ecosystem service layers are meant to show how the data outputs created for this project can be combined to help with conservation, management, and restoration decisions. However, it should be noted that the locations highlighted as areas with the greatest number of co-benefits should be examined at a finer scale before any actions are taken. The data included in this report are at a relatively coarse scale and are meant to help scan the larger GCPO LCC region for localized areas of importance for further examination and more detailed analysis that should be done in preparation for future interventions.

Example Use-Case #1: Finding areas to conserve for the preservation of water quality filtration where it is needed (areas of high NPS coverage) that also provide associated co-benefits

This first hypothetical case assumes that the LCC wants to find and conserve areas with relatively good existing riparian buffers in the southeastern corner of the LCC region because water quality has been found to be declining in the region. Secondarily, the LCC would like to prioritize riparian buffers that can also contribute most to infiltration capacity and biodiversity conservation. It is assumed that conservation of natural habitats in the riparian zone could potentially benefit these other ecosystem services that are of secondary importance. Using these secondary final ecosystem service layers, it is possible to show that areas of riparian preservation could then be prioritized by choosing locations either with the greatest number of co-benefits, or a specific co-benefit that might be of particular interest.

Final layers used:

- 8b. Conservation priority water quality HUC 12s for riparian buffer filtration capacity
- 9a. Conservation priority infiltration capacity HUC 12s
- 3a. Conservation priority pollinator HUC 12s for the analysis including cotton

Data preparation:

- 8b was used as a mask.
- 9a was used as is, and any overlap with 8b was included in the analysis.
- 3a was used as is, and any overlap with 8b was included in the analysis.

Layer 8b was used as the basis for this analysis because conservation of existing riparian buffer capacity where it is needed (high NPS areas) is the primary goal. The co-benefit layers 9a and 3a were overlaid on 8b to see where overlap exists. The output created can be seen in figure 4. Different colors represent different combinations of ecosystem services that have been prioritized in individual HUC 12s. The most common overlap in this case is riparian buffer conservation and pollinator habitat conservation, and the light blue highlighted HUCs in figure 4 indicate where both of these ecosystem services are prioritized.

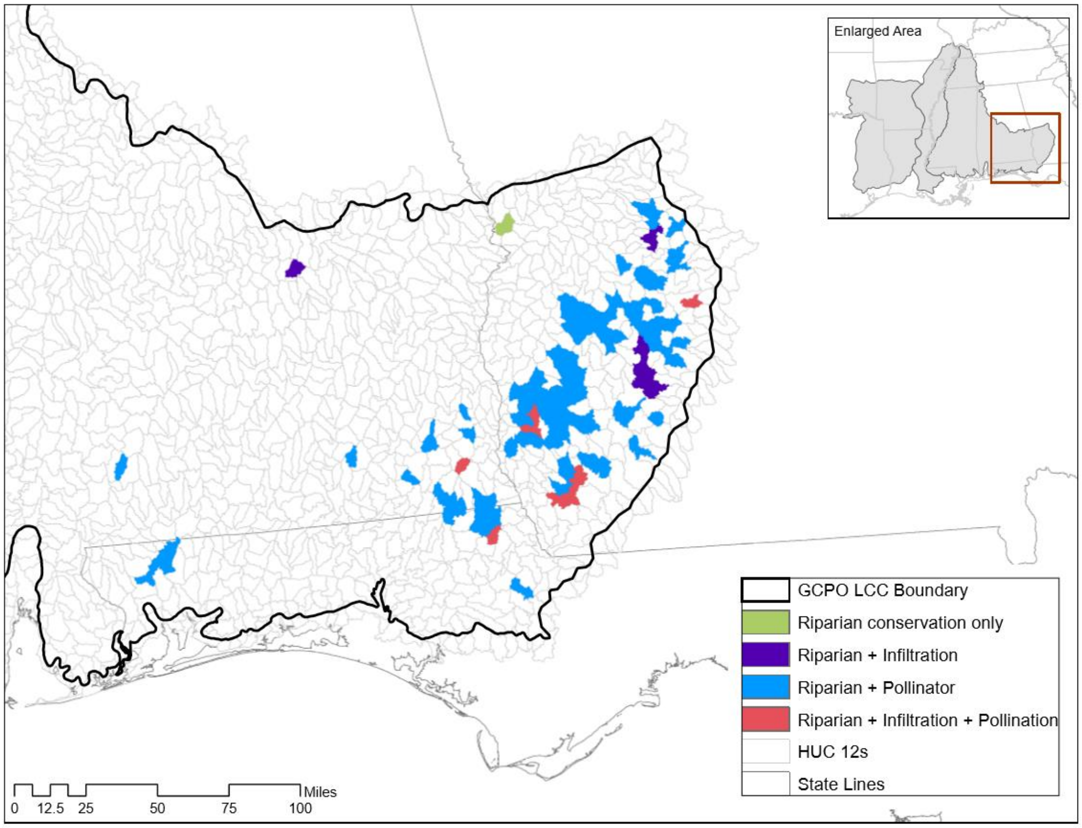


Figure 4. HUC 12s falling in the southeast corner of the GCPO LCC where riparian buffer water quality filtration capacity exists and is in need due to high NPS coverage. Each color represents a different combination of these water quality filtration services with the other co-benefits that are likely to be provided by these HUCs if preservation of riparian buffer habitat occurs.

Example Use-Case #2: Finding agricultural areas that can be restored to natural habitat with the least opportunity costs (due to lost crop value) and the most associated co-benefits.

This second hypothetical use-case assumes that the LCC wants to locate and restore agricultural lands to natural habitats while avoiding large opportunity costs in the East Gulf Coastal Plain. When locating restoration targets, the LCC would like to prioritize endemic species, specifically amphibians, as well as potential carbon storage in these newly restored areas. It is assumed that habitats restored on existing agricultural lands could benefit the secondary ecosystem services listed here. Using these additional ecosystem service layers, it is possible to show which agricultural areas could be prioritized for restoration by choosing locations either with the greatest number of co-benefits or a specific co-benefit that might be of particular interest.

Final Layers Used:

- 1b. Area-weighted crop value
- 4a. Amphibian species richness
- 8c. Restoration priority water quality areas
- 7b. Restoration priority carbon

Data Preparation:

- Layer 1b was altered slightly before being used as a mask. First, only counties with ≥10,000 acres of cropland were used. Second, the remaining counties were thresholded at a $/acre value ≤514 (the 1st quartile of the area-weighted crop value data). This mask then displays those counties with adequate coverage of cropland, but relatively low values associated with those croplands. Therefore, restoration of these agricultural lands comes at a relatively low opportunity cost.
- Layer 4a was thresholded at a species richness ≥ 9.4 (the 3rd quartile of the average amphibian richness data). Any overlap between those thresholded HUCs and the 1b mask was used in this analysis.
- Layer 8c was used as is, and any overlap with the 1b mask was used in this analysis
- Layer 7b was used as is, and any overlap between those counties and the 1b mask was used in this analysis.

Layer 1b was used as the mask because restoration of low-value agricultural lands is the primary goal in this case. The co-benefit layers were chosen based on other hypothetical priorities that the LCC might have. These co-benefit layers were overlaid on the mask created from layer 1b, and areas of overlap could then be examined (Figure 5). Unlike the last example, the input layers for this case were not all on the HUC 12 scale, so the output is not in the HUC 12 scale but rather a combination of HUC 12s and counties. The most common overlap in this case is agricultural restoration and high amphibian richness.

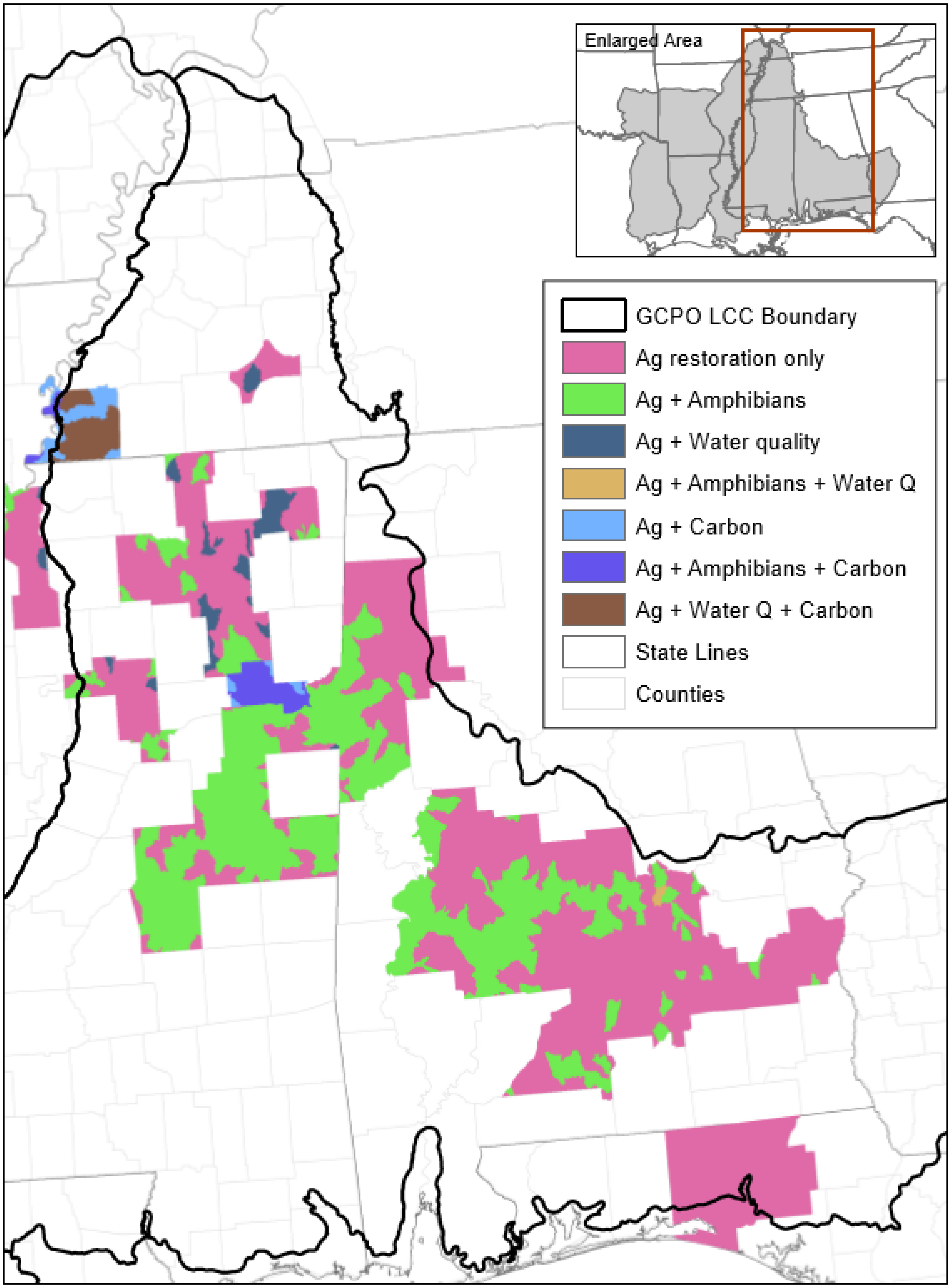


Figure 5. Agricultural areas falling in the East Gulf Coastal Plain that can be restored to natural habitat with the least opportunity costs and the most associated co-benefits. Each color represents a different combination of prioritized ecosystem services.

Example Use-Case #3: Using survey results to choose a geographic area and primary ecosystem service and then refine targeting using additional co-benefits

This use-case assumes that the LCC aims to use the results of the survey data to choose ecosystem services to conserve or restore based upon what people value regionally. This example focused on survey respondents who reported either a high or essential prioritization of carbon sequestration on their land. The assumption then follows that after locating geographic areas where survey respondents selected carbon sequestration as a high priority the LCC could then choose specific locations within those areas to direct resources based on the greatest number of co-benefits that would arise from restoring or conserving carbon sequestration. Additionally, landowners might be more likely to comply with conservation or management activities if they were aware of the multiple benefits they could be getting from their land, in addition to the carbon sequestration that they already value.

Final Layers Used for Conservation Output:

- Survey layer – question 4 - to select priority counties that prioritize carbon storage
- 7a. Conservation priority counties for forest carbon storage
- 4a. Vertebrate species average richness
- 9a. Conservation priority infiltration capacity

Final Layers Used for Restoration Output:

- Survey layer – question 4 - to select priority counties that prioritize carbon storage
- 7b. Restoration priority counties for forest carbon storage
- 3d. Restoration priority pollinator HUC 12s
- 9b. Restoration priority infiltration capacity

Data Preparation:

- The survey results for question 4 were examined to choose a focal area for this analysis. Zip-codes where responses for the importance of carbon sequestration were ranked as "high priority" or "essential" were examined. These zip codes are shown in light green on the inset map in Figure 6. A concentrated area of these zip codes was chosen in the southern portion of the GCPO (shown in dark green on the inset map in Figure 6), and the boundaries of these zip codes became the extent of this use-case.
- Forest carbon layers 7a and 7b were used as masks within the use-case boundary extent.
- Vertebrate species richness Layer 4a was thresholded at 95.3 species, based on the 3rd quartile of the data. Any overlap between those thresholded HUCs and the 7a mask was used in this analysis.
- Priority areas for pollinator habitat restoration layer 3d were used as is. Any overlap between those HUCs and 7b mask was used in this.
- Priority areas for conserving or restoring infiltration capacity layers 9a and 9b were used as they are. Any overlaps between those HUCs and the 7a/ 7b mask were used in their respective analysis.

When aiming to restore or conserve carbon sequestration based on survey respondents' preferences it may be beneficial to make landowners aware of the co-benefits they could receive when doing so. Not only might it make them more interested in managing their land for carbon sequestration, but they could do it in a more informed way if they were mindful of the other ecosystem services they might be conserving or restoring as a result. Additionally, this analysis could help managers choose whether they would want to focus on carbon storage conservation or carbon storage restoration in this area where landowners have ranked carbon sequestration as a high priority. This case uses a relatively simple example to prioritize ecosystem service conservation and/or restoration based on only one survey question, but responses to multiple questions could be combined to choose the most relevant co-benefits to examine for a specific area.

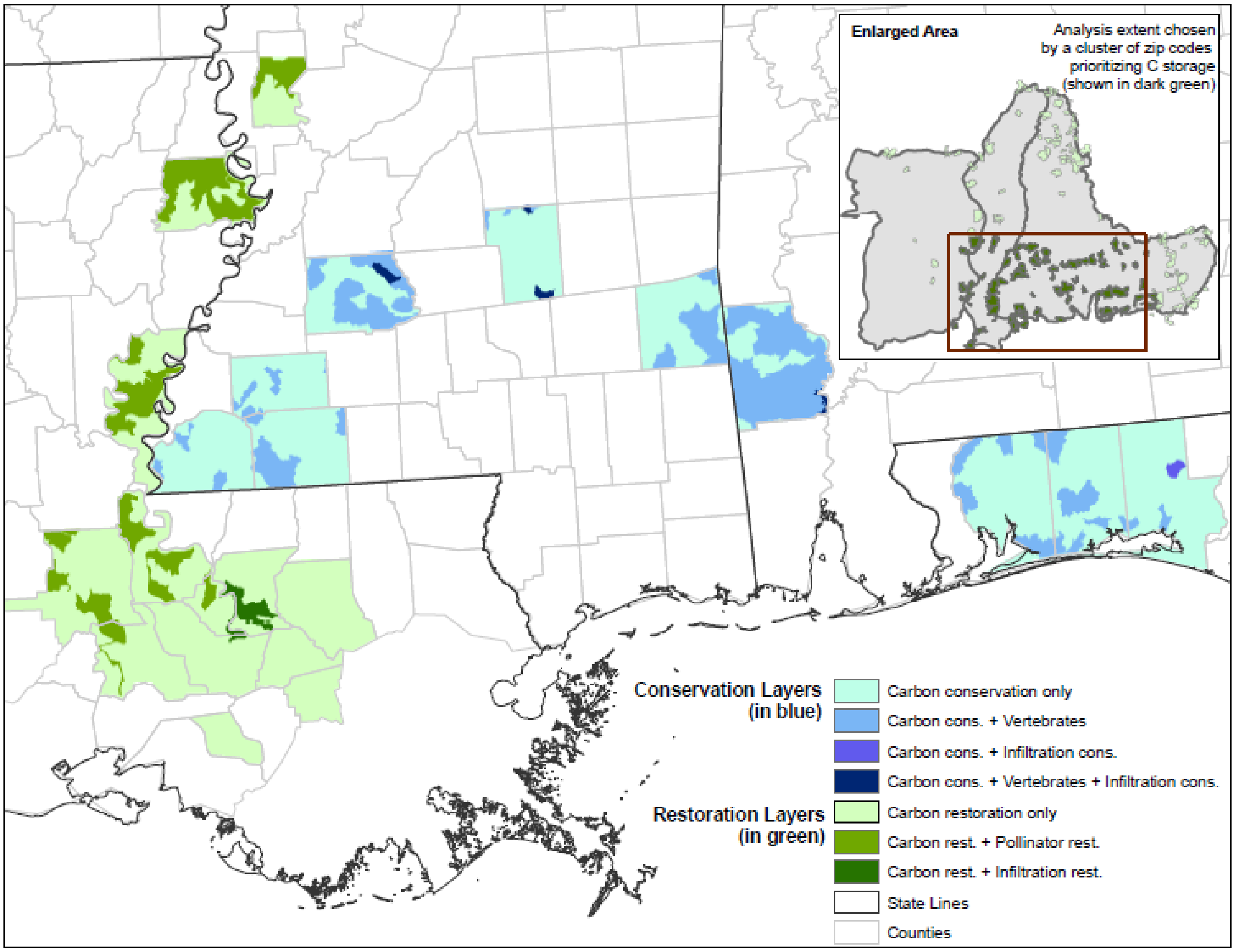


Figure 6. Areas falling in the southern portion of the GCPO LCC where carbon sequestration has been prioritized. The region was chosen for analysis based on survey responses in zip codes of this area ranking carbon sequestration as a high priority or as essential (see inset map). Each color represents a unique combination of ecosystem service co-benefits that would likely arise when conserving or restoring carbon sequestration to this region.

Conclusion

This project offers a coarse-scale summary of ecosystem services in the GCPO LCC region. It outlines the important services in the GCPO landscape but also provides a tool for managers to do a quantitative high-level scan to examine how the provision of these services changes throughout the region. The GIS layers created here deliver an adaptable tool that can answer various types of management questions (such as questions that were addressed in use cases 1-3). Additionally, by using only publicly available data and by providing detailed descriptions of data sources and analyses (see appendix), we hope that this methodology can be transferred to other locations around the country where managers are working at the landscape scale. The analyses performed to create these layers were basic enough that these methods could be repeated relatively easily, and so that highly advanced GIS technical skills would not necessarily be required to do so.

Knowing where services are provided is important, but combining service provision information with landowner values and perceptions of these services (as determined by the landowner survey detailed in the Grala et al 2016 report) gives the GCPO LCC an extremely valuable lens through which they can examine the landscape. Every conservation management organization has limited resources, and additional information that can help discern where conservation and restoration activities might be more effective due to support of the local community is especially important.

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Appendix: GIS Analyses Used to Generate Ecosystem Services Maps

Introduction

This appendix contains detailed notes, methods, data-sources, and interpretations of the results provided in this report. It is broken down based on the analyses done for each ecosystem service type. There are intermediate maps provided in this appendix that are not included in the final layers, due in some cases to the fact that these intermediate maps are provided solely for reference or additional background information, but in other cases due to uncertainty about the data.

Note: These analyses were performed in the summer of 2016, and products reflect data availability as of that time. Data sources used for this project are updated periodically, and those aiming to repeat these analyses should check for updates so that the most up-to-date data can be used for future examinations of ecosystem services.

Food Provision (Crops)

The goal of this analysis is to map food provision within three subgeographies for the Gulf Coast Plains and Ozarks LCC (East Gulf Coastal Plain, West Gulf Coastal Plain, and Mississippi Alluvial Valley). We approximate supply of this ecosystem service using the location of cropland within the region. Using total crop sales data for each county in the region, a dollar per acre of cropland value was also calculated for each county (similar to the methods of Grêt-Regamey et al 2014).

Data Sources

Cropland Data Layer

Cropland in the United States is tracked and documented by the USDA. They produce a GIS product titled the Cropland Data Layer (CDL) which is available for download from their website. The national CDL has been produced annually since 2008, and this analysis used the 2012 CDL. The 2012 CDL was chosen because it is comparable to 2012 crop sales data from the National Agricultural Statistics Service from the 2012 US Census of Agriculture.

CDL Data Properties

The CDL is downloadable as an IMG file at a 30m resolution. Each crop is assigned a unique raster value. The CDL contains pixel values for the entire land area of the United States, so where cropland does not exist the landcover is represented as the class it would appear in the NLCD (developed, forested, open water etc.)

Initial Data Processing. The CDL was clipped to the GCPO LCC study region. In this clipped region, 77 land classification values exist, with 63 of those values representing a type of crop. A "crops only" layer was created to represent only those pixels that identify cropland (Figure 3a). This layer was created using the 'reclassify' tool. The landclasses coded as "not crops" (i.e. they were left out of this layer) include: background, barren, deciduous, developed, evergreen, fallow/idle, grassland/ pasture, herbaceous wetland, mixed forest, open water, shrubland, sod/grass seed, switchgrass, woody wetlands. This crop layer was then used as an input in the 'tabulate area' tool to determine the area of cropland in each county of the GCPO LCC region of interest (Figure 3b).

Additionally, using the attribute table of the clipped CDL layer, the top 20 crops of the region (by area) were identified (Figure 4). While the top 7 crops represent ~90% of the total cropland area, the top 20 crops are shown for more detail. These top 20 crops represent 99.7% of the total cropland area (Table 1).

National Agricultural Statistics Service

Total crop sales data was downloaded in CSV format from the National Agricultural Statistics Service (NASS) quick stats online platform. The query used to obtain this data was:

Program: Census
Sector: Crops
Group: Crop totals
Commodity: Crop totals
Category: Sales
Data Item: Crop totals- Sales measured in $
Geographic level: County
State: AL, AR, FL, GA, IL, KY, LA, MO, MS, OK, TN, and TX
Year: 2012

The definition of what total crop sale value represents should be noted, and it is described in this excerpt from Appendix B of the 2012 Agricultural Census:

> This category represents the gross market value before taxes and production expenses of all agricultural products sold or removed from the county in 2012 regardless of who received the

> payment […] The value of crops sold in 2012 does not necessarily represent the sales from crops harvested in 2012. Data may include sales from crops produced in earlier years [...] The value of agricultural products sold was requested of all operators. If the operators failed to report this information, estimates were made based on the amount of crops harvested […] Caution should be used when comparing sales in the 2012 census with sales reported in earlier censuses. Sales figures are expressed in current dollars and have not been adjusted for inflation or deflation.
>
> (USDA Census of Agriculture, 2012)

Initial Data Processing. A GIS layer of all the counties that are contained or partially contained within the GCPO LCC study area was created. County crop value data in CSV or XLS format can be joined to the GCPO LCC county layer attribute table in GIS using the unique county FIPS code. This join resulted in a map that displays total crop sales for each county (Figure 5).

Using 2012 Data

We chose to do this analysis with 2012 data because this is the only year that CDL data and crop sales data from NASS overlap. However, we wanted to examine how cropland and crop sales change over time in order to determine how representative this analysis of 2012 data might be. Cropland area across the United States has been declining slowly for the past few decades. From 1997-2002 cropland was reduced by 3% (13 million acres) and from 2002-2007 was reduced by 8% (34 million acres) (Nickerson et al 2011). However, a more detailed look at data from the GCPO LCC region of interest shows that cropland area in much of this region of the country has remained relatively constant (Figure 1).

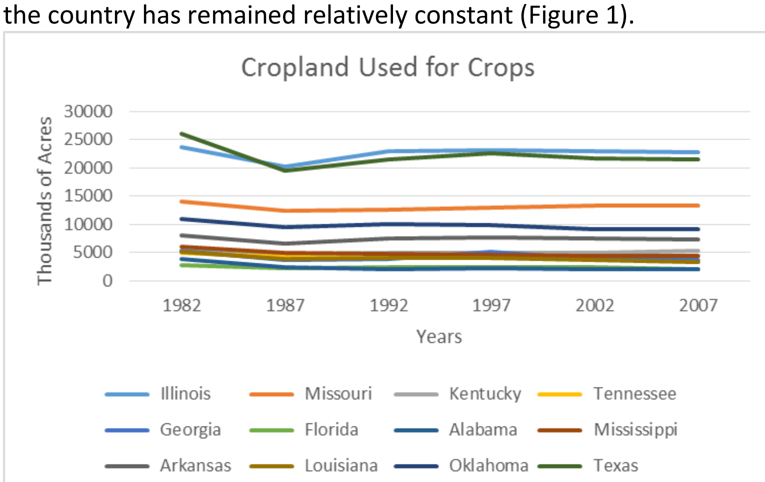


Figure 1: Acres of cropland land cover in the states falling within the GCPO LCC subregion from 1982-2007. (Data from the USDA Economic Research Service, 2011).

Total crop sales by county are collected every 5 years by NASS for the US Census of Agriculture. These values do show significant changes from 2007-2012. The median difference between 2007 county total crop sales and 2012 county total crop sales in the GCPO LCC region is ~5.7 million dollars. However, an examination of the trends in crop value over time reveal that the counties with relatively high or low crop values tend to remain similar over time relative to the other counties of the region (Figure 2). The maps in figure 2 show that it is the same counties in the Mississippi Alluvial Valley subgeography that consistently produce the highest crop sales in the region, regardless of what those values are.

Because cropland area and trends in total crop sales in the GCPO LCC region have remained largely constant, we feel that the relative trends among GCPO LCC counties mapped in this analysis can be taken to represent the current state of crop supply and value. While specific dollar or dollar per acre values might not represent reality, the relationship between these counties is likely accurately represented.

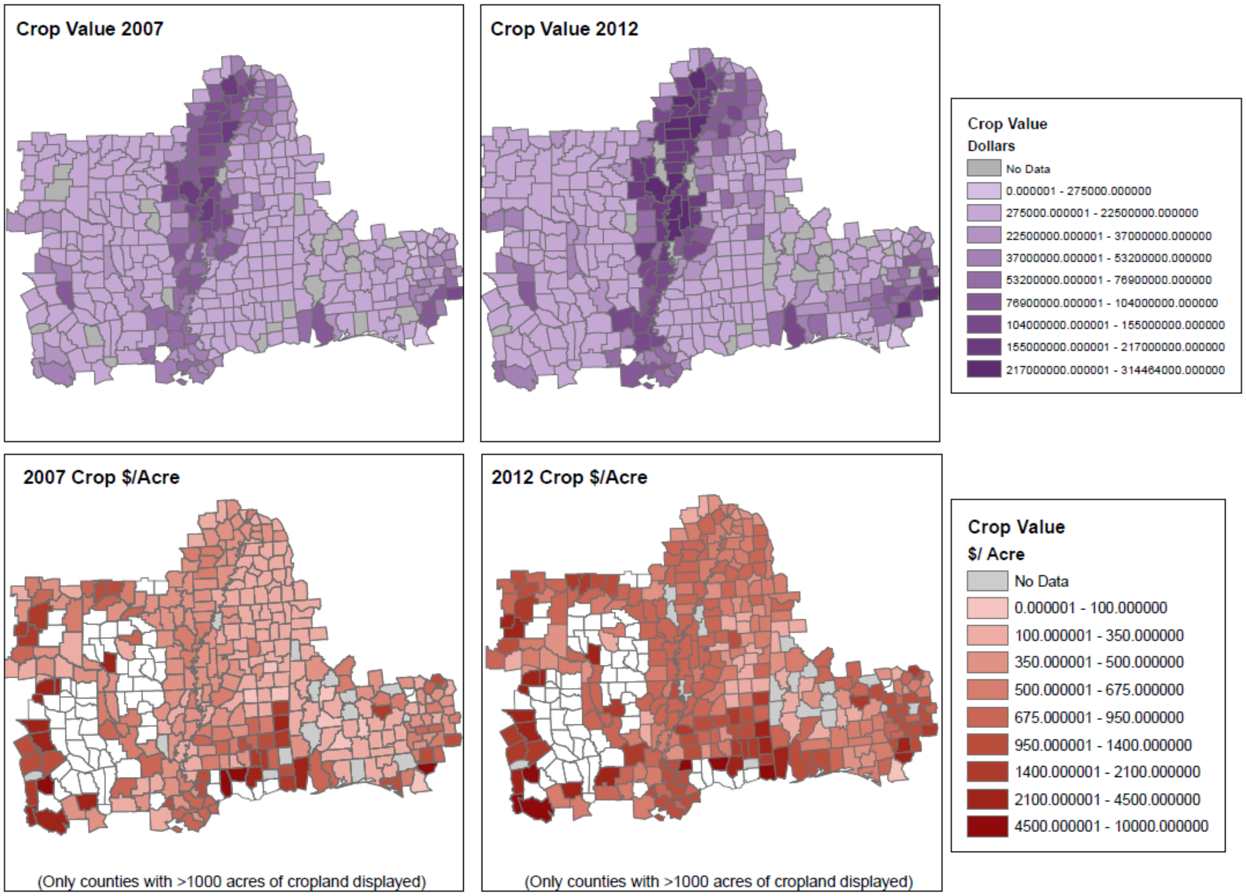
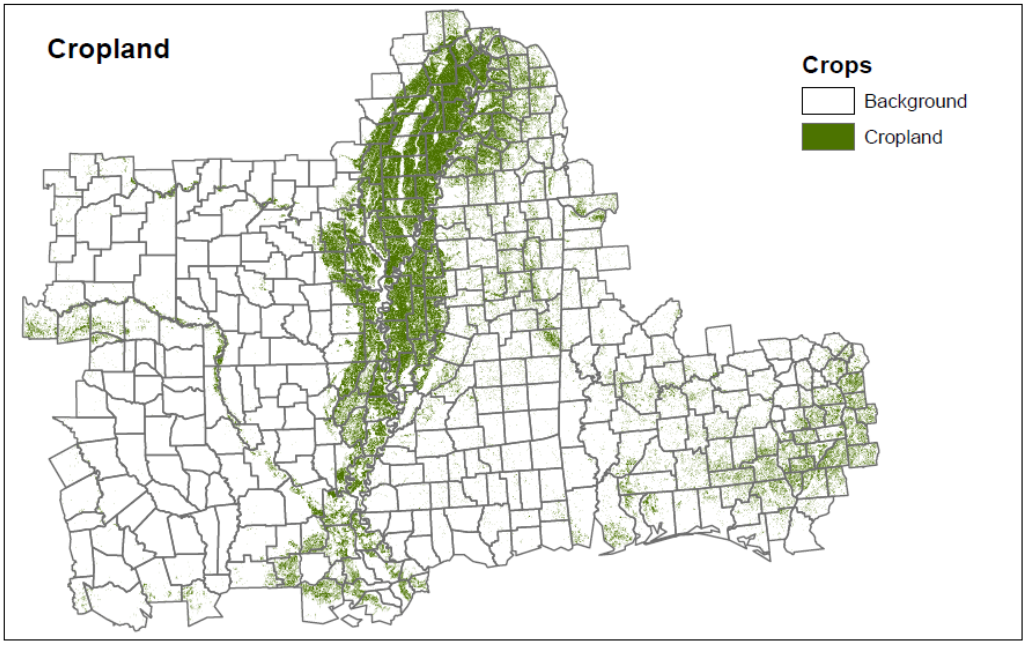


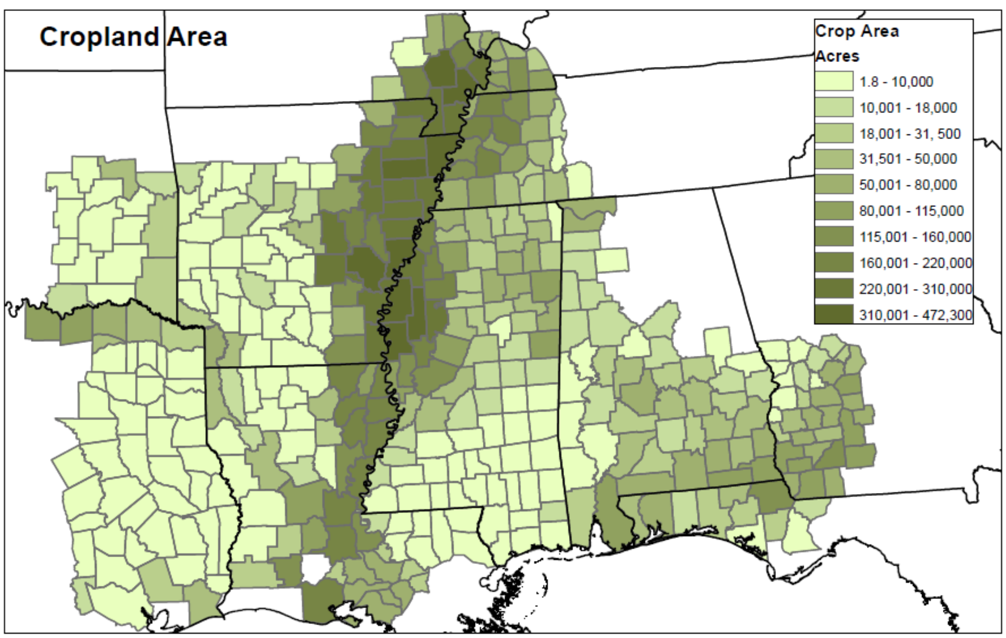
Figure 2: A comparison of crop values, both unweighted and area weighted, between 2007 and 2012.

Analysis and Results

Crop Supply. The “crops only” layer created from the CDL can be used to display where current cropland exists in the region (Figure 3a). This data can also be visualized differently by mapping the amount of cropland (in acres) in each county (Figure 3b). Both maps indicate the concentration of crop cultivation in the Mississppi Alluvial Valley subgeography.



a)



b)

Figure 3: a) Existing Cropland in the GCPO LCC subregion at a 30m resolution. **b)** Acres of cropland in each county in the GCPO LCC subregion.

Top 20 Crops. A brief analysis of the clipped CDL attribute table in excel yielded the top 20 crops by area in the region. These crops were then isolated from the clipped CDL using the 'reclassify' tool, to produce a map of only these top crops (Figure 4). Again, these top 20 crops (out of 63 grown in the region) represent 99.7% of all cropland area, and the top 7 crops account for ~90% of the cropland area. Table 1 displays the total acreage of each crop and the percentage of all cropland that it represents.

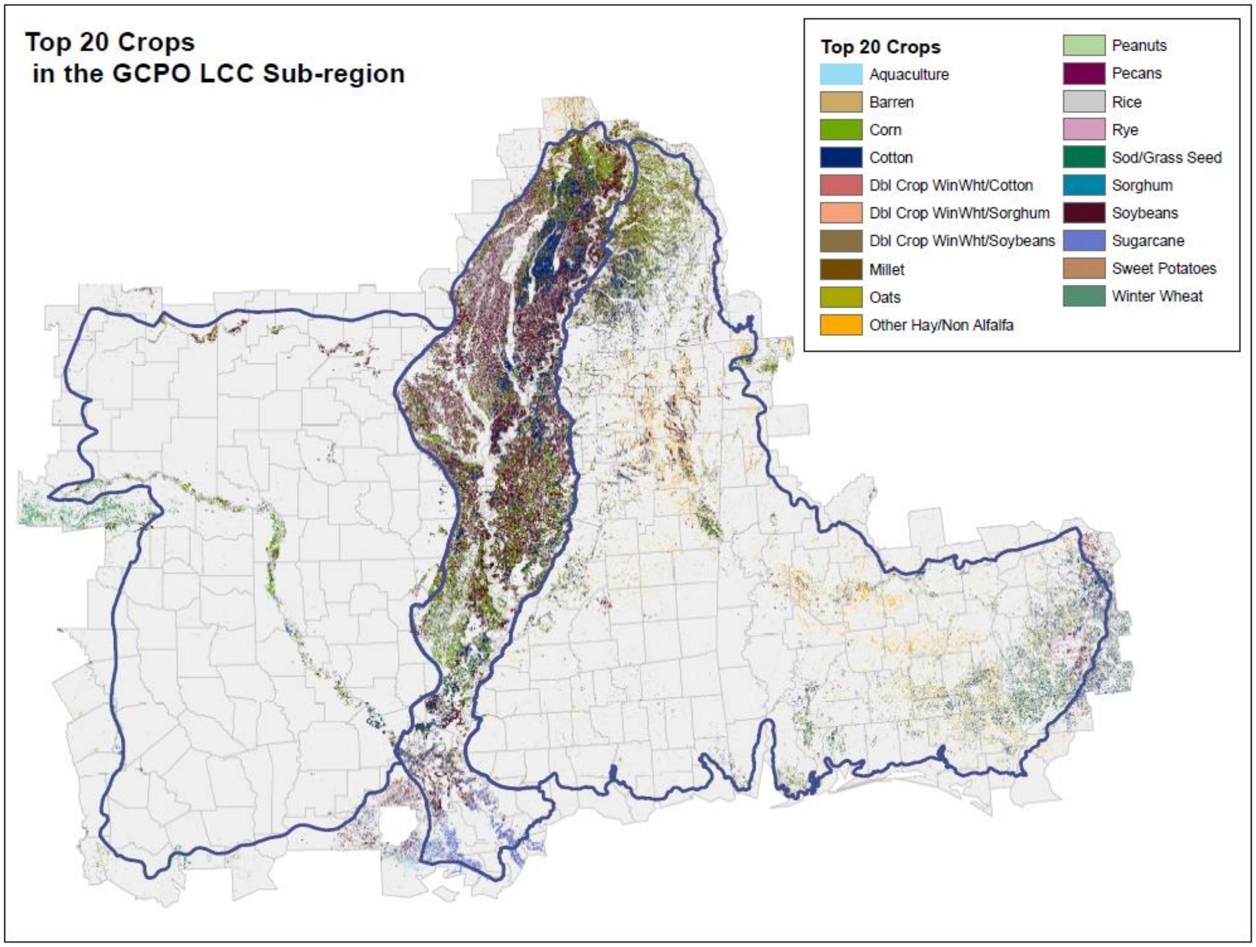


Figure 4: The top 20 crops grown in the GCPO LCC subregion.

Table 1. The top 20 crops grown in the region, ordered by acreage.

Crop	Acres	Percentage of total cropland
Soybeans	7943450	34.95
Corn	3910710	17.21
Cotton	3004393	13.22
Rice	1874327	8.25
Dbl Crop WinWht/Soybeans	1451588	6.39
Other Hay/Non Alfalfa	1300462	5.72
Peanuts	899004	3.96
Winter Wheat	737108	3.24
Sugarcane	435114	1.91
Sorghum	361308	1.59
Pecans	224629	0.99
Barren	164782	0.72
Aquaculture	163892	0.72
Dbl Crop WinWht/Cotton	73026	0.32
Sod/Grass Seed	38688	0.17
Sweet Potatoes	32258	0.14
Oats	12241	0.05
Dbl Crop WinWht/Sorghum	11804	0.05
Millet	10194	0.04
Rye	7945	0.03

Crop Sales. Joining the county crop sales values obtained from NASS to the GCPO LCC county layer in GIS produces a map that displays crop sales for each county (Figure 5).

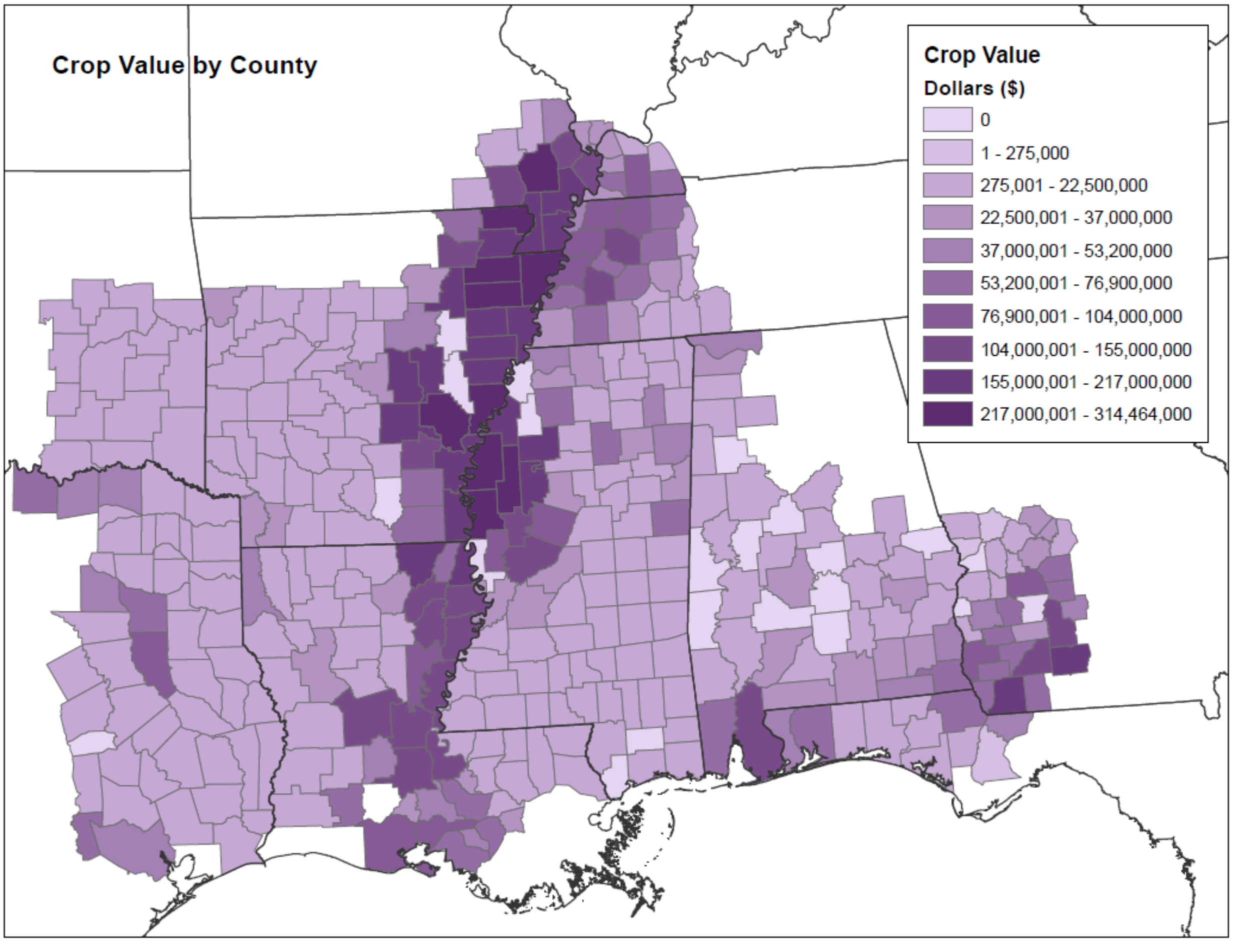


Figure 5: Total crop sales ($) in each county in the GCPO LCC subregion.

Cropland Value ($/Acre). The results of the 'tabulate area' tool that calculated the acreage of cropland in each county was joined to the GCPO LCC county attribute table. A new column was created in this table to hold a cropland value index. The cells of this new column were populated using the formula (county crop sales total/ county cropland total acreage). This index value could then be mapped to display the dollar/ acre value of cropland in each county.

It was noted that there were multiple counties in the south and south-west portion of the region with very high cropland value indexes but with very little cropland area. Upon further examination of those counties, there do not appear to be any unique, high-value crops that could help account for why these counties with very little cropland would have relatively high crop sale values. It is possible that either the crop sale values for these counties were incorrectly reported or that the CDL is not correctly displaying the cropland that truly exists in these counties.

This anomaly only occurred in counties where there is very little total cropland, and it has been documented that CDL cropland acreages can be downward biased (Cropscape and CDL FAQ, 2016), meaning that estimates of cropland acreages based on pixel counts from the CDL will result in smaller acreages than are actually present. It was thus assumed that the very small cropland areas were biasing the index for those counties. To account for this bias, we have isolated counties with >1000 and >10,000 acres of cropland (Figure 6).

To investigate these anomalies further and to help indicate that this bias is real, an examination of the top 20 crops by area grown in counties with <1000 and <10,000 acres of cropland was performed. These counties' top 20 crops are very similar to the top 20 crops grown in the entire region. The only additional top crops that appear in these low-cropland acreage counties are watermelons, alfalfa, tomatoes, peas, and greens. None of these crops has a high enough value that would account for the abnormally high crop index that appears here.

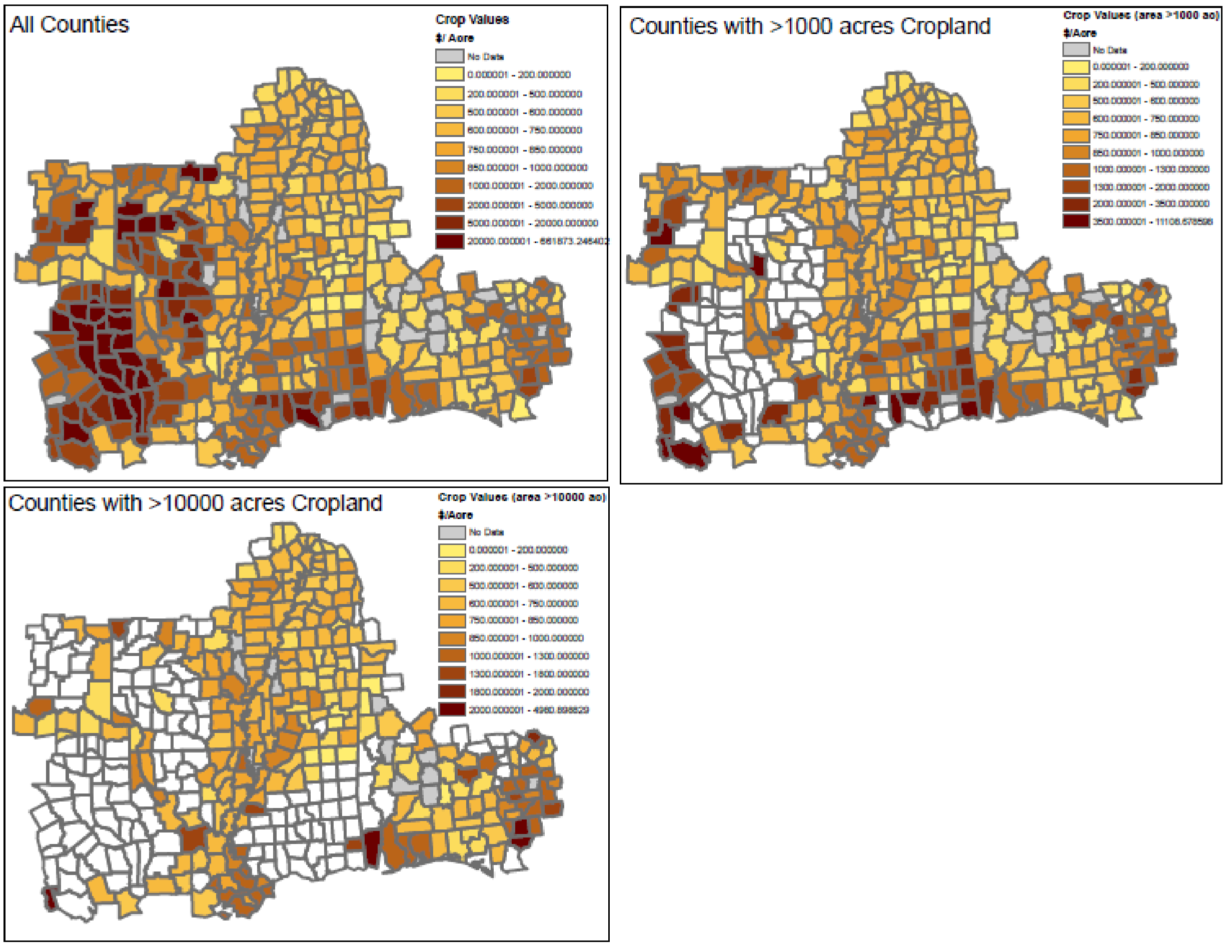


Figure 6: Cropland value in dollars/ acre for the counties in the GCPO LCC subregion.

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Pollination Potential

The goal of this analysis is to map pollination services within three subgeographies of the Gulf Coast Plains and Ozarks LCC (East Gulf Coastal Plain, West Gulf Coastal Plain, and Mississippi Alluvial Valley). We approximate this ecosystem service by analyzing how much pollinator habitat is present within a buffered distance around crops that benefit from insect pollination.

Data Sources

Cropland Data Layer

Cropland in the United States is tracked and documented by the USDA. They produce a GIS product titled the Cropland Data Layer (CDL) which is available for download from their website. The national CDL has been produced annually since 2008, and this analysis used the 2012 CDL. See justification and details about the choice to use 2012 data in the 'Food Provision' section of this report.

CDL Data Properties

The CDL is downloadable as an IMG file at a 30m resolution. Each crop is assigned a unique raster value. The CDL contains pixel values for the entire land area of the United States, so where cropland does not exist the landcover is represented as the class it would appear in the NLCD (developed, forested, open water etc.)

Initial Data Processing. This analysis focuses on cropland dedicated to growing crops that either depend on or benefit from insect pollinator visitation. A paper by Calderone (2012) helped determine which crops within the GCPO LCC region fall into this category. Calderone defines two different groups of crops that benefit from pollinators. Group 1 contains crops that receive direct benefits from pollinators, while group 2 contains crops that receive indirect benefits as they do not themselves require pollination but are grown from seeds that require pollination.

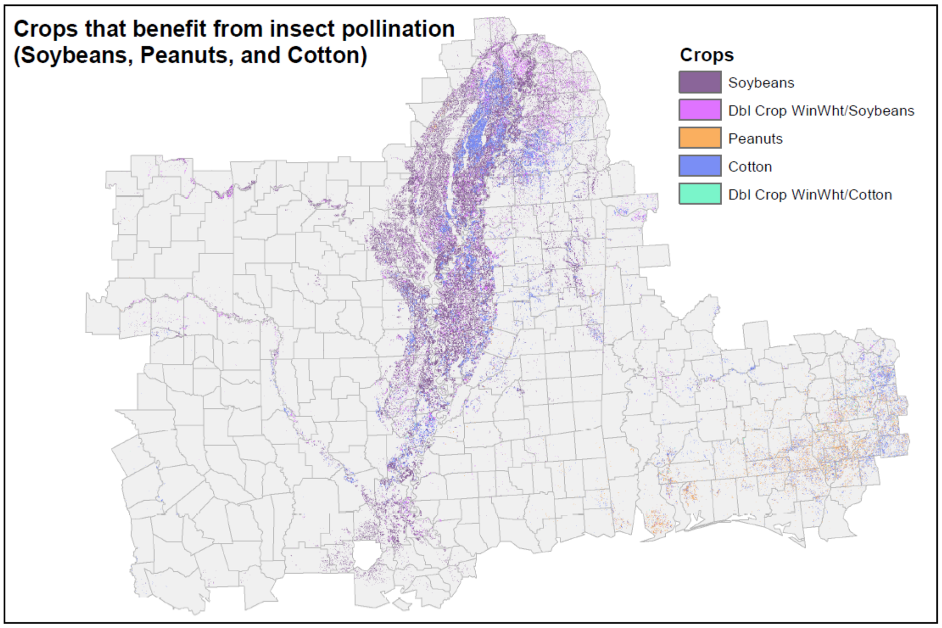
It was decided that only the top 20 crops by area for the GCPO LCC region would be considered for this analysis. These top 20 crops cover 99.7% of the cropland area, and we wanted to focus on crops with significant enough coverage that a landscape scale analysis would be applicable. The only top 20 crops falling within Calderone's pollinator crop groups are soybeans and peanuts in group 1, and cotton in group 2. Because cotton does not directly benefit from pollinators, and because only some varieties of cotton receive any benefits from pollinators (University of Georgia, 2015), it was decided to do two sets of analyses: one that includes cotton and one that does not.

By reclassifying the CDL using the 'reclassify' tool, it was possible to isolate only those crops that benefit from insect pollinators. The first pollinator crops layer was created using the CDL classes for 'soybeans,' 'double crop winter wheat/ soybeans,' 'peanuts,' 'cotton,' and 'double crop winter wheat/ cotton' (hereafter, "all pollinator crops") (Figure 7a). The second pollinator crops layer was created using the CDL classes for 'soybeans,' 'double crop winter wheat/ soybeans,' and 'peanuts' (hereafter, "reduced pollinator crops") (Figure 7b).

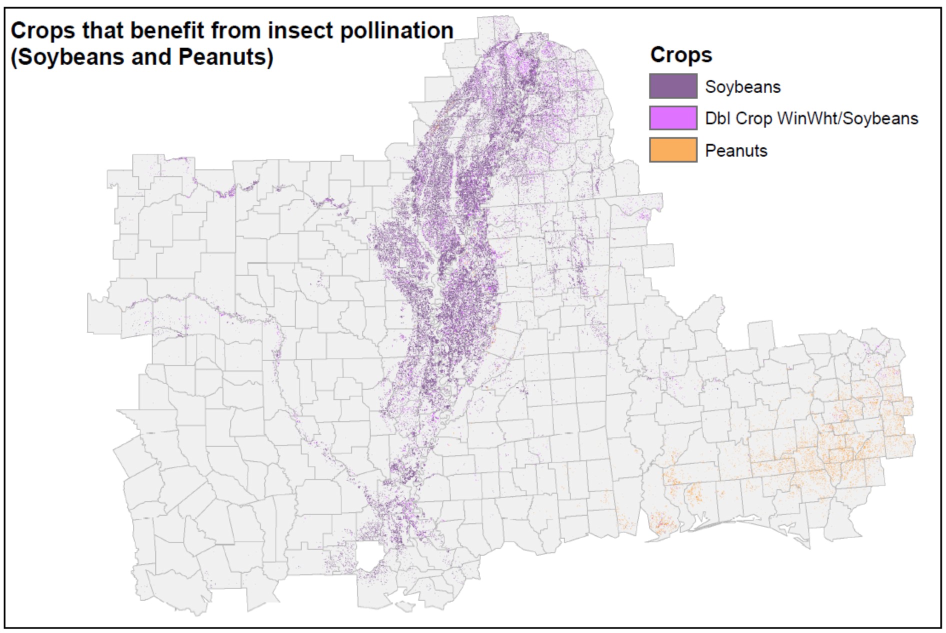
Note: Calderone (2012) also reports a PIP value that represents the proportion of crop production that can be attributed to insect pollinators. Soybeans and peanuts have a PIP = 0.1, while cotton has a PIP = 0.2.

Analysis and Results

Location of Pollinator Crops. Using the CDL it is possible to display only those crops that benefit from insect pollinators (Figure 7).



a)



b)

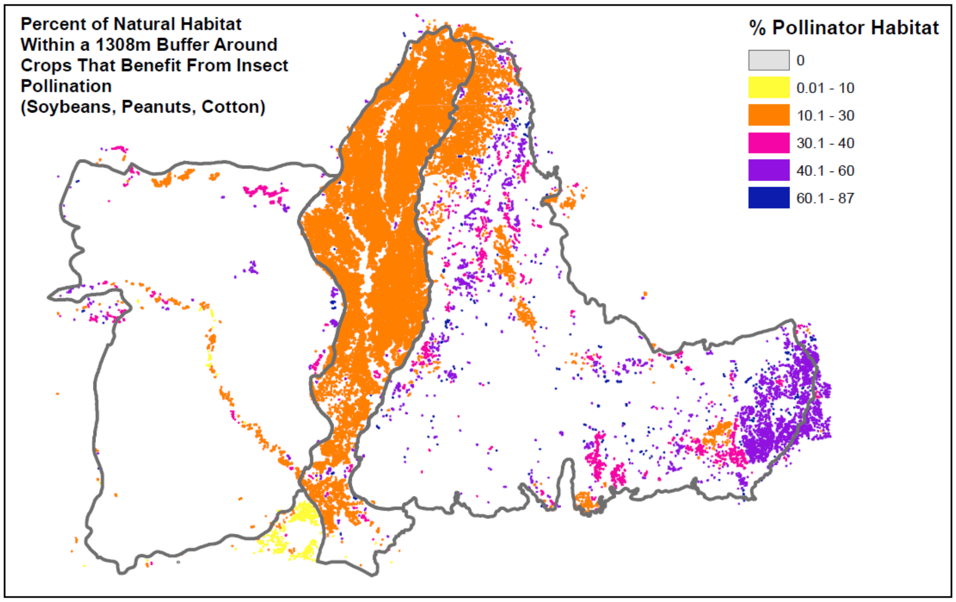
Figure 7: a) All pollinator crops and **b)** reduced pollinator crops in the GCPO LCC subregion.

Pollinator Habitat Within Reach of Pollinator Crops. Upon examination of insect pollination literature it was found that the amount of pollinator habitat surrounding crops plays an important role in successful pollination (Kremen et al 2004, Ricketts et al 2008). We used a meta-analysis of crop pollination services performed by Ricketts et al. (2008) to determine a buffer distance around pollinator crops that would be examined for pollinator habitat. Ricketts et al. (2008) found that in temperate regions visitation by pollinators fell to 50% of its maximum value at 1308m away from pollinator crops. Additionally, Kremen et al. (2004) performed an experiment on pollinator visitation to crops in California, and examined a 1.2 km buffer (1200m) around cropland. These two papers using similar buffer distances serve as guides for our buffer creation.

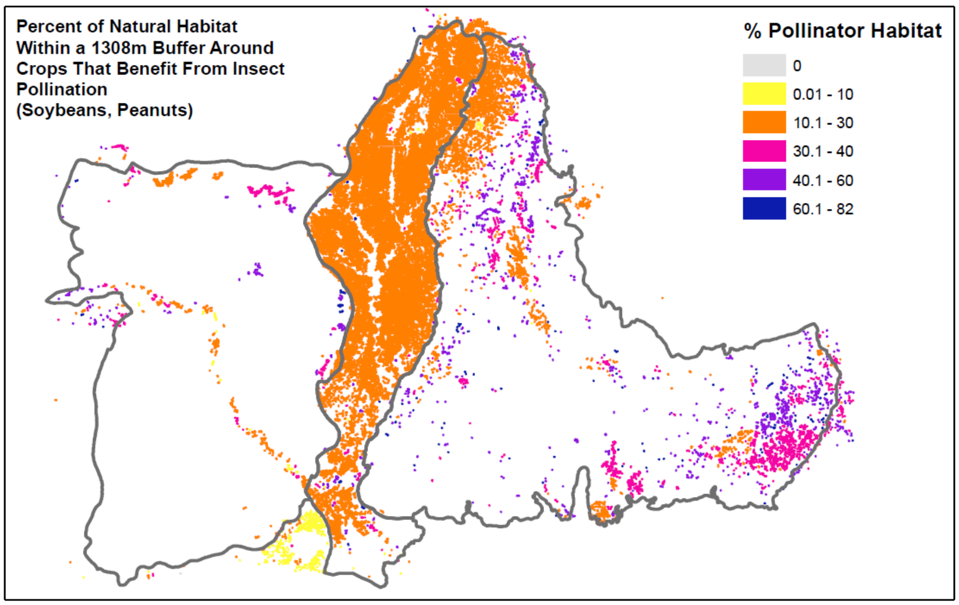
The ‘region group’ tool was used to classify regions of pollinator crops. These regions were transformed to polygons, and only polygons representing pollinator crop areas greater than 100 acres were used for subsequent analyses. This landscape-scale analysis is most useful for relatively large crop patches, so this step ensured that patches of crops only consisting of a few pixels were removed. A 1308m buffer was then created around these pollinator crop patches by reclassifying the output of the ‘euclidean distance’ tool. These buffers were transformed to polygons in order to give each polygon a unique ID number. The crop buffer polygons were then re-transformed back into raster format for further analysis.

Pollinator habitat was considered to be any forest, grassland, or wetland pixel, as classified by the NLCD 2011 (landclasses 41, 42, 43, 71, 90, and 95). Pollinators are known to live in all three of these habitat types (USDA NRCS 2013, Hanula et al 2015) and it should be noted that for this analysis all three of these habitat types were considered equally good habitat for pollinators.

Using the ‘raster calculator’ tool the number of pollinator habitat pixels falling within each crop buffer polygon was calculated. It was then possible to calculate the percentage of each crop buffer polygon made up of pollinator habitat (Figure 8). Areas with a low percentage of pollinator habitat indicate regions of the GCPO LCC where pollination services are in demand.



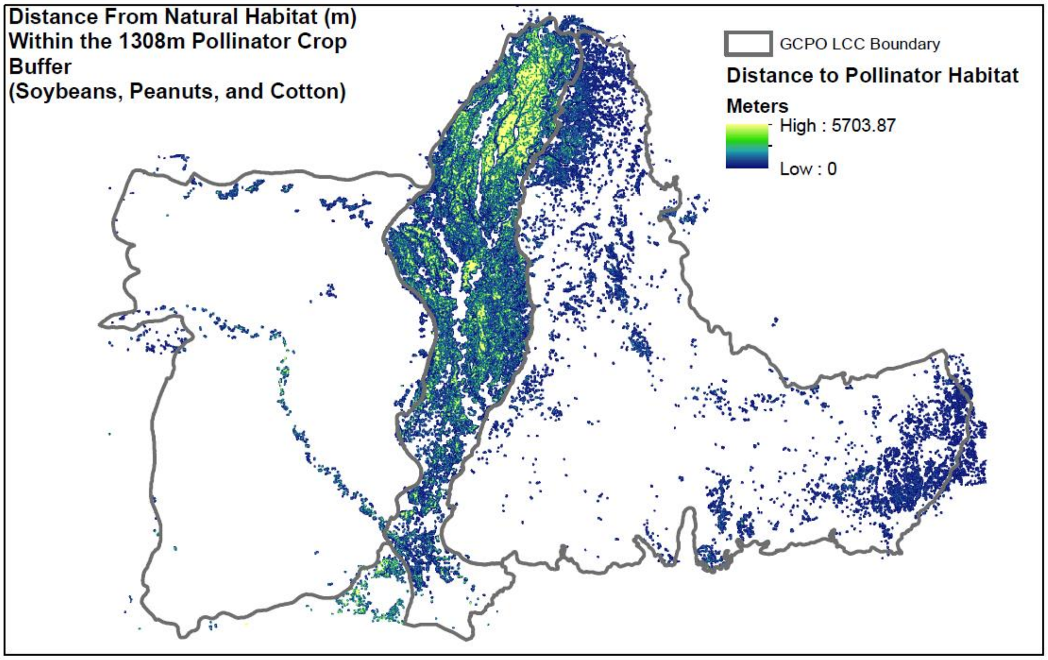
a)



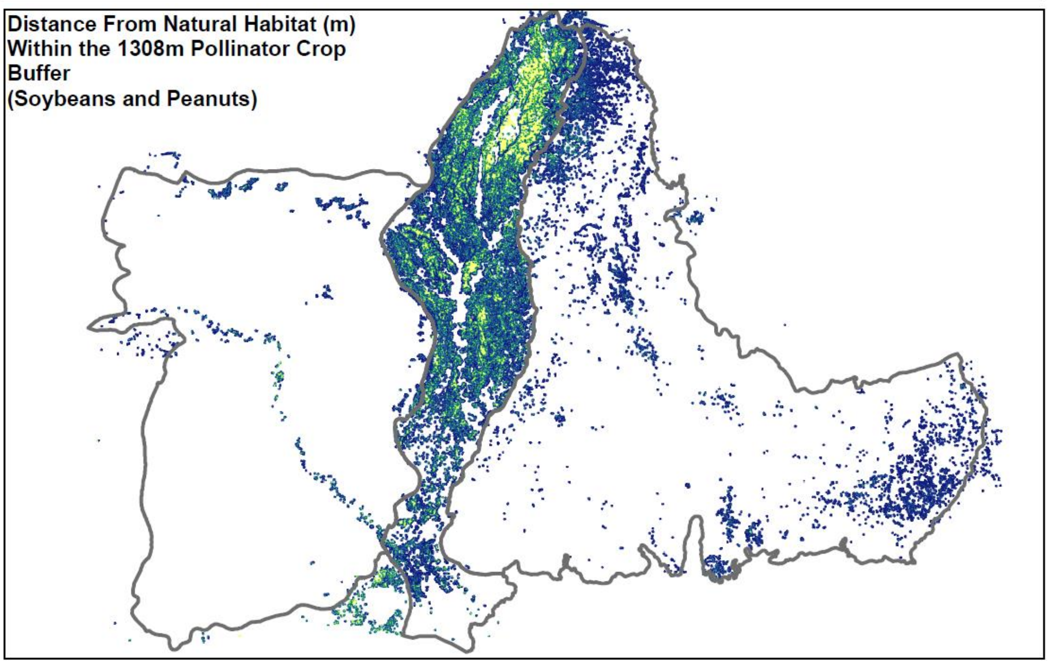
b)

Figure 8: The percentage of pollinator habitat within the 1308m buffer around **a)** all pollinator crops, and **b)** reduced pollinator crops.

Distance From Pollinator Habitat. The 'euclidean distance' tool was used to calculate the distance from pollinator habitat patches to any point within the crop buffer polygons (Figure 9). It is clear that there are certain areas inside the larger crop buffer polygons that have no pollinator habitat nearby (see northern portion of GCPO LCC subregion highlighted in yellow). These areas especially far from pollinator habitat indicate where in the crop buffer polygons demand for pollination services might be highest.



a)



b)

Figure 9: Distance from pollinator habitat within the crop buffer polygons for **a)** all pollinator crops and **b)** reduced pollinator crops.

Pollinator Priority Counties. We wanted to create summary output layers combining the presence of relevant crops and likelihood of pollinator visitation that could be used as an overlay for decision-making. To do this, we aggregated data by HUC 12 so that priority HUCs could be identified. First, the percentage of pollinator benefitted crop coverage was calculated for each HUC 12 in the GCPO region. Next, a simple decay distance function was created to estimate the likelihood of pollinator visitation to any location across the landscape, based on the distance from pollinator habitat. This function was created using the data from the pollinator meta-analysis that found pollinator visitation in temperate regions is 50% of its maximum at

1308m away from pollinator habitat (Ricketts et al 2008). Using this information, a simple exponential decay function was created:

$$V(k) = e^{D*k}, \text{ where } V(k) = \text{visitation likelihood, D is distance, and k is a constant, so:}$$

$$0.5 = e^{1308*k} \text{ (if visitation is 50\% at 1308 meters)}$$

Solving for k provides the value -0.0005299, which can be input into the raster calculator tool to create a decay distance raster for the GCPO region, where every pixel represents the likelihood of pollinator visitation. The expression Exp(-0.0005299* "Euclidean distance raster from pollinator habitat") was used to calculate the decay distance raster. For reference, the shape of the decay function can be seen in figure 10.

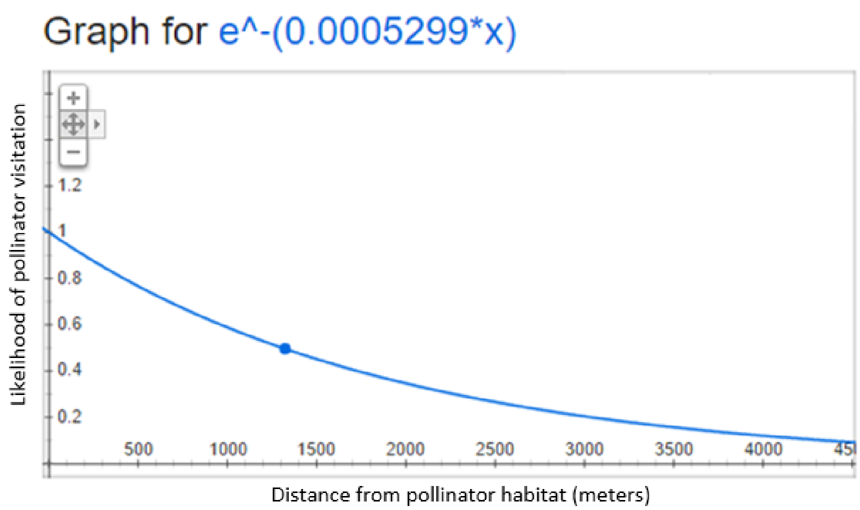


Figure 10: The decay function that models likelihood of pollinator visitation. The point on the graph is (1308, 0.5) which is the data point from Ricketts et al (2008) that was used to build the decay function.

The resulting decay distance raster was then aggregated by HUC 12, producing an output with each HUC 12 value representing the mean decay distance of all pixels in that HUC. The percentage of pollinator benefitted crop coverage in each HUC 12 was combined with this mean decay distance data to produce the final output layers. The percentage of pollinator crop coverage was thresholded at a value of 10%, and the likelihood of visitation was thresholded at 0.9. These values were chosen after careful examination of the distribution of the data. HUC 12 coverage by pollinator-benefitted crops ranges from 0-73% (for the analysis excluding cotton) and 0-87% (for the analysis including cotton), however the means of these datasets are only 5.9% and 7.7%, respectively. Because of the strong right-skew of the data, 10% was chosen as a cutoff to try to isolate counties with relatively high pollinator-benefitted crop coverage, but to also be inclusive and provide some variety of priority HUC 12s. The likelihood of pollinator visitation dataset is also skewed, but to the left. The cutoff was chosen to be 0.9 for similar reasons as the 10% cutoff was chosen for crop coverage: to preserve both inclusivity and relativity. While much of the landscape has relatively high likelihood of pollinator visitation based on this model, a 90% chance of visitation marks a good cutoff between those locations with relatively sure visitation likelihoods and those places with relatively unsure likelihoods of visitation. Priority HUCs 12s were then identified for both conservation of existing pollinator habitat and restoration of needed pollinator habitat.

The conservation priority HUC12 have ≥10% pollinator crop coverage, and ≥0.9 mean likelihood of pollinator visitation (Figure 11a and b). In other words, these are areas with relatively high coverages of pollinator benefitted crops and relatively high likelihoods of pollinator visitation, meaning that pollinator habitat in these HUCs should be conserved in order to preserve existing pollinator services.

Alternatively, the restoration priority HUC 12s have ≥10% pollinator crop coverage, and <0.9 mean likelihood of pollinator visitation (Figure 11c and d). In other words, these are areas with relatively high coverages of pollinator benefitted crops and relatively low likelihoods of pollinator visitation, meaning that pollinator habitat should be restored in these HUCs to provide needed pollinator services.

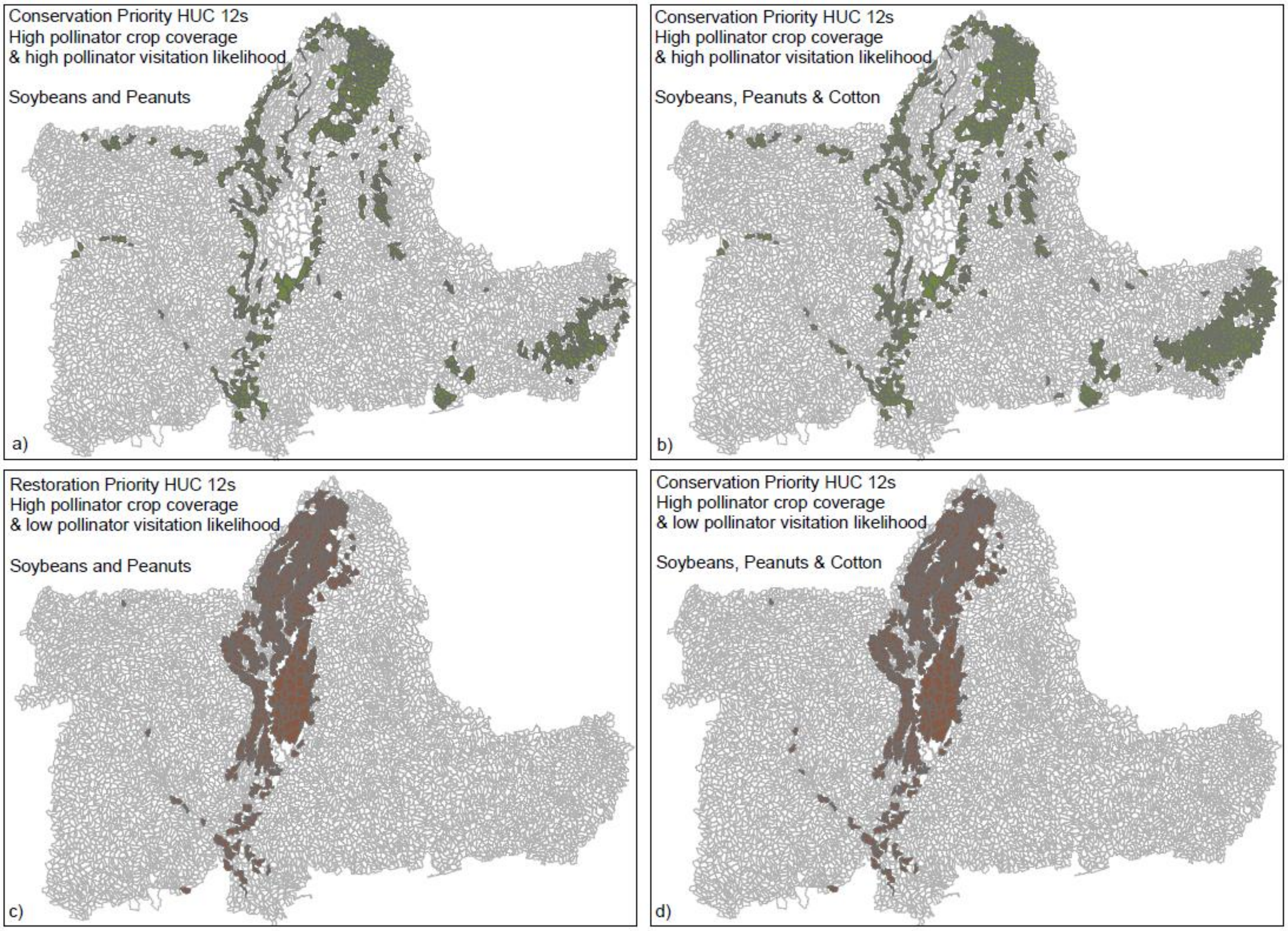


Figure 11: Priority HUC 12s for pollination ecosystem services for both conservation and restoration. Conservation priorities are identified by high pollinator benefitted crop coverage and high likelihood of pollinator visitation, based on presence of nearby pollinator habitat for **a)** soybeans and peanuts, and **b)** soybeans, peanuts, and cotton. Restoration priorities are identified by high pollinator benefitted crop coverage and low likelihood of pollinator visitation, based on absence of nearby pollinator habitat for **c)** soybeans and peanuts, and **d)** soybeans, peanuts, and cotton.

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Forest Carbon Sequestration (Climate Stabilization)

The goal of this analysis is to map climate stabilization services within three subgeographies of the Gulf Coast Plains and Ozarks LCC (East Gulf Coastal Plain, West Gulf Coastal Plain, and Mississippi Alluvial Valley). We approximate this ecosystem service using data on existing forest carbon storage, an estimation of potential future carbon storage, and estimates for annual forest growth rates.

Data Sources

Carbon Online Estimator

The Carbon Online Estimator (COLE) allows users to extract data describing forest carbon characteristics of any area of the continental United States. COLE was created by the National Council for Air and Stream Improvement (NCASI) and the US Forest Service. Data provided by COLE is drawn from the US Forest Service's Forest Inventory and Analysis (FIA) and Resource Planning and Assessment datasets.

Data Properties

Two datasets were pulled from the COLE data portal. The first was an estimation of current carbon storage by forests, measured in tonnes/ hectare. The following query was used to extract this data:

> *State:* all 12 states falling within the GCPO LCC subregion (AL, AR, FL, GA, IL, KY, LA, MO, MS, OK, TN, TX)
> *Quantitative Variable:* 2 separate queries, one using 'Total Aboveground Carbon,' and one using 'Total Belowground Carbon'
> *Quantitative Variable:* County
> *Analysis Type:* Table-Means (represents the mean value from 2006-2012)

This data was copied into excel, and a column representing total carbon was created, consisting of the 'Total Aboveground Carbon' and 'Total Belowground Carbon' values combined for each county.

The second dataset extracted from COLE represents data on the carbon storage in each stocking class, measured in tonnes/ hectare. Stocking classes are the same classes defined by the FIA database: overstocked, fully-stocked, medium-stocked, poorly-stocked, and non-stocked. The following query was used to extract this data:

> *State:* all 12 states falling within the GCPO LCC subregion (AL, AR, FL, GA, IL, KY, LA, MO, MS, OK, TN, TX)
> *Quantitative Variable:* Total Aboveground Carbon (did not include soil carbon in this part of the analysis)
> *Quantitative Variable:* County + Growing-stock (selected together)
> *Analysis Type:* Table-Means (represents the mean value from 2006-2012)

Initial Data Processing. Data from COLE was saved in excel and units were transformed from tonnes/ hectare to tonnes/ acre so that comparisons between COLE and FIA data (reported in acres) could easily be made. COLE data is provided in units of tonnes/ hectare of forest, and we wanted to examine the values of tonnes/ acre of all land so that the COLE data could be compared to EnviroAtlas data. To do this, we took the calculated tonnes/ acre of forest value and converted it to tonnes by multiplying the (tonnes/ acre of forest)*(acres of forest). (The acres of forest for each county was obtained from FIA, and details for how it was downloaded can be seen in the 'Timber' section of this report.) The resulting tonnes of carbon per county value was then divided by the total acreage of the county, to produce a tonnes C/ acre of all land value for each county in the GCPO.

Forest Inventory Analysis

Forests in the United States are monitored by the US Forest Service (USFS). The USFS maintains a database of these monitoring efforts in the Forest Inventory Analysis (FIA). The purpose of the FIA monitoring program and the database containing the monitoring information is to document the extent, condition, volume, growth, and use of trees on the Nation's forest land (O'Connell et al 2015). The way FIA data is collected and compiled means that one year's data actually represents that year and the previous 5 years' data. Every year 1/5 of all FIA plots are measured, and one year's value estimates are calculated by summing the area-weighted individual annual estimates of each of the previous five years. 2012 data was used for this analysis because it aligns with the COLE data. The 2012 data analyzed here includes data collected from 2008-2012, matching closely the 2006-2012 data provided by COLE.

Data Properties

Two datasets were downloaded from FIA. The first was obtained through the FIA Forest Inventory Data Online (FIDO) portal to download acreages for each stocking class by county. The following query was used to download the data:

Region: Each county in the GCPO LCC subregion was chosen individually from the state dropdown lists
Report: 2.7: Area report- area in acres by owner and stocking class
Year: 2012
Filters: Land ownership- undifferentiated private

Only private acreages were downloaded because this analysis focuses on potential carbon stocks that could be provided by private landowners.

The second dataset was obtained through the Forest Service's FIA tool EVALIDator and used to download annual net growth data. The EVALIDator tool is useful when a ratio of tree measurement attributes is required, which in this case was annual net growth/ acre of forestland. The following query was used to download the data:

Numerator: Average annual net growth of live trees
Denominator: Area of forestland, in acres
Geographic Area: All 12 states in the GCPO LCC subregion (AL, AR, FL, GA, IL, KY, LA, MO, MS, OK, TN, TX)
Page variable: none (temporal basis = current)
Row variable: county code and name (temporal basis = current)
Column variable: All live stocking – this variable is necessary to input to run the tool, but outputs for stocking codes were ignored (temporal basis = current)

This provided a table of annual net growth in cuft/ acre of forestland/ year for each county in the GCPO LCC subregion.

EnviroAtlas

EnviroAtlas is an EPA data product meant to enable users to map and analyze different ecosystem services. The EnviroAtlas layers 'biomass' and 'treerootbiomass' provide measures of carbon storage by aboveground tree biomass and root biomass, respectively, for each HUC 12, measured in kg/ m2. This data was collected from the National Biomass and Carbon Dataset, published in the year 2000.

More information about these EnviroAtlas data layers can be found in the fact sheets here:
https://enviroatlas.epa.gov/enviroatlas/DataFactSheets/pdf/ESN/CarbonStoragebyTreeBiomass.pdf
https://enviroatlas.epa.gov/enviroatlas/DataFactSheets/pdf/ESN/CarbonStoragebyTreeRootBiomass.pdf

Initial Data Processing. The EnviroAtlas data layers were transformed from kg/ m2 to tonnes/ acre so that they could be easily compared with the COLE and FIA data.

Analysis and Results

Carbon per Acre. Datasets from COLE and EnviroAtlas allow an examination of where carbon is currently stored in the GCPO LCC landscape (Figure 12). These maps display values representing tonnes of carbon per acre of land across the study area. These datasets show that where forests exist, carbon storage is high (see the inset map for reference forest areas). The locations with high carbon storage in these maps indicate currently forested lands with a lot of stored carbon, and could help identify locations important for preservation. The COLE data was transformed from its original units of tonnes C/ acre of forest to tonnes C/acre of all land so that it could be compared more easily with the EnviroAtlas data. This comparison was done as a data-check, to ensure that patterns in the data we collected matched existing datasets.

There are a few noteworthy differences between these datasets. First, the carbon pools included are different. The COLE carbon values include all aboveground and belowground carbon, encompassing trees, understory, dead wood, soil carbon, and roots. The EnviroAtlas data reports only live tree carbon. Additionally, COLE data are derived from USFS plot sampling, while the EnviroAtlas data are derived from remote sensing. Finally, the time scales of the data are different; the COLE data represents an average of data collected from 2006-2012, while the EnviroAtlas dataset was produced in 2000.

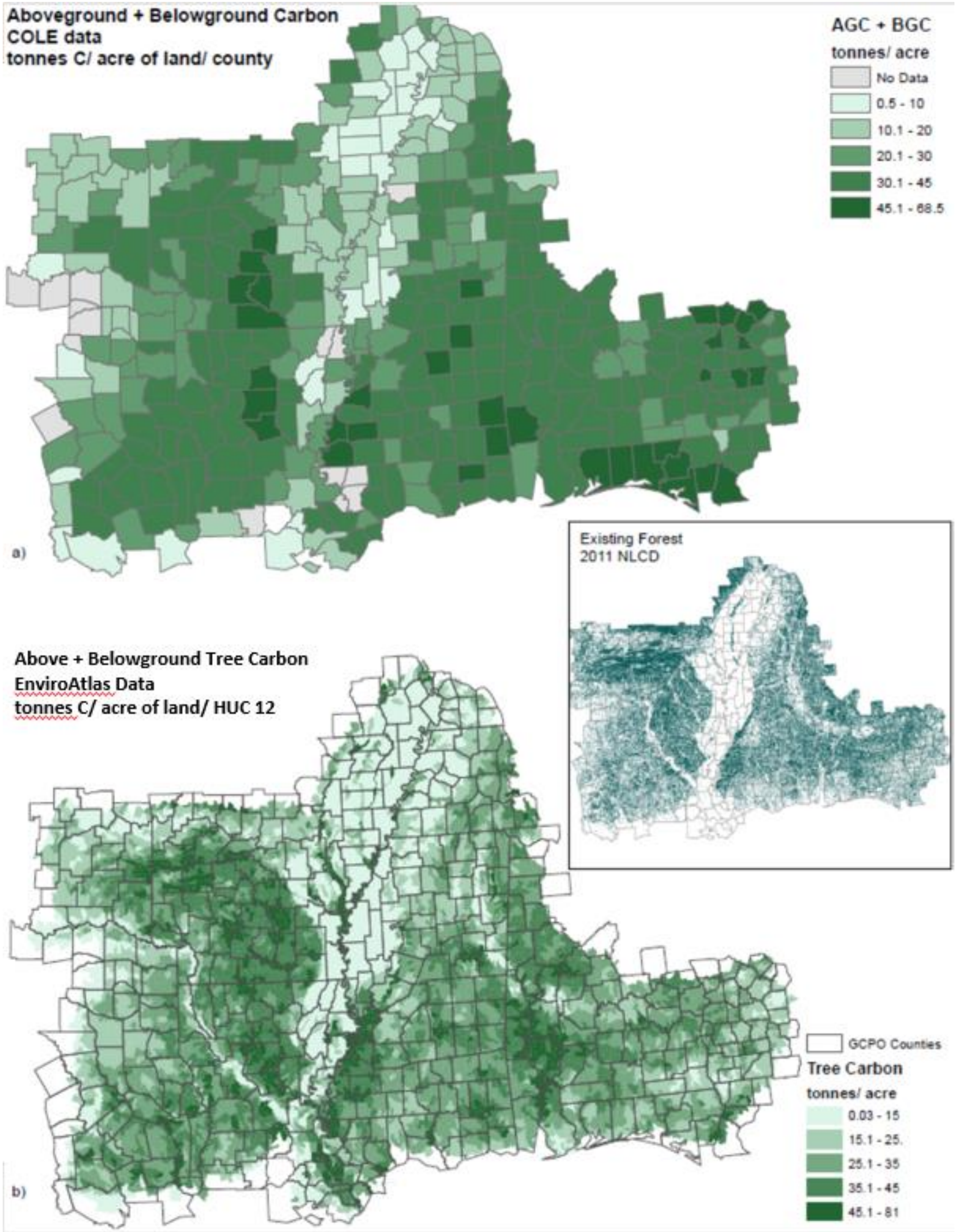


Figure 12: a) Aboveground + belowground carbon, measured in tonnes/ acre of land/ county. Data from COLE, and **b)** tree carbon, measured in tonnes/ acre of land/ HUC 12. Data from EnviroAtlas. Inset map shows existing forests, as classified by the 2011 NLCD, for reference.

Carbon per Acre Belowground. We wanted to examine belowground carbon storage across the GCPO landscape (Figure 13). In general, where forests exist belowground carbon seems to be high. However, belowground carbon is especially high in the southeast corner of the GCPO region, a location primarily covered by forests, wetlands and agricultural lands, with a few interspersed urban areas. This would be an important location to consider for conservation, as belowground carbon is often lost with land conversion from forests or wetlands to other land uses. It should be noted that this area of high belowground carbon falls along the state lines of the Florida panhandle and the southwestern corner of Georgia. Because the high values appear distinctly at state lines, it is possible that differences in state reporting methods might have resulted in these high values.

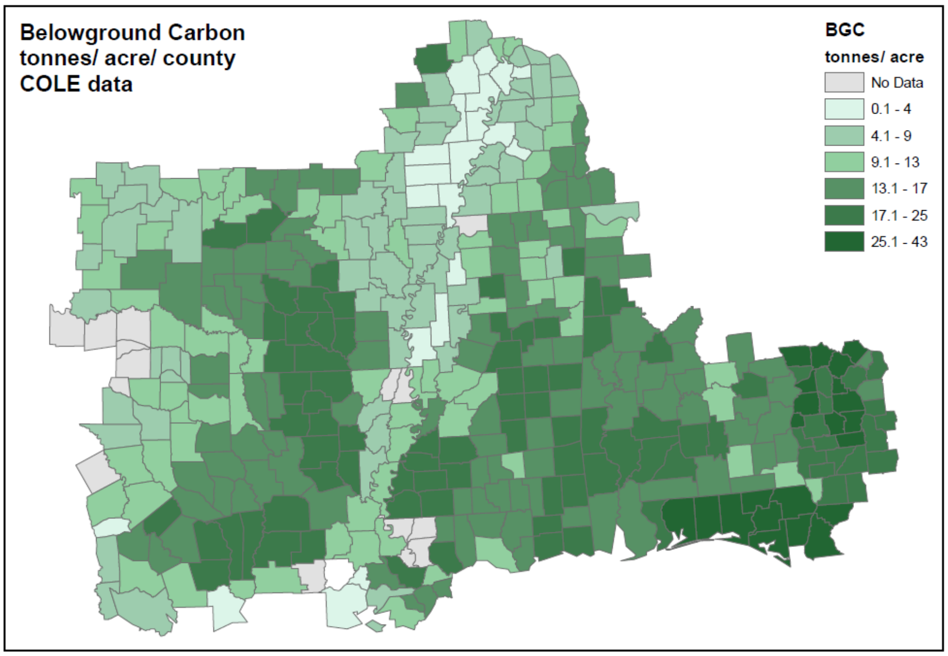


Figure 13: Belowground carbon, measured in tonnes/ acre/ county. Data from COLE.

Carbon Potential in Existing Forests. Different forests store different amounts of carbon. While this can be due to forest type, it can also be due to forest stocking level. Poorly stocked forests usually contain lower stocks due to poor management or site conditions, but with restoration could be brought to a fully stocked level. Using the rationale outlined in Galik et al. (2013), we assumed that a rough estimate of potential additional carbon storage could be identified using the difference between carbon storage in poorly stocked and fully stocked stands (Figure 14a). Potential additional tonnes of carbon in each county were calculated using the following formula:

$$\textbf{Potential Additional C}_{\text{tonnes}} = (\textbf{Fully stocked C}_{\text{tonnes/acre}} - \textbf{Poorly stocked C}_{\text{tonnes/acre}}) * \textbf{Poorly stocked forest area}_{\text{acres}}$$

COLE and FIA data were used for these calculations. Only aboveground carbon was used for this calculation because changing stocking level is unlikely to change soil carbon significantly, so belowground carbon values were not included. Additionally, it is important to note that these calculations only estimate potential carbon on private lands, as private landowners are the focus for these analyses.

It is interesting to note that there are counties where potential "additional" carbon is negative. This results from counties where poorly stocked forests have higher reported carbon values than fully stocked forests. It is unclear why this might be occurring. One explanation may be the large errors associated with these data. FIA data (which is the source of COLE data as well) is collected on a scale that makes county level reports very rough estimates. Percent standard error for the values reported throughout this carbon analysis can be between 25 – 75%.

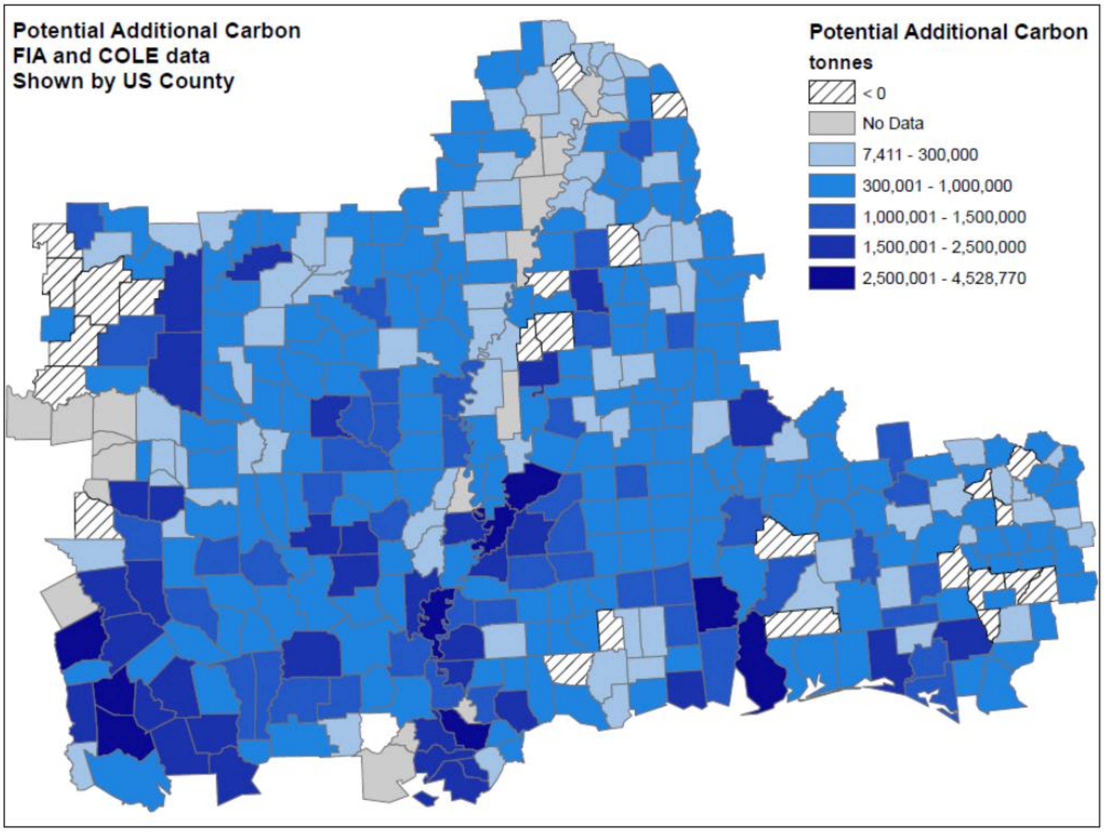


Figure 14a: Potential additional tonnes of carbon that could be provided by private lands in each county in the GCPO LCC subregion. Values shown indicate a tonnes C/ county estimate.

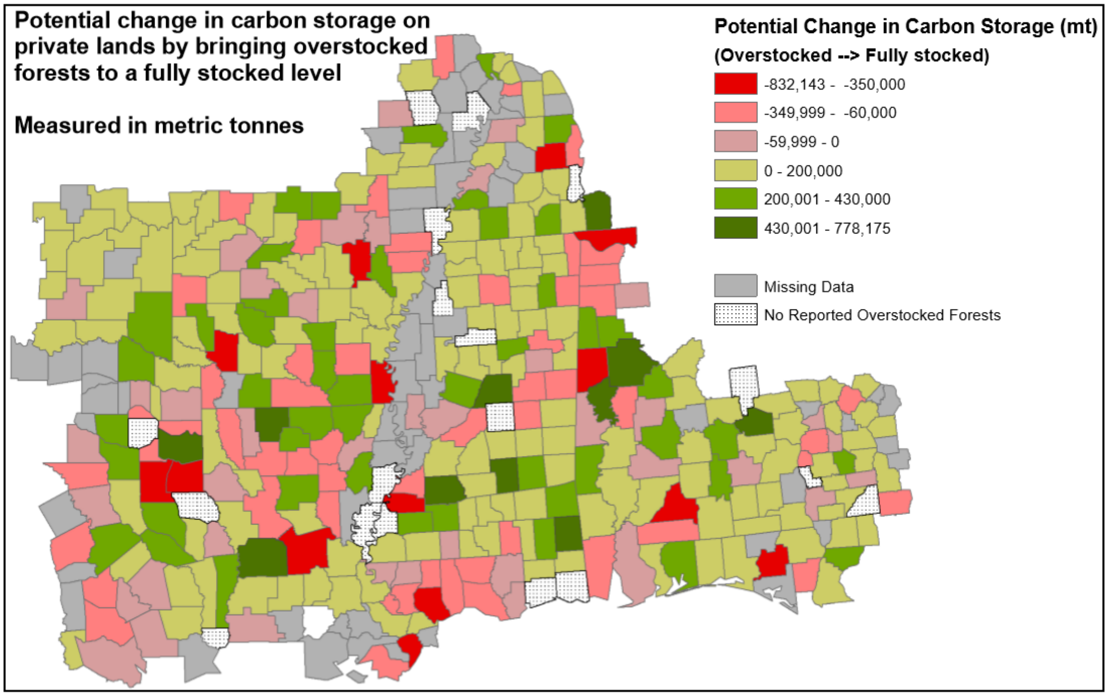
In certain areas of the GCPO LCC managers are considering reducing stocking level in order to provide habitat benefits for certain wildlife groups. We wanted to provide maps that could illustrate how carbon storage across the GCPO might change if this management intervention took place. Using the same logic that was used to derive Figure 14a, we calculated the potential change in carbon storage on private forest lands in each county of the GCPO LCC if stocking level was reduced from overstocked to either full or medium stocking levels (Figure 14b-c). The following formulas were used to calculate these carbon storage differences:

$$\textbf{Potential Change in C}_{\textbf{tonnes}} = (\textbf{Fully stocked C}_{\textbf{tonnes/acre}} - \textbf{Overstocked C}_{\textbf{tonnes/acre}}) * \textbf{Overstocked forest area}_{\textbf{acres}}$$

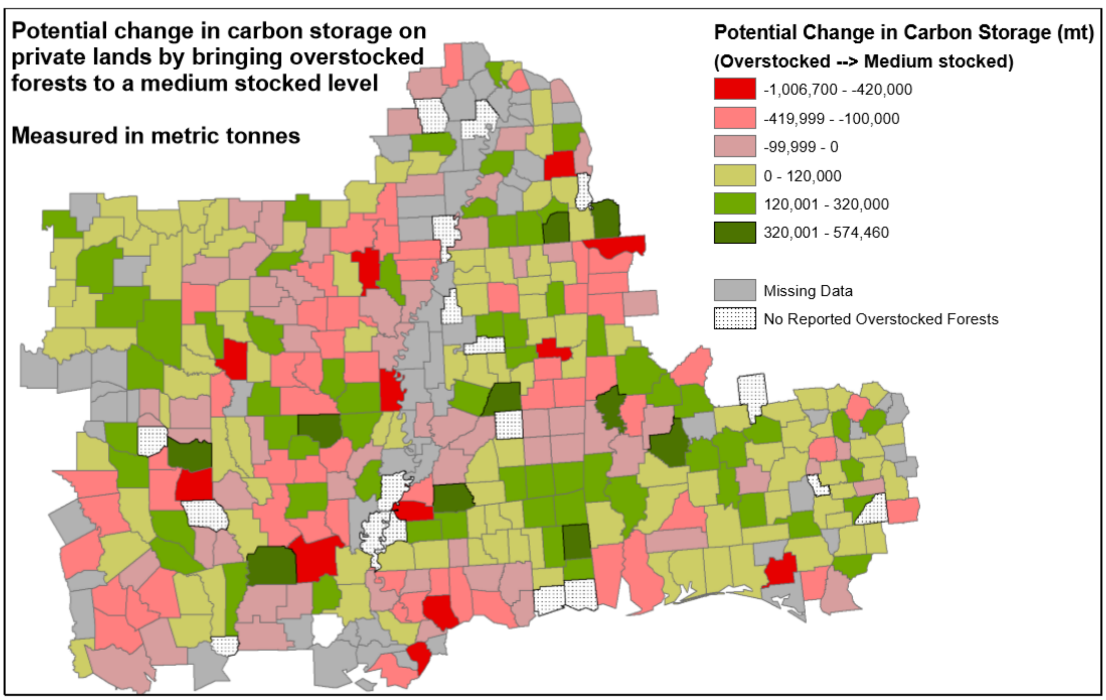
used to create figure 14b

$$\textbf{Potential Change in C}_{\textbf{tonnes}} = (\textbf{Medium stocked C}_{\textbf{tonnes/acre}} - \textbf{Overstocked C}_{\textbf{tonnes/acre}}) * \textbf{Overstocked forest area}_{\textbf{acres}}$$

used to create figure 14c



b)



c)

Figure 14b-c: Potential changes in carbon storage that could occur on private lands in each county in the GCPO LCC subregion if overstocked forests were brought to a **b)** fully stocked, or **c)** medium stocked level. Values shown indicate a tonnes C/ county estimate.

Negative values in these figures represent counties where carbon would be lost if stocking level was reduced, whereas positive values indicate counties where carbon could be gained if stocking level was reduced. One possible reason that carbon storage could either increase or decrease with a reduction in stocking level is because different forest types store different amounts of carbon, and as forest stocking levels change forest types can subsequently shift.

Carbon per Acre of Forest. The COLE data that reports tonnes of carbon per acre of *forestland* provides more detail about carbon storage in different forest types (Figure 15). These data tell us the finer distinctions between carbon storage in different areas of forest, not simply that carbon is high where forests exist. However, the high carbon areas in this map do not necessarily match up with existing forests. A county could have small, but high carbon forests. It is in these counties where forest restoration might be successful for additional carbon storage. Because this analysis focused on forest carbon, and this data displays carbon in units of tonnes C/ acre of *forest*, this map provides the basis for the analyses performed to isolate priority counties for carbon storage conservation and restoration.

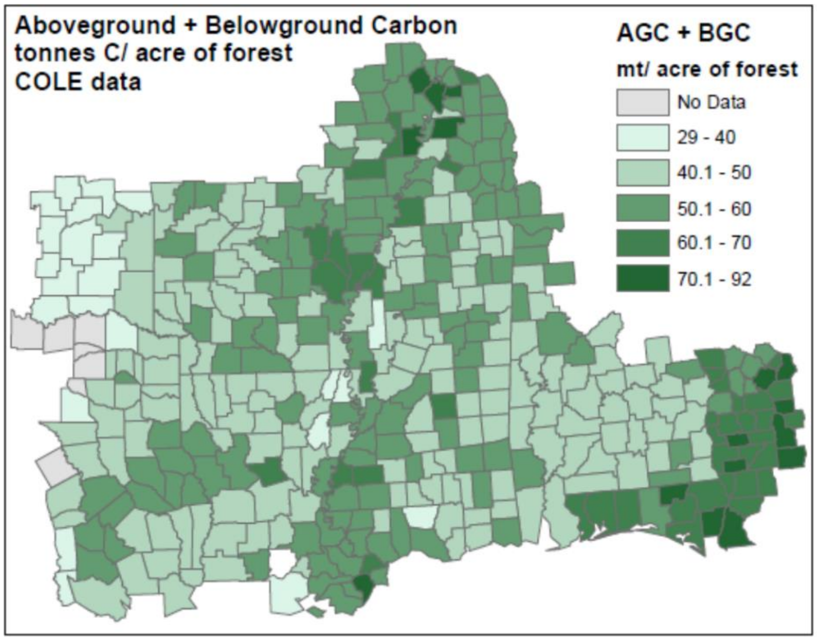


Figure 15: Aboveground + belowground carbon, measured in tonnes/ acre of forest/ county. Data from COLE.

Carbon Accumulation. Unfortunately, we could not find the data to map either biomass accumulation or carbon accumulation across the entirety of the GCPO LCC landscape. If managers are interested in assessing carbon accumulation in a localized region, they could use known information about existing forest types and data provided by the USFS on carbon accumulation in these forests. Managers interested in doing this could use FIA report 2.8, which provides acreages of each forest type, by county. Appendix A and B from the 2005 USFS report on calculating forest carbon could then be used to identify carbon accumulation rates for the specific forest types of a county of interest.

Carbon Priority Counties. We wanted to combine the carbon data into final layers that could be used as inputs for the decision tool. To do this, we created layers that identify areas most important for conservation of high carbon forests as well as layers that identify areas most important for restoration of high carbon forests (Figure 16). To do this we first isolated counties with relatively high forest carbon by selecting only those counties with ≥55 tonnes carbon/ acre of forest (the 3rd quartile of the forest carbon data, shown in Figure 15). From this subset, conservation priority counties were those that had ≥226,500 acres of private forest (The 3rd quartile of the NLCD forest data. For a more detailed description of how forest area was calculated for each county, see the Timber section of this report) (Figure 16a). From the same subset of high forest carbon counties, restoration counties were those that had ≤66,852 acres of private forest (the 1st quartile of the data) (Figure 16b). There were relatively few priority counties identified for conservation or restoration using these cutoffs, and especially few conservation counties. This likely occurred because many of the highest carbon forests are in areas with very productive soils that are used primarily for agriculture, and so have low acreages of forest. It was therefore decided that a slightly more inclusive second set of conservation and restoration priority counties would be created using the median of the forest carbon data (Figure 16c-d). The starting subset of counties was then those with ≥50 tonnes carbon/ acre of forest.

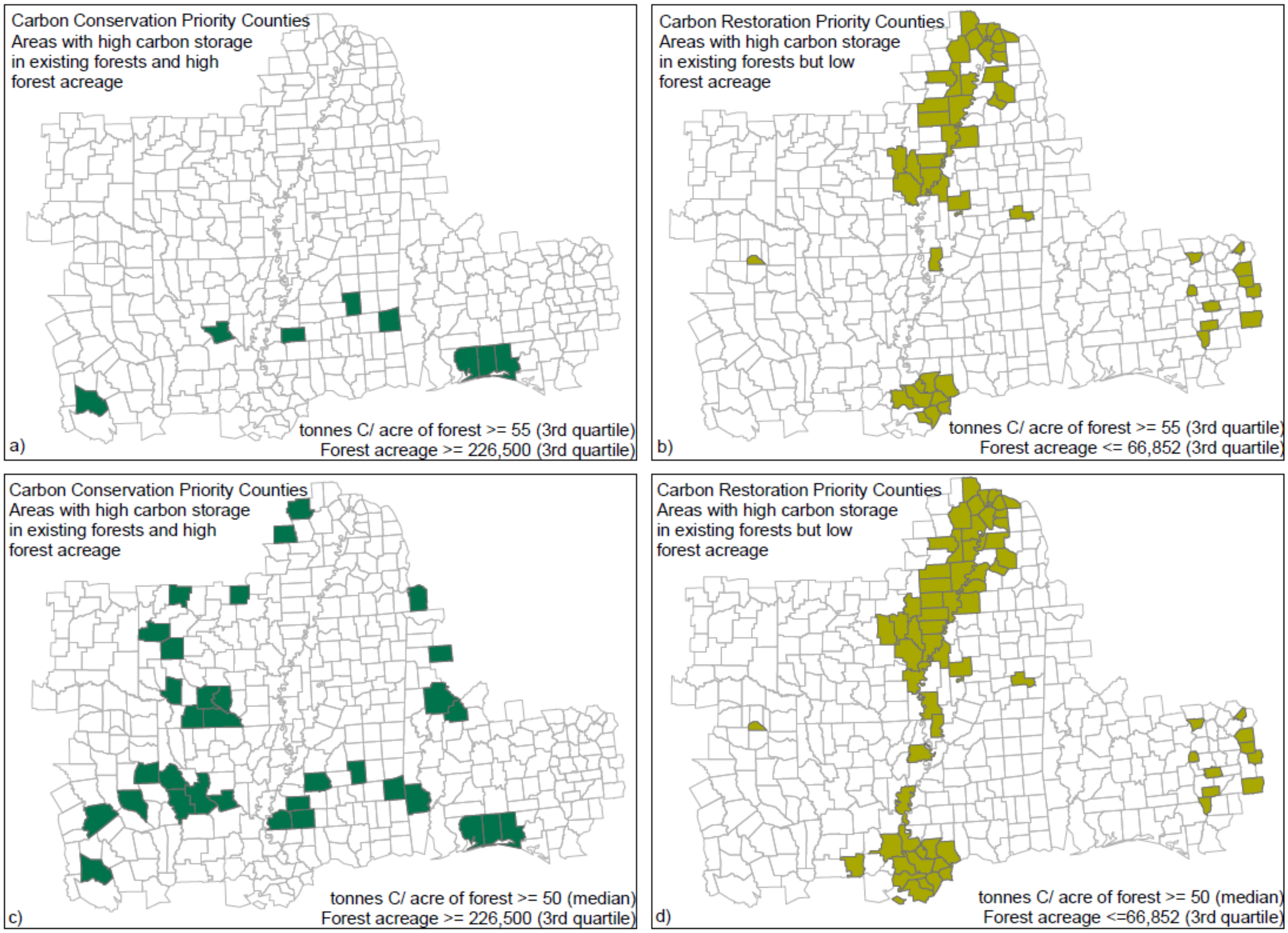


Figure 16: Priority counties for conservation and restoration of carbon storage. Conservation counties are identified by high carbon forests and high forest area using **a)** the 3rd quartile of the carbon data, and **c)** the median of the carbon data. Restoration counties are identified by high carbon forests and low forest acreages, using **b)** the 3rd quartile of the carbon data, and **d)** the median of the carbon data.

Citations

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USDA Forest Service. “Forest Inventory and Analysis National Program.” FIA Standard Reports, 2016. http://apps.fs.fed.us/fia/fido/index.html.

Timber Production

The goal of this analysis is to map merchantable timber removals within three subgeographies of the Gulf Coast Plains and Ozarks LCC (East Gulf Coastal Plain, West Gulf Coastal Plain, and Mississippi Alluvial Valley). We approximate supply of this ecosystem service using timber removals reports from the Forest Inventory Analysis conducted by the US Forest Service. Using acres of forestland found in each county in the region, a cubic feet per acre of forestland value was also calculated for each county.

Data Sources

Forest Inventory Analysis

Forests in the United States are monitored by the US Forest Service (USFS). The USFS maintains a database of these monitoring efforts in the Forest Inventory Analysis (FIA). The purpose of the FIA monitoring program and the database containing the monitoring information is to document the extent, condition, volume, growth, and use of trees of timber on the Nation's forest land (O'Connell et al 2015). The USFS annually measures 1/5 of all national survey units. The most recent year that all survey units in the states falling within the GCPO LCC region were measured is 2013, so all data downloads from FIA were taken from this year.

Using specific queries in the FIA database it is possible to obtain reports on the cubic feet of timber extracted from each county within the GCPO LCC region. FIA data can be downloaded through the FIDO (Forest Inventory Data Online) data portal. Using the standard reports link, the following queries were used to obtain timber removals reports. The 'cubic feet' measure for each county obtained from these reports is the output we used for timber removals.

Region of Interest: AL, AR, FL, GA, IL, KY, LA, MO, MS, OK, TN, TX
Choose Reports: Tree removals reports—Report 40.2 (average annual removals of growing-stock trees at least 5 inches d.b.h. in cubic feet, by county and species group)
Survey Years: 2013
Filter Options:

- Land (condition) attributes—ownership group
  - 1 set of reports was downloaded for private forest data, so "private" was chosen for ownership type
  - 1 set of reports was downloaded for public forest data, so "forest service," "other federal," and "state and local gov't" was chosen for ownership type
- Tree attributes—tree species groups: Longleaf and slash, loblolly and shortleaf, cypress, selected white oaks, selected red oaks, other white oaks, other red oaks, other Eastern soft hardwoods, other Eastern hard hardwoods, oak, woodland hardwoods

Upon completion of a query and before viewing a FIA report, the user is asked whether data should be reported for "forestland" or "timberland." Forestland was chosen for this analysis, as timberland is a subset of forestland and the more comprehensive dataset was desired.

It should be noted that much of the public land timber removals data for the counties of interest were missing, and the percent standard errors for much of the existing public data are ≥50%.

Using 2013 Data. While data from the year 2013 was downloaded, the way FIA data is collected and compiled means that one year's data actually represents that year and the previous 5 years' data. Every year 1/5 of all FIA plots are measured, and one year's value estimates are calculated by summing the area-weighted individual annual estimates of each of the previous five years. This means that the 2013 data analyzed here includes data collected from 2009-2013.
According to a 2012 USFS report, forestland in the United States has been increasing across the country, however has remained relatively constant in the majority of the states contained within the GCPO LCC region of interest. Louisiana, Mississippi, Alabama, Georgia, Tennessee, Kentucky, Missouri, and Arkansas had <5%

changes in forest area from 2007-2012. Florida and Illinois had 10% gains in forest area, Texas gained 10-20% of forested area, and Oklahoma had 20-25% gains in forestland (Oswalt et al 2014).

The USFS Southern Forest Futures Project provides a brief history of Southern US timber markets that can give insight as to the stability of timber harvests in the region. Following a production peak in 1997-1998 timber harvests decreased in the south from 1998-2009. Hardwood pulpwood harvests declined throughout this period, falling a total of almost 60%. Harvests of softwood pulpwood fell from 1997-2000, but stabilized between 2000- 2009. Softwood sawtimber saw harvest declines during this period, especially from 2005-2009, likely due to declines in the construction market (Wear and Greis, 2013, 190). Planted pine in the region increased 25% from 1999-2010, implying that harvests of these trees will increase over the next 10-20 years as these plantations reach maturity (Wear and Greis, 2013, 205). It is unclear how timber supply in this region will change in the future, as it is largely dependent on changes in land use and land ownership. However, it is forecasted that if the demand for timber products returns to the level it was at in 2006 (before the recession), timber production could expand by roughly 25% in the South in the next 50 years (Wear and Greis, 2013, 183). This changing history of timber production in the region indicates that use of this 2013 data should be used with caution when extrapolating these trends into the future.

Initial Data Processing. The FIA data portal provides an html table that can be saved in PDF format. Data from the online html table was copied and pasted into excel. Two excel spreadsheets were created, one for public data and one for private data. Each spreadsheet contains 12 tabs for each individual state's timber data.

Because FIA data does not download with a unique county FIPS, to join the FIA data to county level GIS data the join had to be done by county name. There are some county names that appear in two or more states in the GCPO LCC region. This meant that the counties falling in each state had to be isolated, and then subsequently joined to their state's FIA timber removals data. This left 12 layers of county data (one layer for each of the 12 states in the region), now joined to the FIA data. These 12 layers were combined using the 'merge' tool to create a "timber removals" layer.

NLCD 2011

The NLCD 2011 was used to identify forested land that falls within the GCPO LCC region.

Initial Data Processing. Pixels classified as 41, 42 and 43 (deciduous, evergreen, and mixed forest) were isolated in a "forest only" layer using the 'set null' tool.

A public lands mask was created for the purpose of separating public forest land from private forest land. This mask used the following input layers:

- National Conservation Easement Database and the Protected Area Database (2 layers): http://app.databasin.org/app/pages/datasetPage.jsp?id=84021a47599945169219665d587d1348
- Federal lands as listed by USGS: //nationalatlas.gov/atlasftp.html?openChapters=chpgov%2Cchpref%2Cchpbound#chpbound

All federal lands were masked out, however only select National Conservation Easement Database (NCED) and Protected Area Database (PAD) lands were used in the mask. Only easement ownership types listed as federal, local government, or state were included in the mask. Private conservation land was not masked out of the PAD layer because some private conservation lands are able to produce timber and we did not have the data to distinguish which ones those are. The complete federal lands layer and the manipulated NCED and PAD layers were combined to create a mask that represents only private land, and the inverse of the mask represents only public land.

This mask and its inverse were used to mask the “forest only” layer, creating “public forest” and “private forest” layers. It should be noted that some public forests may also not be available for timber harvests, but again we didn’t have data to distinguish which ones those were.

Analysis and Results

Forest Land. The “public forest” and “private forest” layers are a representation of where public and private forests exist within the GCPO LCC region (Figure 17). These forests include land-classes 41, 42, and 43 from the NLCD dataset (deciduous, evergreen, and mixed forests.) It should be noted that not all forest lands are available for timber harvests, due to varied protection status.

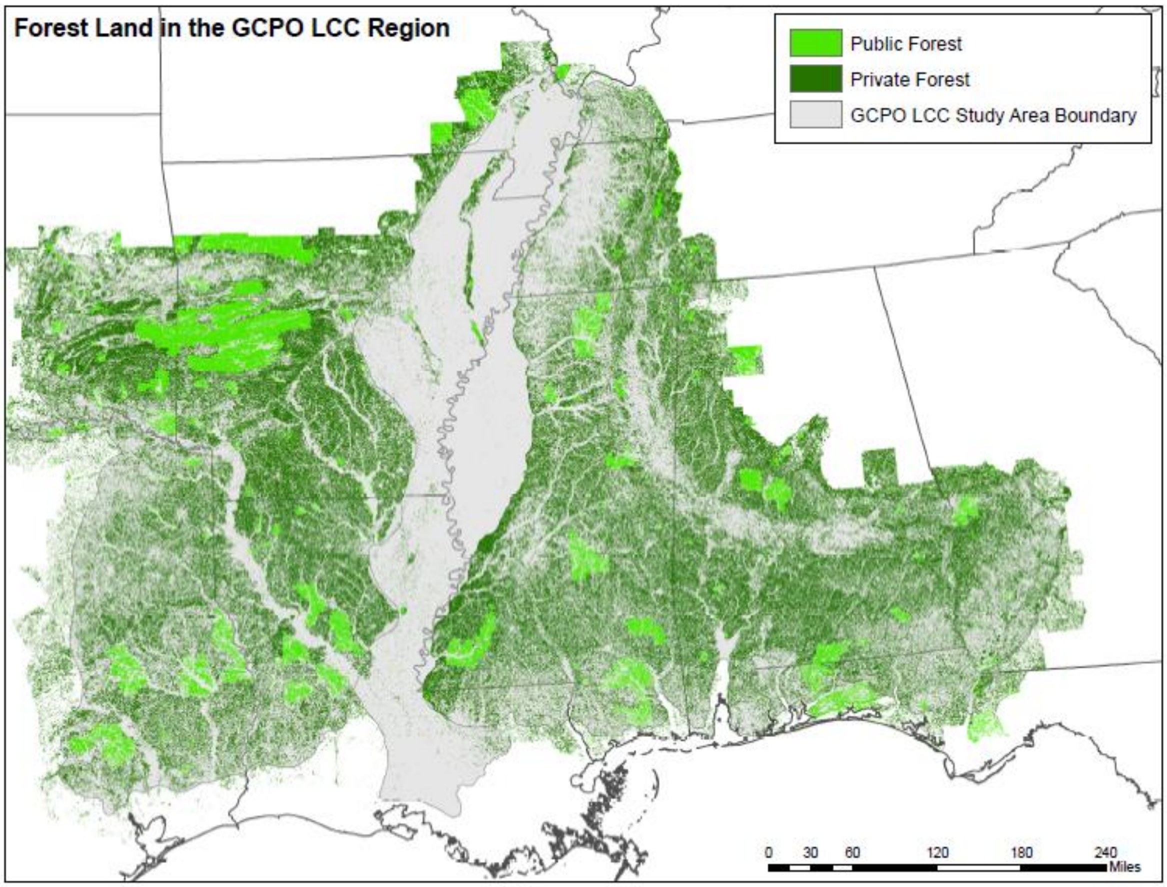
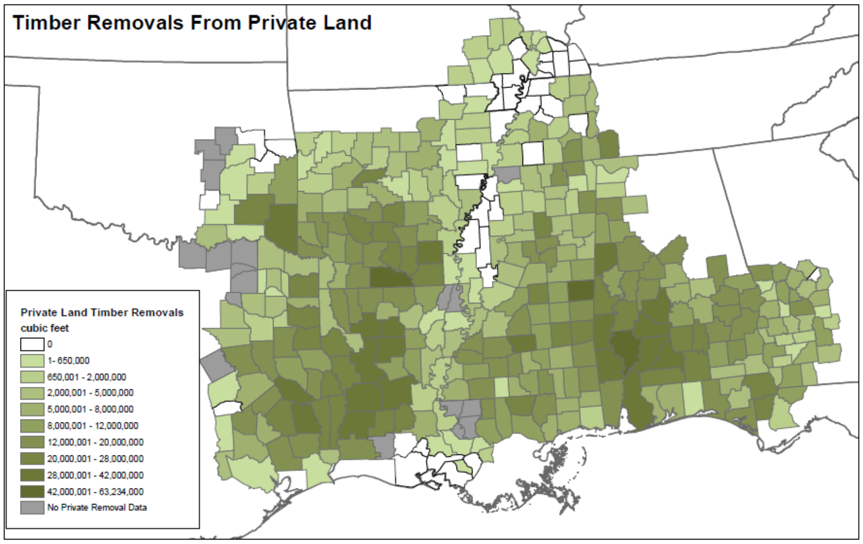


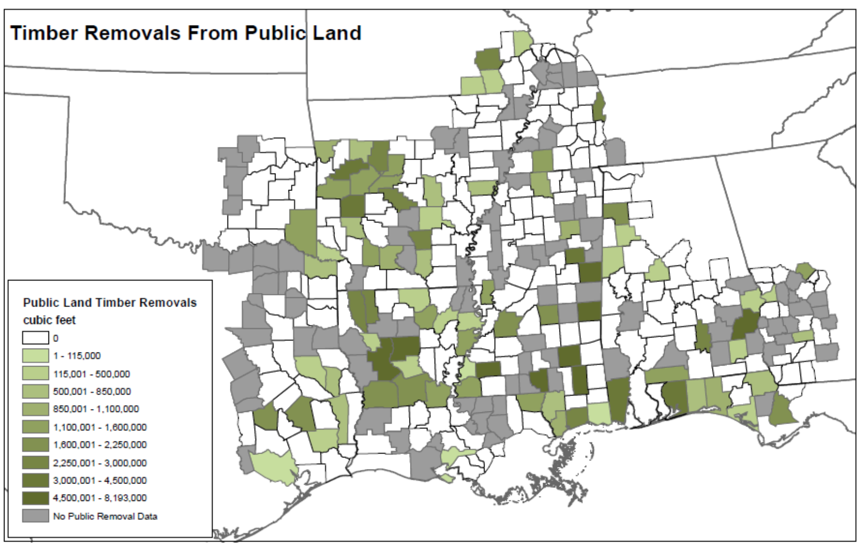
Figure 17: Existing public and private forested lands in the GCPO LCC subregion at a 30m resolution.

Timber Removals. By joining the FIA timber removals data to the GCPO LCC counties GIS data, the number of cubic feet of timber removed from each county can be visualized (Figure 18 a and b). Figure 2b makes clear how little public removals data are available. Figure 18a indicates that generally, private timber removals are highest in the southern portion of the region, just east and west of the borders of the Mississippi Alluvial Valley subgeography. Additionally, these maps indicate that merchantable timber in this region is mainly originating from private lands.

Private timber removal values are much higher than the public timber removals. The highest public removal for any one county is ~8 million cubic feet, while the highest private removal is ~63 million cubic feet. However, because so many counties do not have representative public removal data, it is unclear whether there truly is much higher removal from private lands or whether the high public timber removals counties are simply undocumented. It should be noted that percent standard error for this FIA removals data is relatively high, especially for public removals. The majority of public county removals values percent standard error was ≥50%.



a)



b)

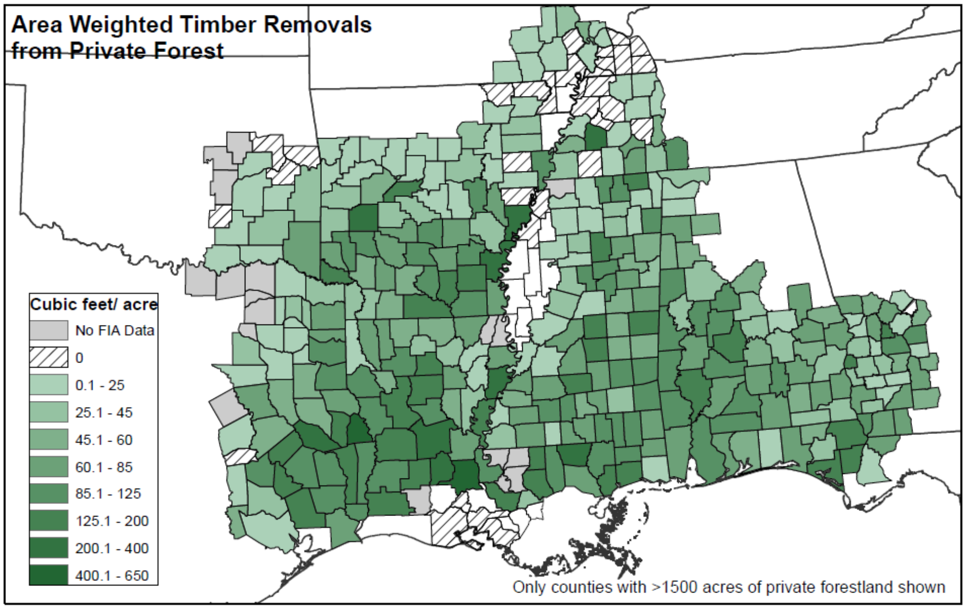
Figure 18: Growing stock (merchantable) timber removals by county from **a)** private forest land, and **b)** public forest land in the GCPO LCC subregion.

Area Weighted Timber Removals. Using the 'tabulate area' tool on the "public forest" and "private forest" layers using counties as zones, it was possible to calculate the total acreage of public and private forest in each county. This tabular information could be joined to the county timber removal GIS layer (used to create Figure 18) to create a new layer that displays cubic feet of timber removed per acre of forest land (cuft/ acre). To find area weighted timber removals for both public and private forests, two new columns were created in the GCPO LCC county attribute table. The first was filled with values that represent (public cuft/ public forest acreage), and the second with values that represent (private cuft/ private forest acreage). Those two columns can then be visualized in maps that indicate the cubic feet of timber removed per acre of forest, by county (Figure 19 a and b).

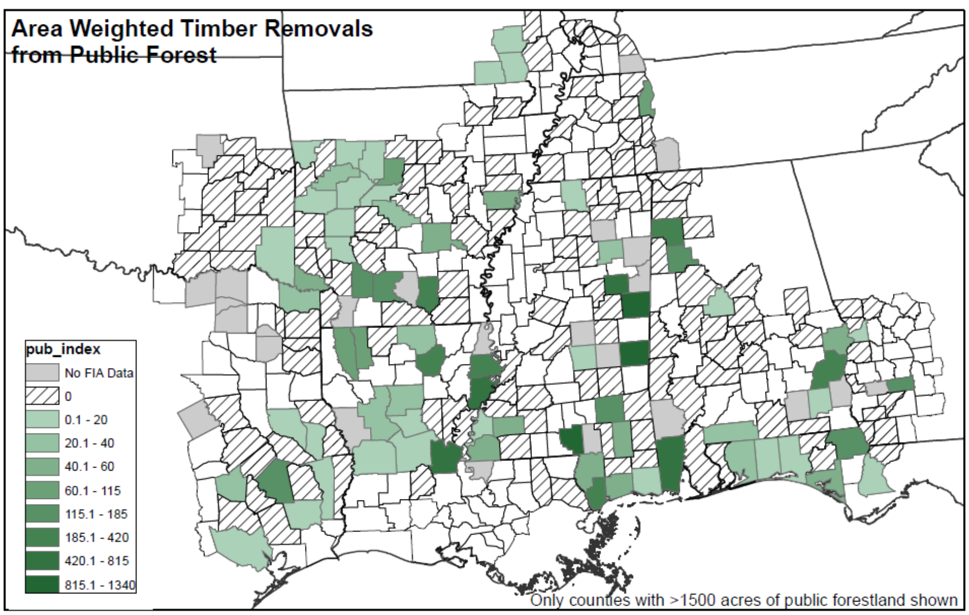
The maximum timber cuft/acre value for public timber removals is higher than that for private timber removals; the highest public cuft/acre value is 1330, while the highest private value is only 650. This could be due to multiple possible factors. Certain areas of public land could be more intensely logged than private land, meaning that there are more cubic feet of wood removed from an acre of public land that there would be from an acre of private land. However, this is unlikely the entire story. It could also be that of all private forest land, there are only very specific areas where logging is occurring. These logging locations are then diluted by other private forestland that is not being logged and the resulting private index values are relatively low. It is also possible that the public timber removals data is greatly biased, due to the very high percent standard error (≥50%) reported for much of the public timber removals data points downloaded from FIA.

Only counties with >1500 acres of private forestland or >1500 acres of public forestland are shown in figures 3a and 3b, respectively. This was done because it was found that counties with very low forestland areas had disproportionately high cuft/ acre values (cuft/ acre values were up to 20x higher than the rest of the values). By setting a threshold of 1500 acres of forestland, these outliers were eliminated.

It appears that the highest cuft/ acre private removals appear west of the Mississippi river, especially in the southwestern corner of the GCPO LCC region. Because the public data is so sparse, it is difficult to draw any regional conclusions about cuft/acre removals on public land.



a)



b)

Figure 19: a) The cubic feet of timber removed from private lands per acre of private forest, and b) the cubic feet of timber removed from public lands per acre of public forest. Cubic feet per acre are displayed by county in the GCOP LCC region.

NLCD vs. FIA Forestland Estimations. It was decided that NLCD forestland area estimations should be used for this analysis because FIA data was unavailable for many counties in the region, especially for public data. However, we did want to check our NLCD forestland area estimates for both public and private lands to make sure that the NLCD estimations were within reason. Using the following query FIA forestland acreages were downloaded for both public and private forests:

Region of Interest: AL, AR, FL, GA, IL, KY, LA, MO, MS, OK, TN, TX
Choose Reports: Area reports: Report 2.8 (area, in acres, by county and forest-type group)

Survey Years: 2013
Filter Options:

- Land (condition) attributes—ownership group
    - 1 set of reports was downloaded for private forest data, so "private" was chosen for ownership type
    - 1 set of reports was downloaded for public forest data, so "forest service," "other federal," and "state and local gov't" was chosen for ownership type

This provided data that could be joined to existing GIS county maps to make comparisons between NLCD forest acreage estimations and reported FIA acreages (Figure 20). These comparisons indicate that the trends in NLCD forestland and trends in FIA forestland are quite similar. Though the scales may be a bit different, the pattern across the landscape appears the same. Ranges of forestland acreages between the two data sources for public and private forest differ, but appear on the same relative scale. Private NLCD forestland acreage estimations by county range from 112- 586,000 acres, while FIA data range from 1435- 763,000 acres. Public NLCD forestland acreage estimations range from 0- 407,000 acres, while FIA data range from 367- 355,000 acres.

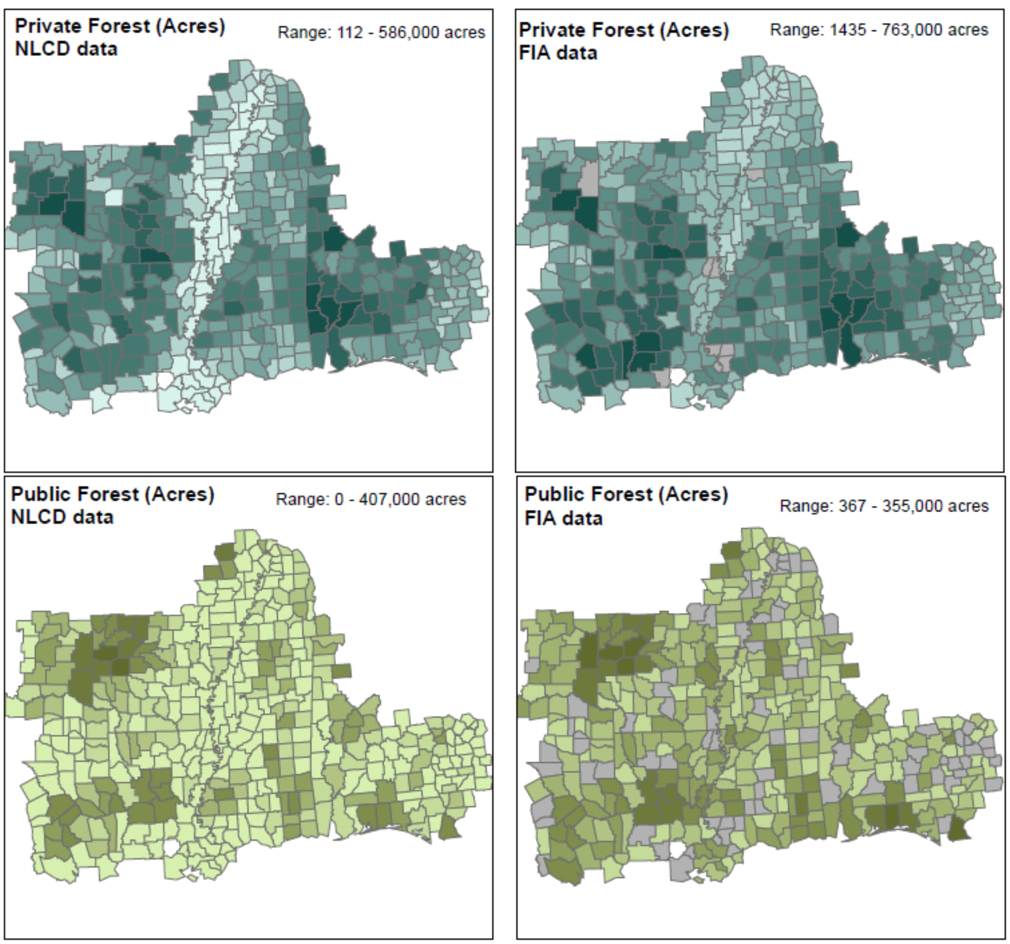


Figure 20: Maps comparing NLCD forestland acreage estimations with FIA forestland acreage reports. The top two maps compare private forest acreages and the bottom two maps compare public forest acreages. Ranges for each map's forestland acreages by county are included as text.

Citations

Homer, C. G., J. A. Dewitz, L. Yang, S. Jin, P. Danielson, G. Xian, J. Coulston, N. D. Herold, and J. D. Wickham. "K. Megown. 2015. Completion of the 2011 National Land Cover Database for the Conterminous United States-Representing a Decade of Land Cover Change Information." Photogrammetric Engineering and Remote Sensing 81, no. 5 (n.d.): 345–354.

O'Connell, Barbara M.; LaPoint, Elizabeth B.; Turner, Jeffery A.; Ridley, Ted; Pugh, Scott A.; Wilson, Andrea M.; Waddell, Karen L.; Conkling, Barbara L. 2015. The Forest Inventory and Analysis Database: Database description and user guide version 6.0.2 for Phase 2. U.S. Department of Agriculture, Forest Service. 748 p. [Online]. Available at web address: http://www.fia.fs.fed.us/library/database-documentation/

Oswalt, Sonja N.; Smith, W. Brad; Miles, Patrick D.; Pugh, Scott A. 2014. Forest Resources of the United States, 2012: a technical document supporting the Forest Service 2015 update of the RPA Assessment. Gen. Tech. Rep. WO-91. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. 218 p.

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Biodiversity (Richness and At-Risk Species)

The goal of this analysis is to map biodiversity and at-risk species within three subgeographies of the Gulf Coast Plains and Ozarks LCC (East Gulf Coastal Plain, West Gulf Coastal Plain, and Mississippi Alluvial Valley). We approximate this ecosystem service using data representing plant and animal species richness, concentrations of rare or threatened species, and ecosystem rarity.

Data Sources

EnviroAtlas

Southeastern Biodiversity. This layer is saved in the EnviroAtlas database as "biodiversity_SE." This dataset provides biodiversity metrics relating to species richness for all vertebrate species except fish. These data were used to create Figure 21.

Data Properties

The richness values are derived from species distribution models created by the Southeast GAP Analysis Project, and not from actual wildlife counts. This GAP project covers 9 southeastern states, only some of which fall within the GCPO LCC region, so this dataset covers roughly half of the GCPO LCC study area. The vertebrate distribution models created for GAP are based off of known range and habitat relationships and are created for all vertebrate species that breed in the Southeastern U.S. or use habitat there for an important part of their life history (Southeast GAP Analysis Project). Input variables for distribution models include, but are not limited to: landcover, habitat type, ecoregions, soils, elevation, hydrographic features, salinity, and distance to urban areas.

More Information about this EnviroAtlas layer can be found on the fact sheet here: https://enviroatlas.epa.gov/enviroatlas/DataFactSheets/pdf/ESN/MaximumTotalVertebrateSpeciesRichnessSoutheast.pdf

GAP at-risk Species

Data compiled for a project completed by the Nicholas Institute on at-risk species in the Southeast region provide a way of examining at-risk species in the GCPO LCC. These data are also based on GAP distribution models and were used to create Figure 22.

Data Properties

There are 764 at-risk species included in this dataset, consisting of species already listed as threatened or endangered under the ESA, candidate species for listing, and species petitioned for listing by the Center for Biological Diversity (Ihlo et al, 2015). The GAP species distributions for these 764 species were examined, and each HUC 8 and US county that a species falls within was documented. This analysis was carried out for the Southeast, which in this case was defined as AL, AR, FL, GA, KY, LA, MS, NC, SC, TN, and VA. The majority of the GCPO LCC study area is covered by this dataset.

EnviroAtlas

Nature Serve. This layer is saved in the EnviroAtlas database as "natureserve." This dataset provides information on the number of at-risk species (both plant and animal) found within each HUC 12. These threatened/ imperiled species are listed by major habitat type: terrestrial, aquatic, or wetland. At-risk species are classified as species listed as threatened or endangered under the Endangered Species Act or as G1 and G2 species listed by Nature Serve. G1 and G2 species are those with a global conservation status rank of critically imperiled or imperiled (Nature Serve, 2014). These data were used to create Figure 23.

Data Properties

The number of at-risk species is derived from occurrence data collected by Nature Serve. These occurrences are mapped and lists of all species occurring within each HUC 12 were created. The Nature Serve EnviroAtlas metadata makes a point to state that even for HUCs where no at-risk species are listed, it does not necessarily follow that no at-risk species are present in that HUC, only that no one has surveyed for these species in that location.

More information about this EnviroAtlas layer can be found on the fact sheet here:
https://enviroatlas.epa.gov/enviroatlas/DataFactSheets/pdf/ESN/TotalNumberofTerrestrialSpecies.pdf

US Fish and Wildlife Service Critical Habitat

When a species is listed under the Endangered Species Act as threatened or endangered the US Fish and Wildlife Service is required to delineate areas known as critical habitat, which are habitat areas considered critical for that species' survival. Critical habitat can consist of current habitat or habitat not currently occupied but deemed crucial for recovery (FWS, 2016). Critical habitat polygons and linear features were downloaded from the Environmental Conservation Online System and used to create Figure 24 and Table 2.

EnviroAtlas

Rare Ecosystems. This layer is saved in the EnviroAtlas database as "Ecosystem_Rarity_Metrics." Using GAP land cover data the EPA was able to derive an ecoform rarity metric that represents relative uniqueness and rarity of ecosystem types in the United States. There are values in this dataset documenting acres of rare ecosystem and percentage of rare ecosystem for each HUC 12. These data were used to create Figure 25.

Note: the utility of these data have been questioned by members of the GCPO LCC who see areas highlighted as "rare" according to these metrics that they do not believe deserve this designation. These data should be used with caution, and validation of rare ecosystems should be performed (for example, with the use of expert opinion) before they are used in decision-making.

More information about this EnviroAtlas layer can be found on the fact sheets here:
https://enviroatlas.epa.gov/enviroatlas/DataFactSheets/pdf/Supplemental/RareEcosystems.pdf
https://enviroatlas.epa.gov/enviroatlas/DataFactSheets/pdf/ESN/PercentRareEcosystem.pdf

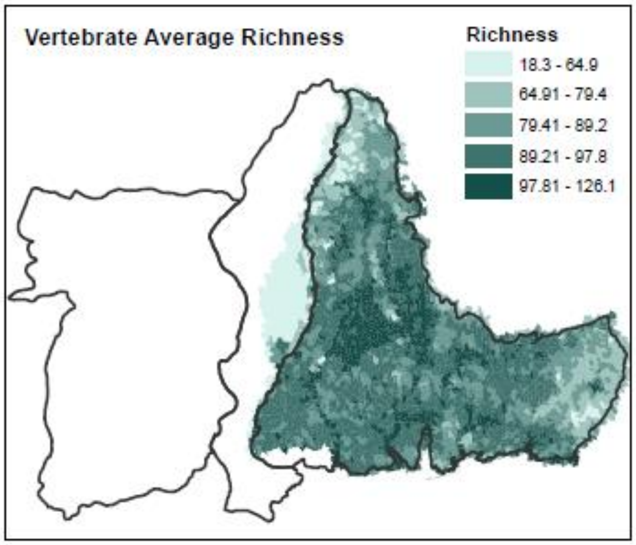
Analysis and Results

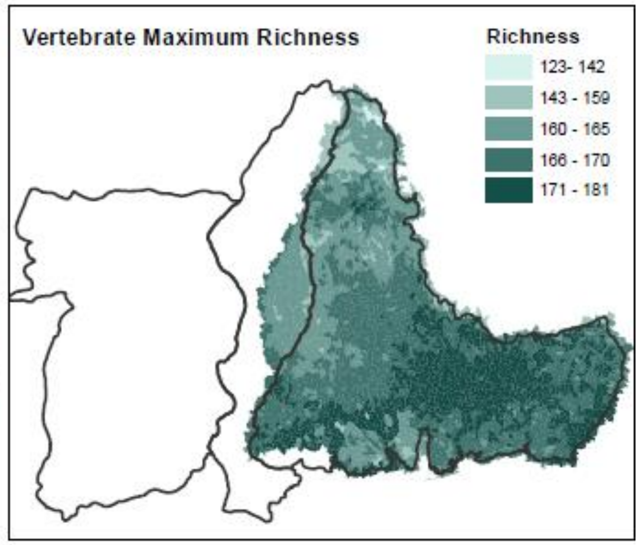
Species Richness: GAP Data. The EnviroAtlas Southeast Biodiversity dataset provides an easy way to visualize how vertebrate species fall across the GCPO LCC landscape (Figure 21). It is important to remember that these species richness values are derived from overlapping habitat distribution models, and not species surveys. Though these habitat models are crafted to agree with each species specific habitat preferences and geographic range, they could be over- or under-predicting which HUC 12s these species appear in.

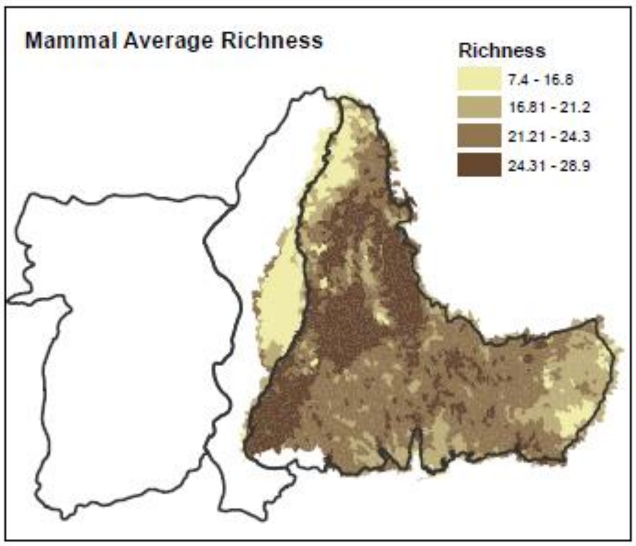
Species richness values for each HUC 12 are displayed by both maximum and average. These values were calculated for EnviroAtlas by overlaying all 606 available distribution models on top of each other. Maximum richness represents the value of the model-scale pixel within each HUC 12 that contains the most overlapping models. The average richness value represents the average number of species falling within all pixels in that particular HUC 12. Both maximum and average are important to take into consideration. Maximum richness represents the highest number of species predicted to appear in a HUC 12, meaning that if all 606 habitat models are correct, this would truly represent the number of species appearing in that HUC. This maximum value could be good for identifying areas important to examine more closely for restoration or conservation, because based on the GAP models there is a very high number of species that *could* live in that HUC. Alternatively, the average richness value gives a more general estimator for the number of species currently in each HUC. While maximum richness could be due to a single pixel occupied by many species' models, the average richness takes into account all the pixels in the HUC 12.

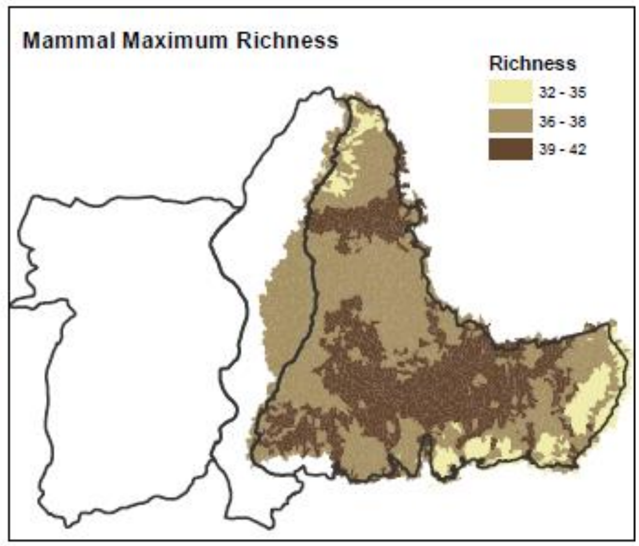
The EnviroAtlas metadata highlights the importance of the different richness values displayed here, which are paraphrased below:

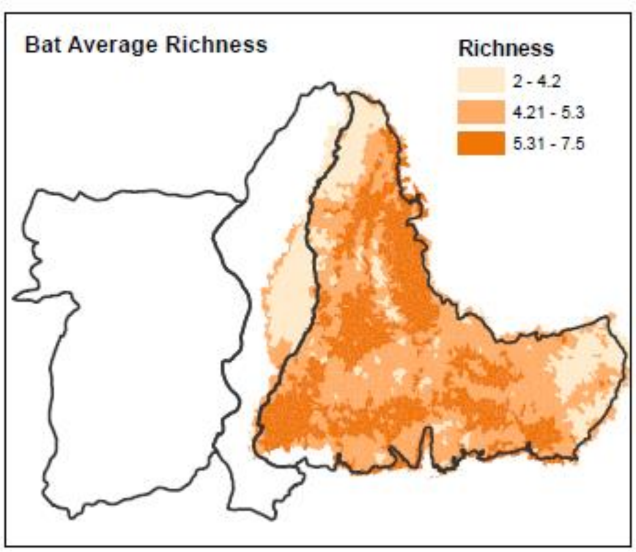
- Total vertebrate species richness can be indicative of recreational opportunities or aesthetic qualities […] Total Vertebrate Species Richness has been used as an indicator of the biodiversity conservation potential of an area and considered an important indicator of biodiversity 'hot spots.'
- Mammal species richness can include many large, charismatic species such as Elk and Deer, but also provide some of the main prey items for carnivorous wildlife. [They are often] important to ecological service categories related to biodiversity conservation and recreation, culture, and aesthetics.
- Bat species richness can indicate valuable pest control and pollination services. [Bats are] important to ecological service categories related to biodiversity conservation and food, fuel, and materials.
- Bird Species Richness can be indicative of recreational opportunities or aesthetic qualities. Birding is a multimillion dollar a year industry […] Bird Species Richness has been used as a major indicator of the biodiversity conservation potential of an area.
- Reptile species richness may indicate where certain reptiles (e.g. snakes) can play an important part in maintaining rodent populations. Other reptiles can be an important prey item for large animals.
- Amphibian species richness provides a characterization of species of national concern; in the last 20 years, amphibian declines have become a national focus. The reasons are varied, but amphibians can act as important sentinels for water quality and can highlight the negative effects of pollution and pesticides in our streams and rivers.

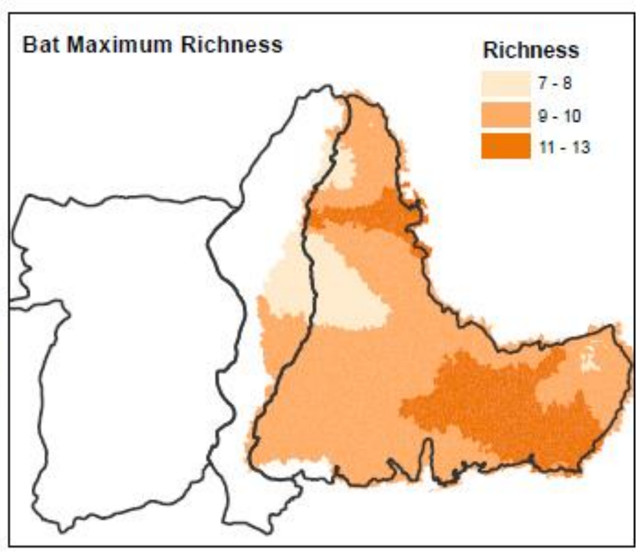

Vertebrate Average Richness
Richness
18.3 - 64.9
64.91 - 79.4
79.41 - 89.2
89.21 - 97.8
97.81 - 126.1


Vertebrate Maximum Richness
Richness
123- 142
143 - 159
160 - 165
166 - 170
171 - 181


Mammal Average Richness
Richness
7.4 - 16.8
16.81 - 21.2
21.21 - 24.3
24.31 - 28.9


Mammal Maximum Richness
Richness
32 - 35
36 - 38
39 - 42


Bat Average Richness
Richness
2 - 4.2
4.21 - 5.3
5.31 - 7.5


Bat Maximum Richness
Richness
7 - 8
9 - 10
11 - 13

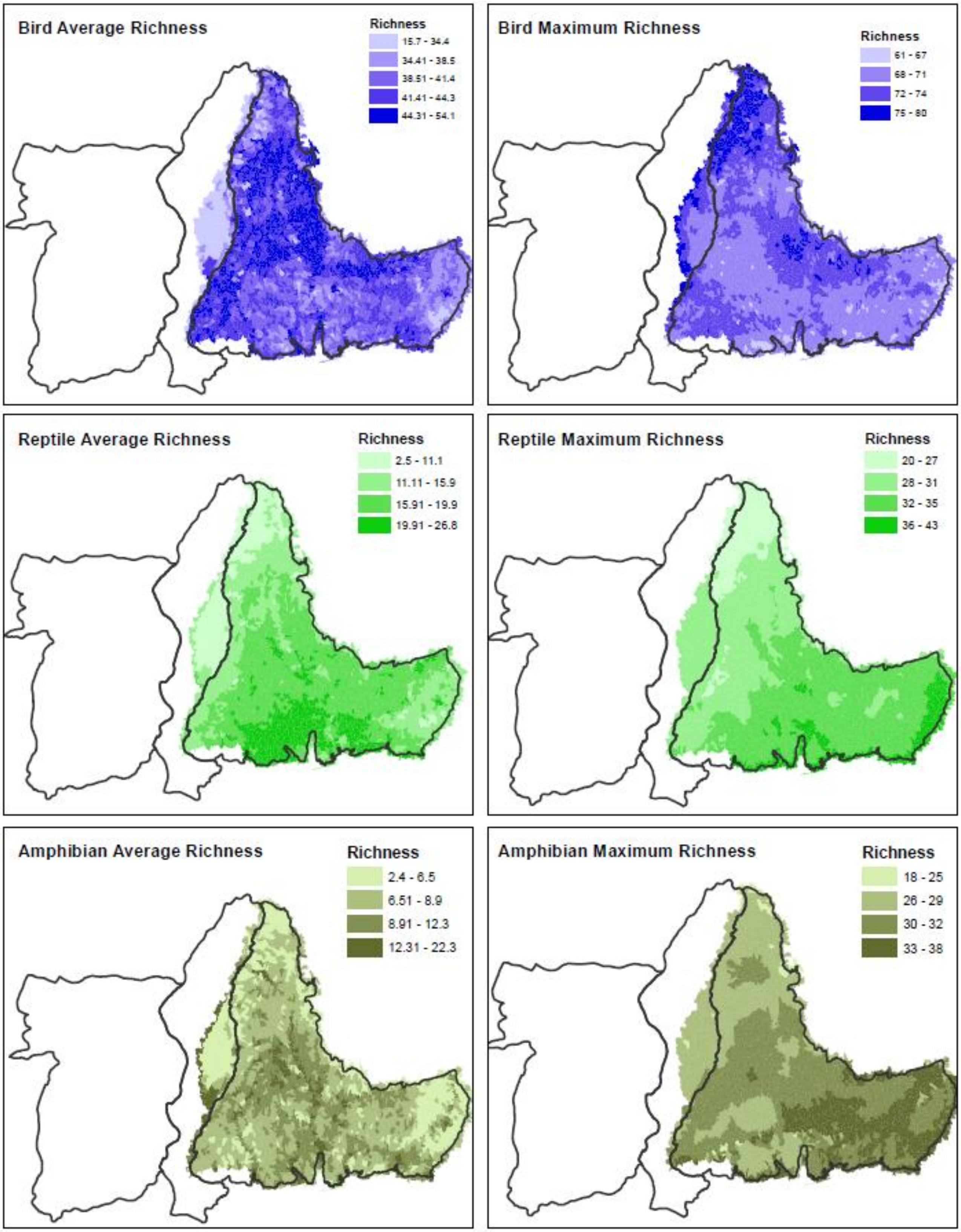
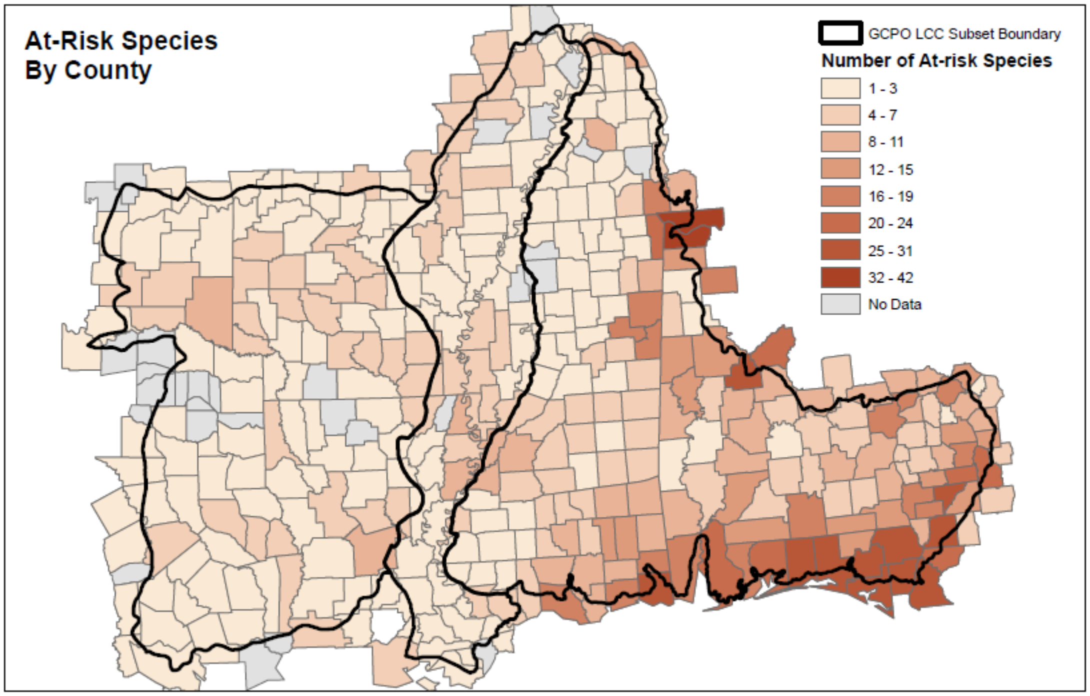
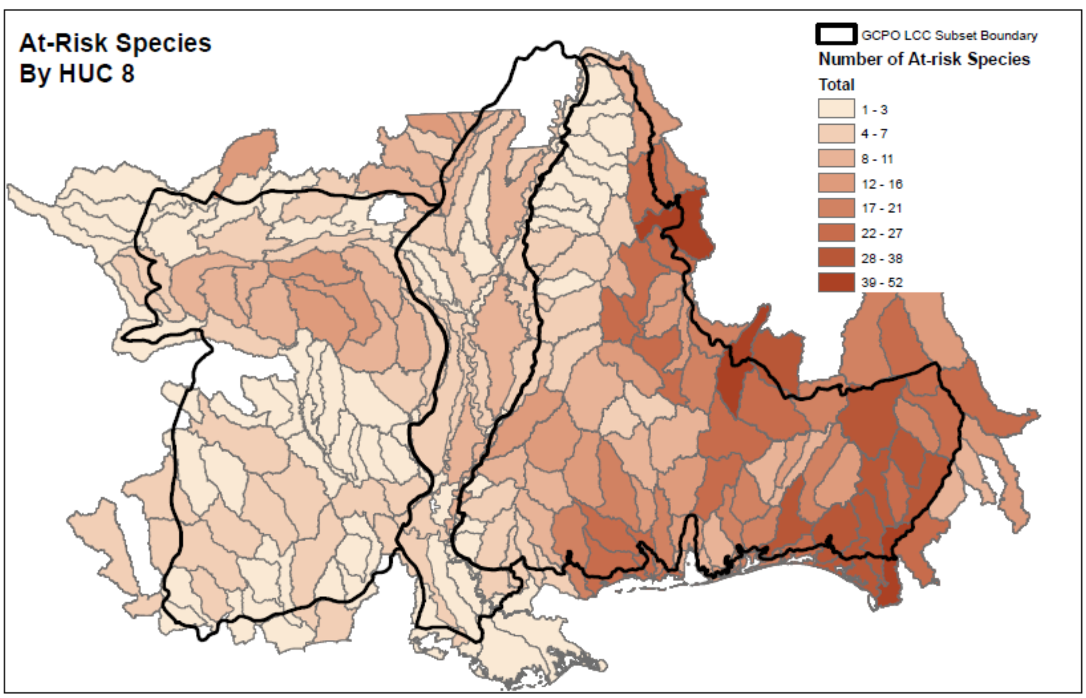


Figure 21: Species richness for vertebrates in the GCPO LCC as determined by GAP distribution models.

At-risk Species: GAP Data. By joining the excel tables of at-risk GAP species distributions to GIS layers for counties and HUC 8s it is possible to display how these at-risk species are spread across the landscape (Figure 22). These maps clearly indicate that the ranges of at-risk species are concentrated in the eastern portion of the GCPO LCC subregion.



a)

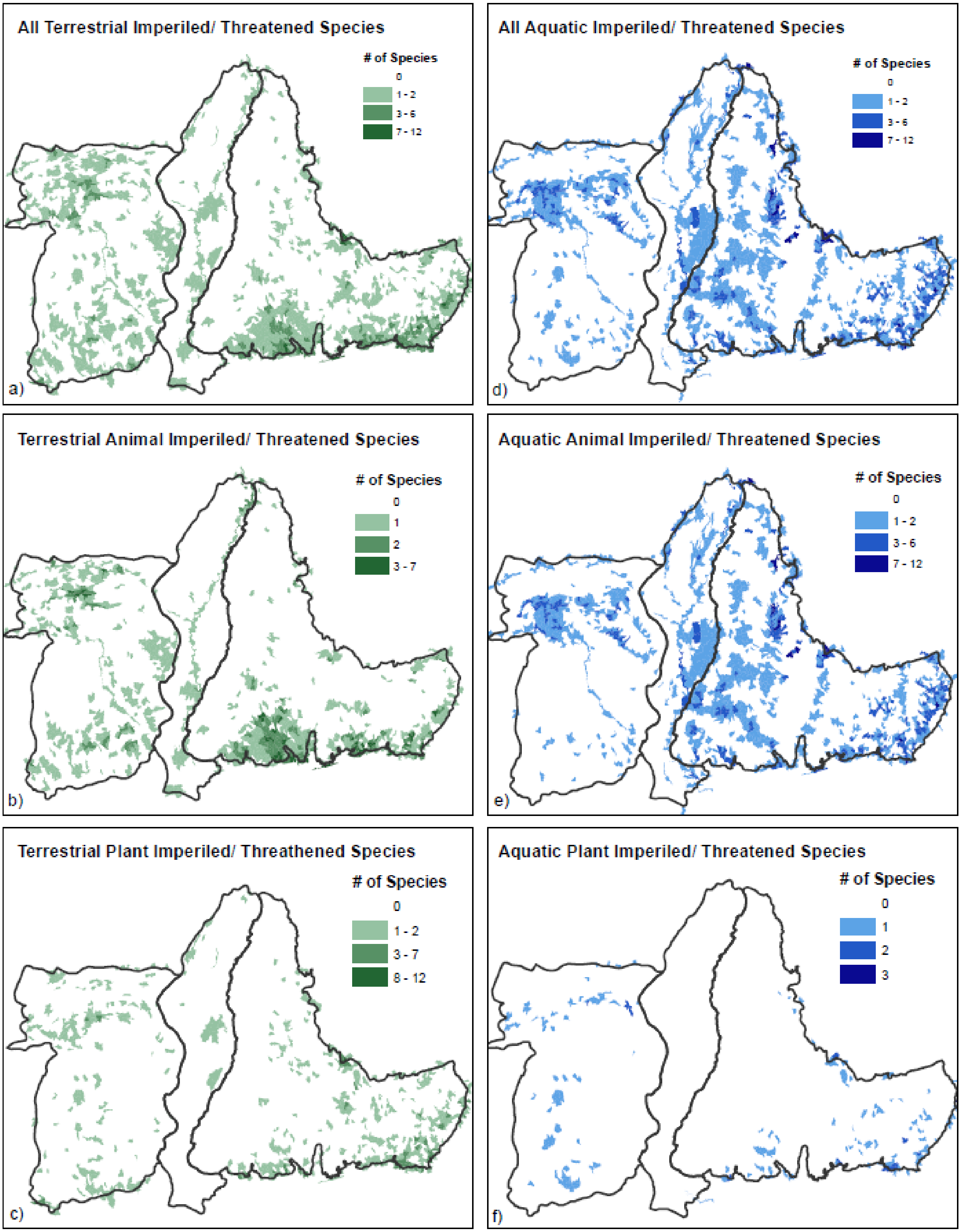


b)

Figure 22: The number of at-risk species (ESA listed, candidate, and petitioned species) in the GCPO LCC as determined by GAP distribution models for each **a)** county, and **b)** HUC 8.

At-risk Species: Occurrence Data. Another way to view at-risk species is by using the EnviroAtlas Nature Serve imperiled/ threatened species data. These data are based on at-risk species occurrences by HUC 12 rather than distribution models (Figure 23).

Both Figure 23 and Figure 22 display at-risk species, however the data sources and methods of data collection for these two maps are quite different. Figure 22 is based upon GAP distribution models. These models are limited in that they represent potential species distributions, rather than actual distributions based upon survey data. Figure 23 is based upon natural heritage occurrence data, however is also limited due to data collection methods. Natural heritage occurrence data are often logged erratically based on fortuitous encounters, rather than by systematic surveys. So while the data points are based on actual existence of a species in a particular HUC, it is important to note that there may only be one individual of that species. Additionally, there is no way of knowing from the Nature Serve dataset the full extent of these at-risk species, only where they have been recorded in the past. The strengths of the GAP dataset help compensate for the weaknesses of the natural heritage dataset, and vice versa. It is important to consider both datasets when examining at-risk species, but the relative importance of each should be established based on the nature of each specific inquiry.


All Terrestrial Imperiled/ Threatened Species
# of Species
0
1 - 2
3 - 6
7 - 12
a)
All Aquatic Imperiled/ Threatened Species
# of Species
0
1 - 2
3 - 6
7 - 12
d)
Terrestrial Animal Imperiled/ Threatened Species
# of Species
0
1
2
3 - 7
b)
Aquatic Animal Imperiled/ Threatened Species
# of Species
0
1 - 2
3 - 6
7 - 12
e)
Terrestrial Plant Imperiled/ Threathened Species
# of Species
0
1 - 2
3 - 7
8 - 12
c)
Aquatic Plant Imperiled/ Threatened Species
# of Species
0
1
2
3
f)

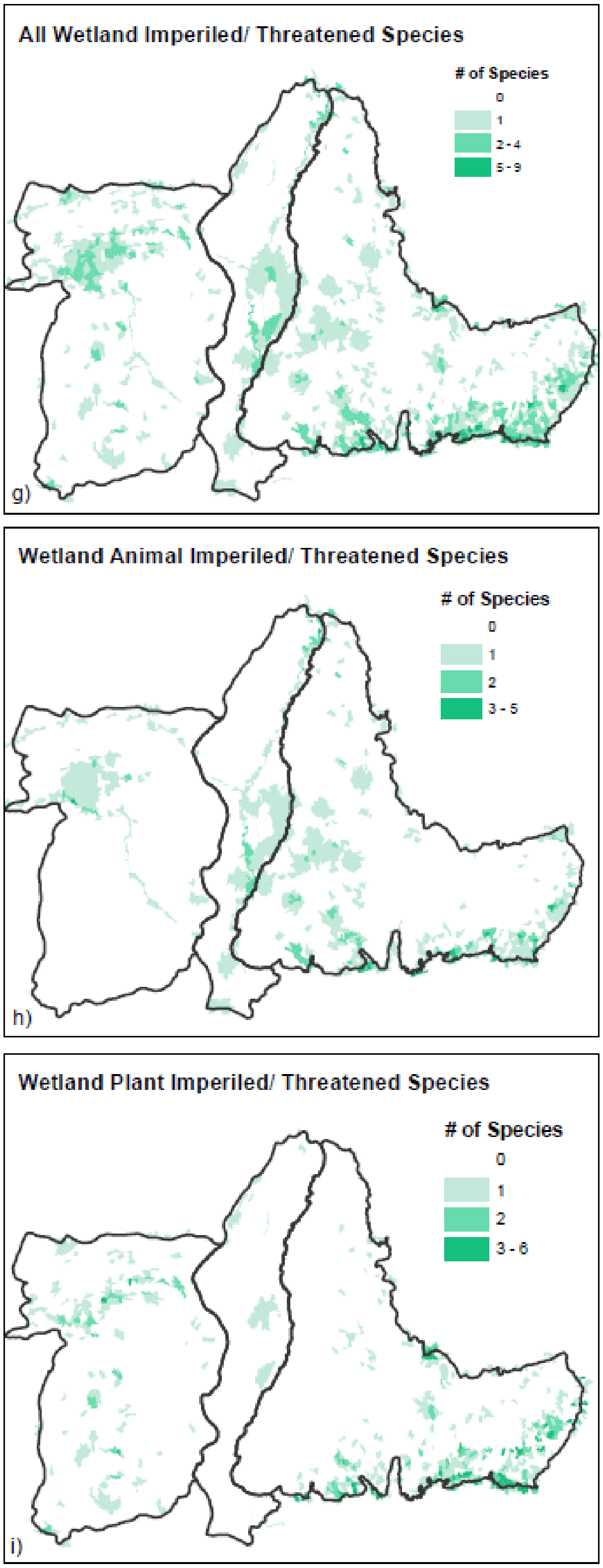


Figure 23: The number of at-risk species (ESA listed or Nature Serve G1/ G2 classified species) in the GCPO LCC as determined by occurrence data for each HUC 12; a-c show terrestrial species, d-f show aquatic species, and g-i show wetland species.

Critical Habitat. US Fish and Wildlife Service designated critical habitats for threatened and endangered species are shown in Figure 4. Details on the species represented are documented in Table 2.

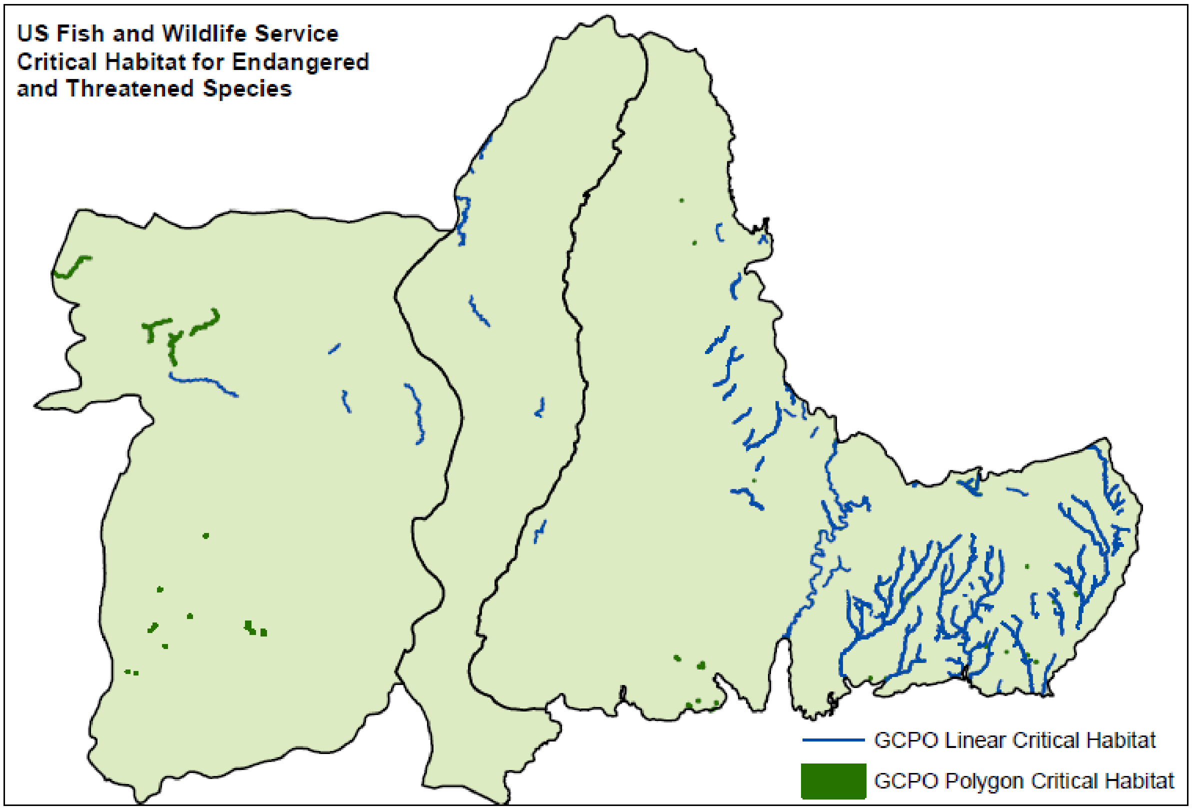
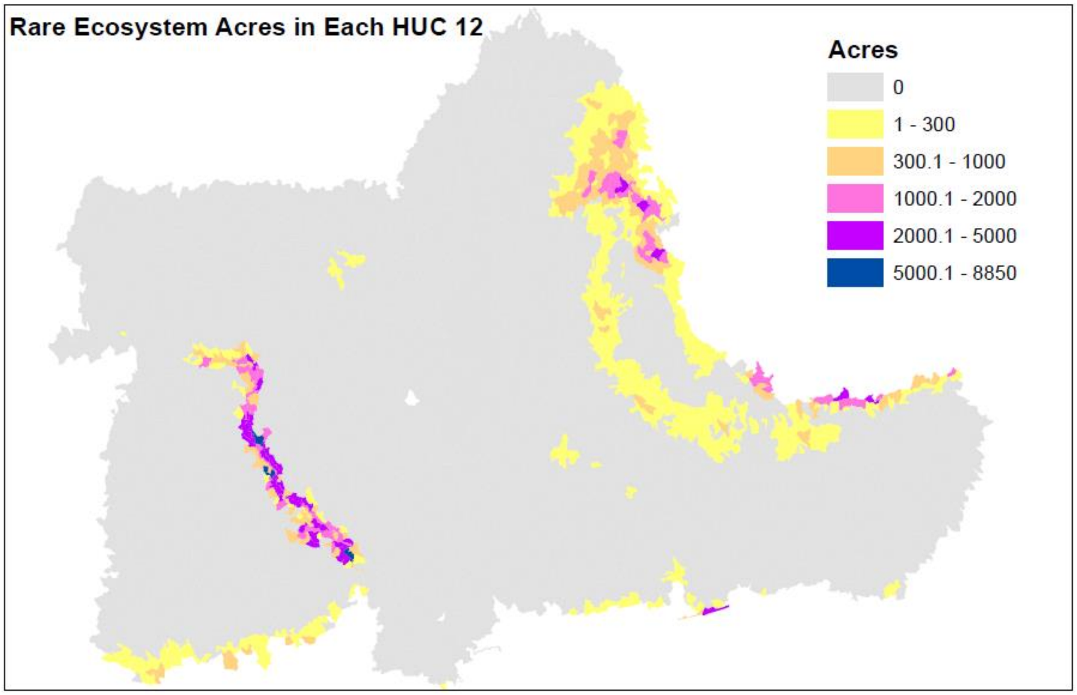


Figure 24: US Fish and Wildlife critical habitat in the GCPO LCC subregion.

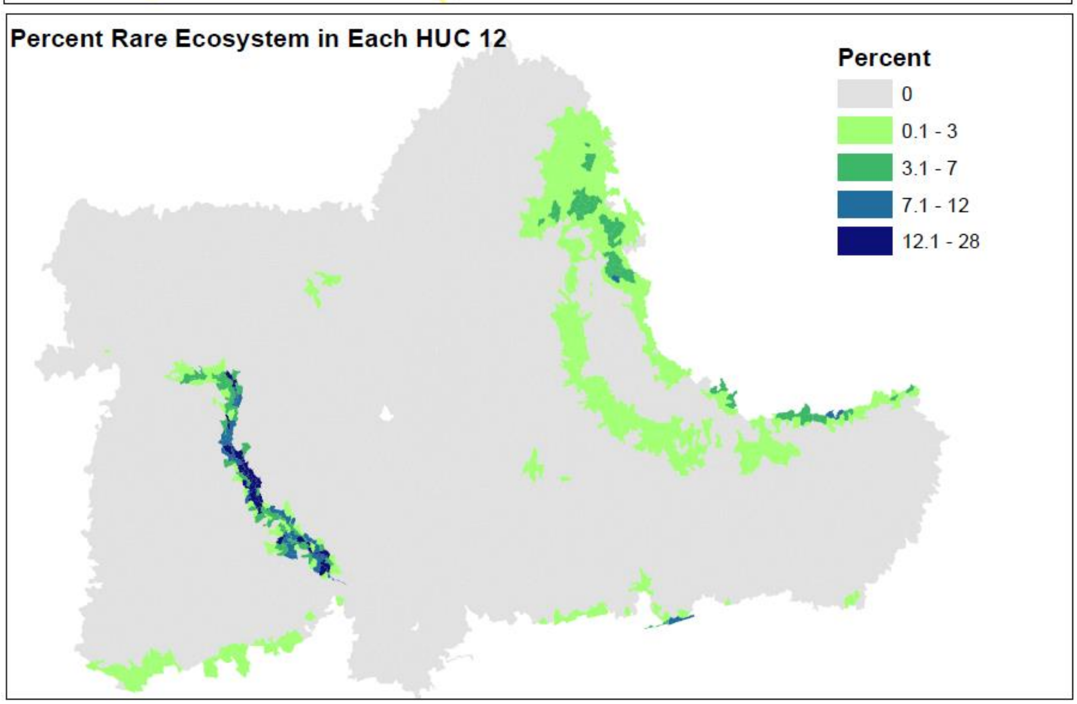
Table 2: ESA endangered and threatened species with critical habitat falling within the GCPO LCC subregion.

Common Name	**Scientific Name**	**Listing Status**
Fat threeridge (mussel)	*Amblema neislerii*	Endangered
Reticulated flatwoods salamander	*Ambystoma bishopi*	Endangered
Georgia rockcress	*Arabis georgiana*	Threatened
Chipola slabshell	*Elliptio chipolaensis*	Threatened
Purple bankclimber (mussel)	*Elliptoideus sloatianus*	Threatened
Cumberlandian combshell	*Epioblasma brevidens*	Endangered
Oyster mussel	*Epioblasma capsaeformis*	Endangered
Upland combshell	*Epioblasma metastriata*	Endangered
Southern acornshell	*Epioblasma othcaloogensis*	Endangered
Slackwater darter	*Etheostoma boschungi*	Threatened
Narrow pigtoe	*Fusconaia escambia*	Threatened
Narrow pigtoe	*Fusconaia escambia*	Threatened
Round Ebonyshell	*Fusconaia rotulata*	Endangered
Mississippi sandhill crane	*Grus canadensis pulla*	Endangered
Southern sandshell	*Hamiota australis*	Threatened
Whorled Sunflower	*Helianthus verticillatus*	Endangered
Neches River rose-mallow	*Hibiscus dasycalyx*	Threatened
Finelined pocketbook	*Lampsilis altilis*	Threatened
Orangenacre mucket	*Lampsilis perovalis*	Threatened
Shinyrayed pocketbook	*Lampsilis subangulata*	Endangered
Texas golden Gladecress	*Leavenworthia texana*	Endangered
Interrupted (=Georgia) Rocksnail	*Leptoxis foremani*	Endangered
Alabama pearlshell	*Margaritifera marrianae*	Endangered
Alabama moccasinshell	*Medionidus acutissimus*	Threatened
Gulf moccasinshell	*Medionidus penicillatus*	Endangered
Black warrior (=Sipsey Fork) Waterdog	*Necturus alabamensis*	Proposed Endangered
Arkansas River shiner	*Notropis girardi*	Threatened
Leopard darter	*Percina pantherina*	Threatened
Southern clubshell	*Pleurobema decisum*	Endangered
Dark pigtoe	*Pleurobema furvum*	Endangered
Ovate clubshell	*Pleurobema perovatum*	Endangered
Oval pigtoe	*Pleurobema pyriforme*	Endangered
Fuzzy pigtoe	*Pleurobema strodeanum*	Threatened
Rough hornsnail	*Pleurocera foremani*	Endangered
Slabside Pearlymussel	*Pleuronaia dolabelloides*	Endangered
Triangular Kidneyshell	*Ptychobranchus greenii*	Endangered
Southern kidneyshell	*Ptychobranchus jonesi*	Endangered
Rabbitsfoot	*Quadrula cylindrica cylindrica*	Threatened
dusky gopher frog	*Rana sevosa*	Endangered
Alabama sturgeon	*Scaphirhynchus suttkusi*	Endangered
Choctaw bean	*Villosa choctawensis*	Endangered

Rare Ecosystems. Rare ecosystems can be indicative of endemic species and therefore high biodiversity. The EPA has developed a normalized ecosystem rarity metric that ranges from 0-100. Any ecosystem classified with a rarity metric ≥75 is documented in the EnviroAtlas rare ecosystem dataset. These ecosystems falling within the HUC 12s of the GCPO LCC can be visualized in Figure 25 by both acreage and area percentage. These rare ecosystems appear in long narrow strips, falling mainly along water features.



a)



b)

Figure 25: Rare ecosystems in each HUC 12 in the GCPO LCC subregion shown by **a)** acres of rare ecosystem, and **b)** percent rare ecosystem area.

Citations

"ECOS: U.S. FWS Threatened & Endangered Species Active Critical Habitat Report." 2016. Accessed October 26, 2016. http://ecos.fws.gov/ecp/report/table/critical-habitat.html.

Ihlo, Christy, Dean Urban, Lydia Olander, and Christopher Galik. 2015. "Exploratory Analysis of Characteristics and Trends of At-Risk Species in the Southeast US: Background, Scope, Methods, and References." Nicholas Institute for Environmental Policy Solutions. https://nicholasinstitute.duke.edu/sites/default/files/esa_scoping_part1.pdf.

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Nature Serve. 2014. "Conservation Status Assessment." Text. February 6. http://www.natureserve.org/conservation-tools/conservation-status-assessment.

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United States Environmental Protection Agency. EnviroAtlas. Ecosystem_Rarity_Metrics. Retrieved: January 29, 2015, from enviroatlas.epa.gov/enviroatlas.

United States Environmental Protection Agency. EnviroAtlas. natureserve. Retrieved: January 29, 2015, from enviroatlas.epa.gov/enviroatlas.

Recreational Hunting and Birding

The goal of this analysis is to map hunting and birding recreational services within three subgeographies of the Gulf Coast Plains and Ozarks LCC (East Gulf Coastal Plain, West Gulf Coastal Plain, and Mississippi Alluvial Valley). Multiple types of hunting are encompassed in this analysis, including small and large game hunting, fur-bearer hunting, and waterfowl hunting. We approximate hunting services using data representing harvestable species richness, waterfowl harvest records, and public hunting areas. Birding services are approximated using bird species richness and Bird Life International's Important Bird Areas.

Data Sources

EnviroAtlas

Southeastern Biodiversity. This layer is saved in the EnviroAtlas database as "biodiversity_SE." This dataset provides biodiversity metrics relating to species richness for all vertebrate species except fish.

Data Properties

The richness values are derived from species distribution models created by the Southeast GAP Analysis Project, and not from actual wildlife counts. This GAP project covers 9 southeastern states, only some of which fall within the GCPO LCC region, so this dataset covers roughly half of the GCPO LCC study area. The vertebrate distribution models created for GAP are based off of known range and habitat relationships and are created for all vertebrate species that breed in the Southeastern U.S. or use habitat there for an important part of their life history (Southeast GAP Analysis Project). Input variables for distribution models include, but are not limited to: landcover, habitat type, ecoregions, soils, elevation, hydrographic features, salinity, and distance to urban areas. EnviroAtlas GAP biodiversity data used in this analysis include those layers relating to harvestable species richness and bird species richness.

Note: the utility of these data have been called into question by some members of the GCPO LCC. We chose to leave them in the report as a reference, but use caution if these data are to be used for decision-making.

More information about these EnviroAtlas layers can be found on the fact sheets here:
https://enviroatlas.epa.gov/enviroatlas/DataFactSheets/pdf/ESN/MaximumTotalHarvestableSpeciesRichnessSoutheast.pdf
https://enviroatlas.epa.gov/enviroatlas/datafactsheets/pdf/ESN/Meanbirdspeciesrichnesssoutheast.pdf

US Fish and Wildlife Service Waterfowl Harvests

The US Fish and Wildlife Service (FWS) conducts annual hunter surveys to estimate the number of waterfowl harvested in the United States. Though this data is published at the flyway and state level, in order to get county-level data we had to contact the Harvest Surveys Branch of the FWS. They were able to provide duck and goose harvest estimates from 2012-2014 for each county in the GCPO where hunters were surveyed.

Data Properties

Duck and goose harvest estimates are made based on hunter surveys conducted for hunters who purchased federal duck stamps (one form of a hunting license for waterfowl). Each state wildlife agency collects data on hunters with licenses and reports to the national Harvest Inventory Program. Survey recipients are then chosen randomly by the FWS Harvest Inventory Program and stratified by the previous year's hunting success. Survey results received from hunters are scaled up to represent all hunters within a county, state, or flyway.

Harvest data for all ducks and geese during the years 2012-2014 were made available to us at a county level. Not all counties in the GCPO LCC had harvest data, however the FWS informed us that a county may have no data reported simply because no hunters were surveyed there during the years 2012-2014 and not necessarily because there were no waterfowl harvests. Data reported here (Figure 27) show the average harvest value for ducks and geese over the 3 year period 2012-2014. Some counties did not have data for all three years, so instead the value shown may be an average of two years or one year of survey data. Our contact at the FWS noted that while this data is available at the county scale, it is collected primarily for analysis at larger scales (states or flyways). The harvest numbers reported here are annually variable and should be taken as a rough estimate.

More information about the Harvest Inventory Program survey techniques can be found here: https://www.fws.gov/migratorybirds/pdf/surveys-and-data/HarvestSurveys/MBHActivityHarvest2013-14and2014-15.pdf

Protected Areas Database

The Protected Areas Database created by the Conservation Biology Institute is available on Data Basin. This dataset provides outlines of all protected areas registered in the United States and includes data attributes about each protected area's ownership, management designations, and conservation status (Conservation Biology Institute, 2015).

Initial Data Processing. Protected areas were filtered to show only lands where hunting is permitted to create a 'public hunting lands' layer. Using the 'Select by Attribute' tool in ArcMap, only protected areas designated as "Wildlife Management Area," "State Wildlife Management Area," "State Game Land," or "State Fishing or Hunting Unit," were included. Additionally, National Wildlife Refuges where hunting is permitted were also included in the public hunting lands layer. A US Fish and Wildlife Service website provides lists of which refuges allow hunting (US Fish and Wildlife Service, 2012).

Important Bird Areas

Bird Life International has created a list of Important Bird Areas (IBAs). The National Audubon Society is the US representative for Bird Life International and hosts the US database for IBAs. IBAs are lands that include essential habitat for at least one species of bird. These sites may be essential for various life history processes including breeding, wintering, or migrating. The sites are designated by Bird Life International regardless of current status as public/ private or protected/ unprotected; as long as a site is deemed important for birds it can be included in the IBA database. To qualify for inclusion, a site must fulfill at least one of the following four requirements: 1) support at least one species of conservation concern, 2) support a restricted range species, 3) support species that have very specific habitat requirements, or 4) support species or groups of species that are vulnerable due to congregative behavior. Each IBA is also given a designation of global, continental, or state importance (Audubon Society, 2010).

Audubon does not publish the IBA GIS layer, but it can be requested for research purposes from their website. We were granted access to this data in July 2016.

For more information on IBA criteria, designation and prioritization see here: http://web4.audubon.org/bird/iba/criteria.html

eBird

The Cornell Lab of Ornithology created eBird to establish a word wide dataset on birds. The data are crowd-sourced, and voluntary participants from around the world enter data on a daily basis. Each data entry includes information about the bird species, number of birds seen, location of the siting, and search time, among other variables. Once a user creates an eBird account, that user can request access to the full eBird database in order to download data from the "download data" tab at the bottom of the linked webpage. By mapping the location of eBird data collection points we aim to approximate the locations that birders value most. It should be noted that there is no distinction between data collected by amateur and more experienced birders, and there is no way to distinguish between observations taken on a birding trip vs. those taken on a daily basis (with the assumption that observations taken on a birding trip would represent locations more valued by birders).

Data was downloaded from the data portal, using data from the "Basic Dataset (EBD)" and the following query:

Species: download all species
Region: downloaded data by state (12 downloads were completed, one for each of the states falling within the GCPO LCC region of interest. The national dataset is very large, and it is easier to work with individual state datasets).
Date Range: January 2015-January 2016 (it was assumed that birders may frequent different areas at different times of year, so an entire recent year of data was downloaded).
Un-vetted data points were not included

Once a data request is made, a link to the data is delivered to the user via email. Clicking the link will begin the data download, which arrives in a zipped file format.

Initial Data Processing. The text files containing eBird observations for each state were saved in excel. The longitude and latitude of each observation was used to plot observation points in ArcMap. These xy point layers were then saved as shapefiles. The 12 state xy shapefiles were then combined into one point layer, and clipped to the GCPO LCC region. Using a spatial join, the number of eBird observation points falling within each HUC 12 could be counted, producing a map that displays HUC 12s by the number of eBird observations within (Figure 31).

Analysis and Results

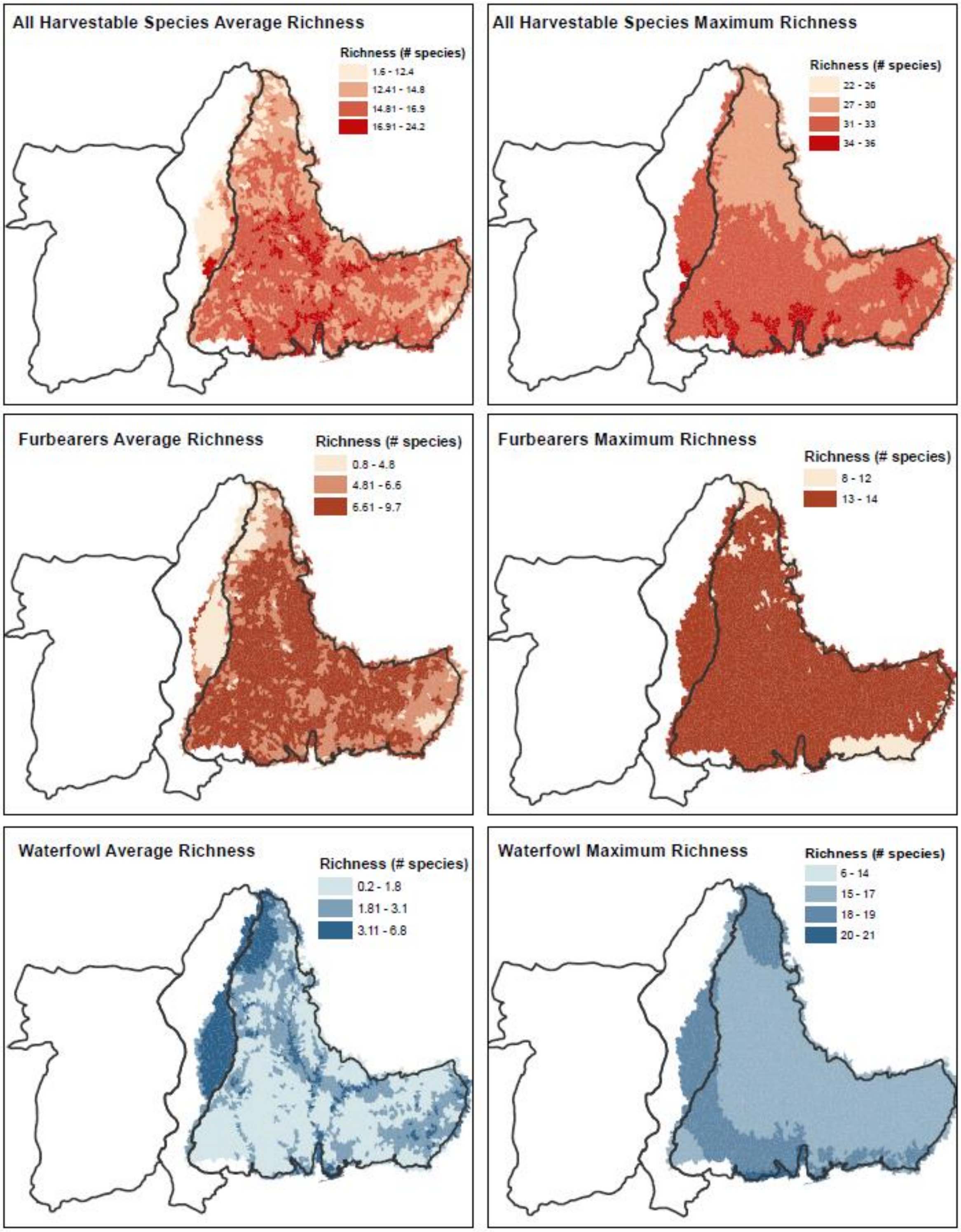
Harvestable Species Richness. The EnviroAtlas Southeast Biodiversity dataset provides an easy way to visualize how harvestable species fall across the GCPO LCC landscape (Figure 26). It is important to remember that these species richness values are derived from overlapping habitat distribution models, and not species surveys.

Species richness values for each HUC 12 are displayed by both maximum and average. These values were calculated for EnviroAtlas by overlaying all relevant distribution models on top of each other. Maximum richness represents the value of the model-scale pixel within each HUC 12 that contains the most overlapping models. The average richness value represents the average number of species falling within all pixels in that particular HUC 12. Both maximum and average are important to take into consideration. Maximum richness represents the highest number of species predicted to appear in a HUC 12, meaning that if all habitat models are correct, this would truly represent the number of species appearing in that HUC. This maximum value could be good for identifying areas important to examine more closely for restoration or conservation, because based on the GAP models there are a very high number of species that could live in that HUC. Alternatively, average richness values give a more general estimator for the number of species currently in each HUC. While maximum richness could be due to a single pixel occupied by many species' models, the average richness takes into account all the pixels in the HUC 12.

The EnviroAtlas metadata highlights the importance of the different richness values displayed here, which are paraphrased below:

- Total harvestable species richness identifies the number of harvestable terrestrial vertebrate species (defined by state hunting regulations) [and are] important to ecological service categories related to food, fuel and materials and recreation, culture, and aesthetics. These species are regulated by state wildlife agencies in in Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia. Harvestable species are an important source of food and revenue in many states. Wildlife agencies in many states rely on proceeds from hunting licenses to fund conservation activities within the state. Hunting also provides a significant source of recreation along with supplying food.

- Small game species richness is important to ecological service categories related to food, fuel and materials and recreation, culture, and aesthetics.
- Big game species richness is important to ecological service categories related to food, fuel and materials and recreation, culture, and aesthetics. These species also represent watchable wildlife. Species include elk, mule deer, and pronghorn.
- Furbearer species richness is important to ecological service categories related to food, fuel and materials and recreation, culture, and aesthetics. These species are often trapped for the main purpose of the fur trade. Species include beaver, badger, and marten.
- Waterfowl species richness is important to ecological service categories related to food, fuel and materials and recreation, culture, and aesthetics. Also, revenue is generated from the sale of "duck stamps" as a federal license required for hunting migratory waterfowl. Birders may also purchase these stamps to gain free access to national wildlife refuges.


All Harvestable Species Average Richness
Richness (# species)
1.6 - 12.4
12.41 - 14.8
14.81 - 16.9
16.91 - 24.2
All Harvestable Species Maximum Richness
Richness (# species)
22 - 26
27 - 30
31 - 33
34 - 36
Furbearers Average Richness
Richness (# species)
0.8 - 4.8
4.81 - 6.6
6.61 - 9.7
Furbearers Maximum Richness
Richness (# species)
8 - 12
13 - 14
Waterfowl Average Richness
Richness (# species)
0.2 - 1.8
1.81 - 3.1
3.11 - 6.8
Waterfowl Maximum Richness
Richness (# species)
6 - 14
15 - 17
18 - 19
20 - 21

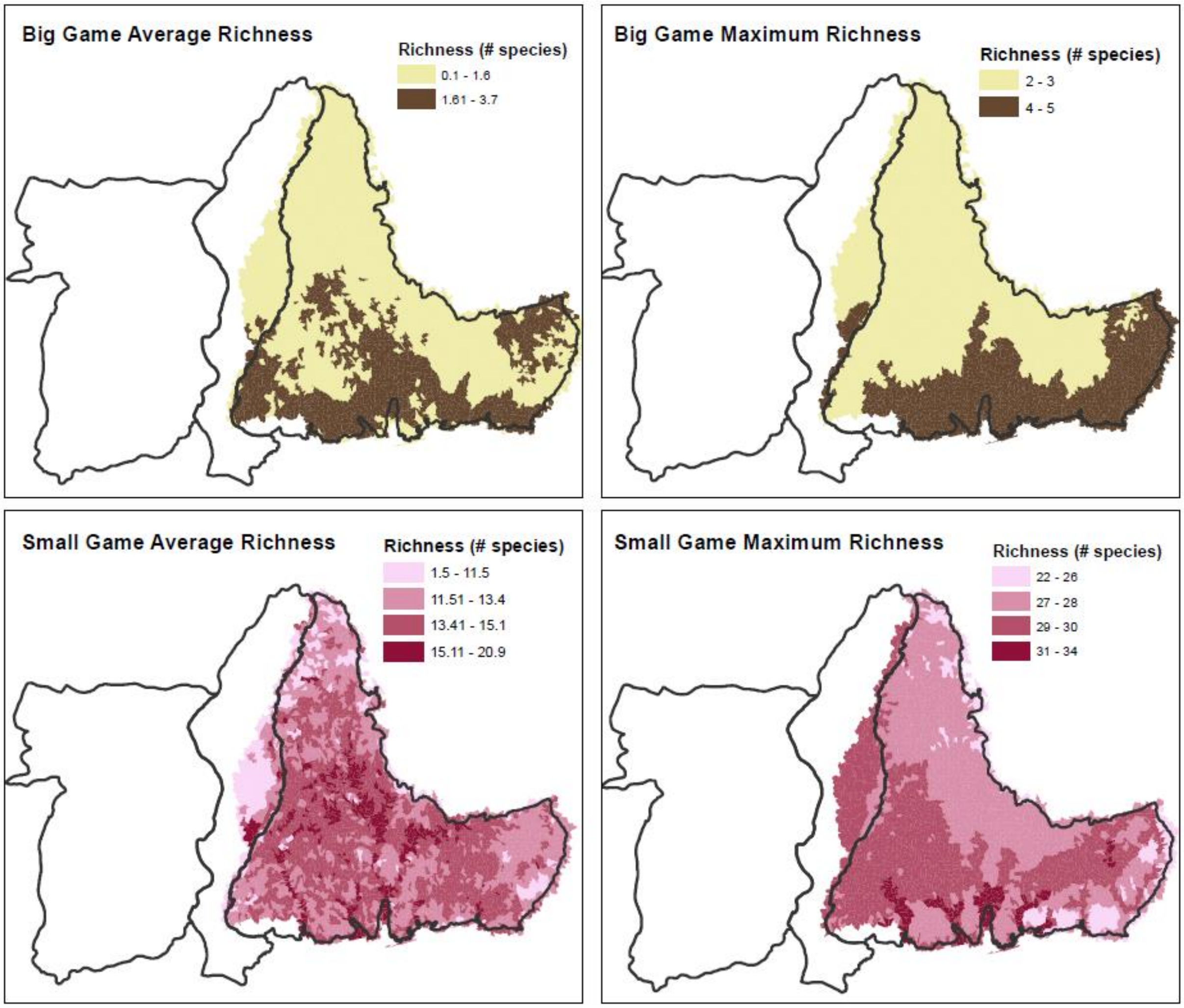
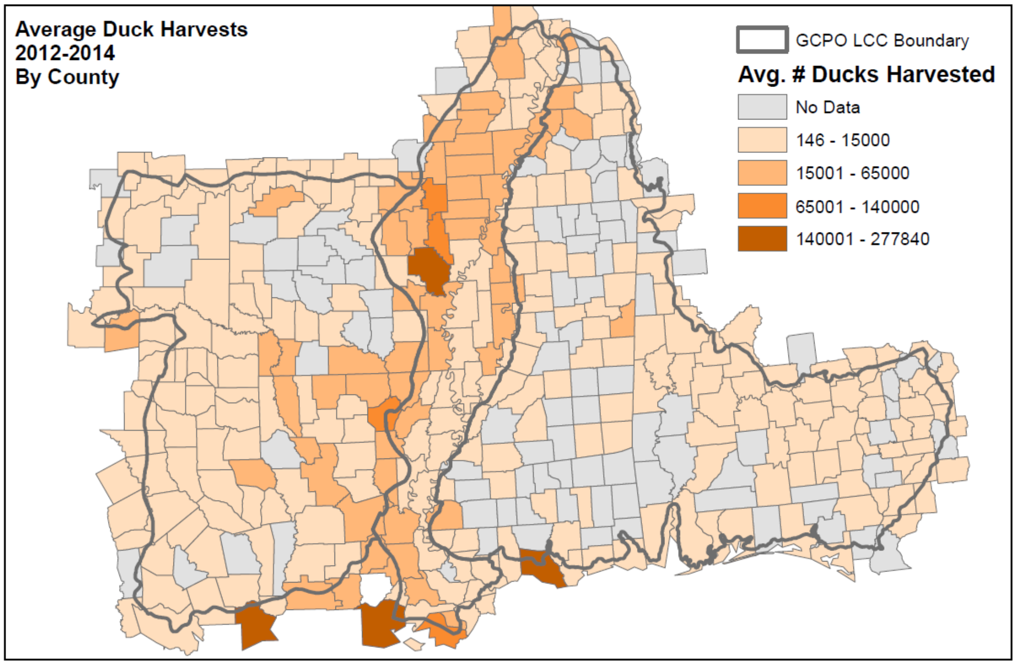


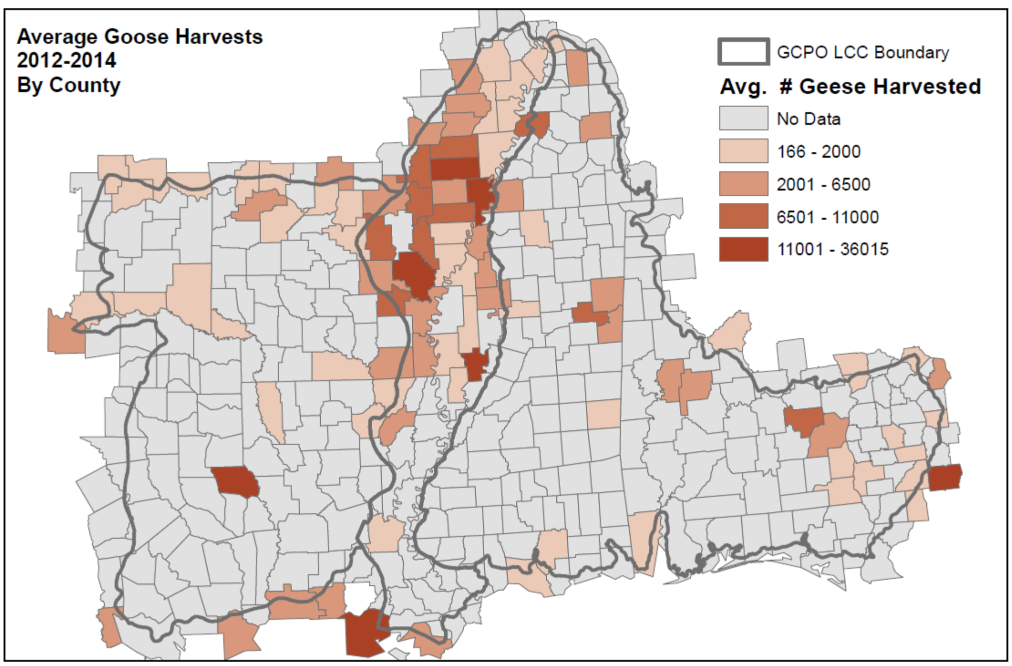
Figure 26: Species richness for harvestable species in the GCPO LCC as determined by GAP distribution models, shown by HUC 12.

Waterfowl Harvests. Average 2012-2014 duck and goose harvests for each county can be viewed in Figure 27. It is evident from these figures that many counties have missing data, especially for goose harvests. However, for both ducks and geese it appears that the majority of hunting occurs within or close to the Mississippi Alluvial Valley (MAV) subgeography. This is logical as the MAV closely tracks the center of the Mississippi flyway.

High duck and goose harvests could result from multiple factors; there could be many hunters in that county, many birds, or simply good access to hunting areas. Because we do not currently have the data to determine which of these factors are influencing duck/ goose harvests, we cannot make assumptions about reasons for high harvests. This data does at least provide us with a regional sense of where waterfowl hunters are successful.



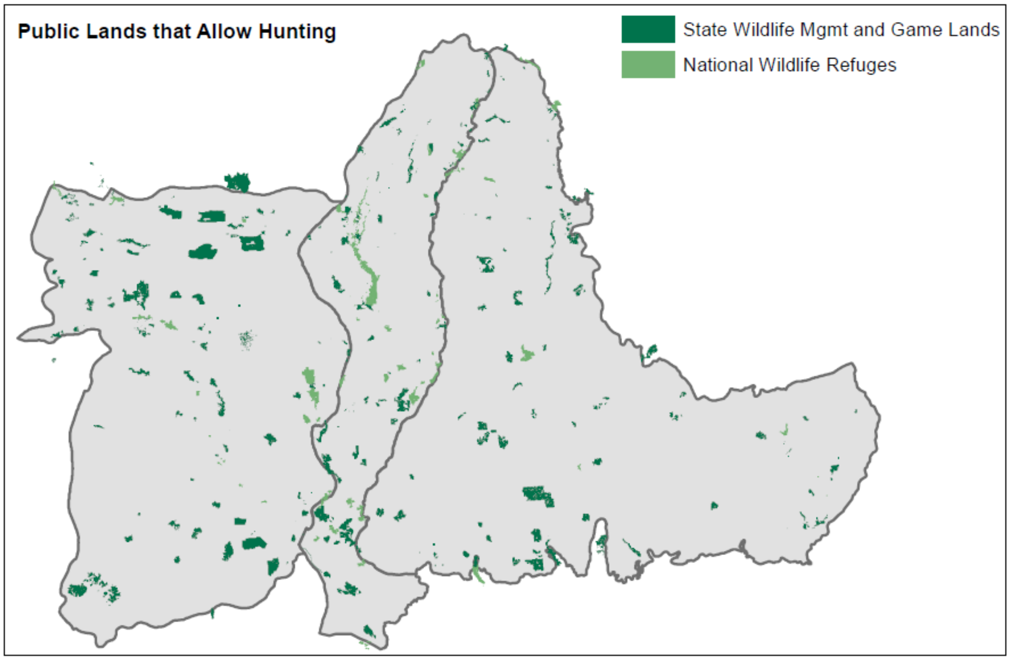
a)



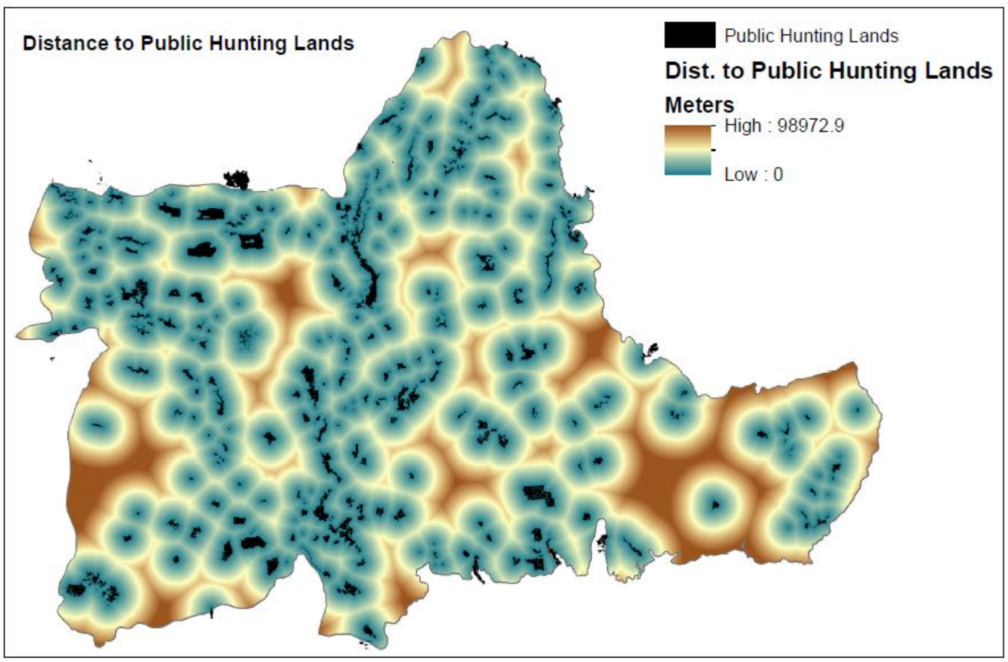
b)

Figure 27: Average duck and goose harvests for each county in the GCPO LCC subregion from 2012-2014.

Public Hunting Lands. Public lands that allow hunting are important for estimating where hunters are active across the GCPO LCC landscape (Figure 28a). Additionally, areas farther from any public lands with hunting access could potentially be targeted as areas where demand for hunting on private land may be higher (Figure 28b).



a)



b)

Figure 28: a) Public lands with hunting access and **b)** distance from public hunting areas in the GCPO LCC subregion.

It is known that there is a negative relationship between the distance that hunters must travel to game lands and their willingness to travel there (Boxall et al 1996). Hunters state that travel distance is important when choosing where to hunt, and when selecting a hunting location they look for easy access and short travel distance (Mehmood et al 2003). Additionally, hunters' willingness to pay for hunting goes down with increased travel distance (Stribling et al 1992). From selected studies we were able to find that many hunters aim to travel less than 50 miles, but will travel 50- 100+ miles for hunting opportunities (Mehmood et al 2003; Devers et al 2016, *unpublished*). Given that the maximum distance from a public hunting area in the

GCPO LCC is 98,973 meters, or 61.5 miles, distance to hunting opportunities does not seem to be a limiting factor in this region. It might be a factor if hunters were targeting specific game, but we do not currently have the data to complete an analysis at that level of detail at this time.

Bird Species Richness. The EnviroAtlas Southeast Biodiversity dataset provides an easy way to visualize how bird species fall across the GCPO LCC landscape (Figure 29). It is important to remember that these species richness values are derived from overlapping habitat distribution models, and not species surveys. Species richness values for each HUC 12 are displayed by both maximum and average; see the earlier 'Harvestable Species Richness' section for more detailed descriptions of maximum and average richness.

Areas of high bird species richness can indicate supply of birding resources across the GCPO LCC landscape. Birders may frequent areas where many species of birds exist. It should be taken into consideration that some birders seek out only rare species, so locations with maximal richness would be of little interest to this subset of the birding community. However, areas with high bird species richness can be considered valuable due to the existence and aesthetic value that these species bring to the landscape.

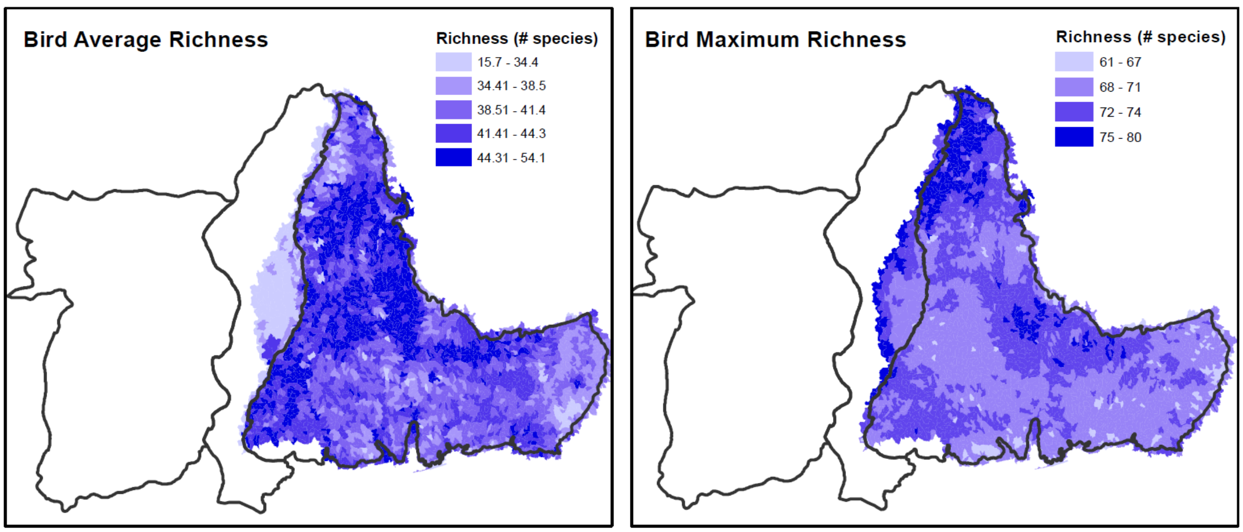


Figure 29: a) Bird species average richness, and **b)** maximum richness in the GCPO LCC subregion, shown by HUC 12. Richness values are based on GAP distribution models.

Important Bird Areas. Important bird areas provided by Audubon can be viewed in Figure 30a. These IBAs are another way of approximating supply of birding services across the GCPO LCC. Because of the criteria for IBA classification it is likely that rare or desirable viewing species will be located in the IBAs. Similarly, these IBAs are known in the birding community as important locations for birds, and thus attract bird watchers.

Because IBAs are designated regardless of current land status as protected/ unprotected or public/ private, they are not necessarily accessible. Overlap between IBAs and public lands indicate areas where birding services are already provided (Figure 30b). Alternatively, in areas where no public lands overlap a particular IBA, there is likely demand from the birding community for access to the IBA. It is in these areas where private landowners might be most successful if they decide to open their lands to birders. Of the 91 IBAs in the GCPO LCC subregion, 81 are at least partially covered by public lands. There are 1523 separate public land parcels that intersect the IBAs.

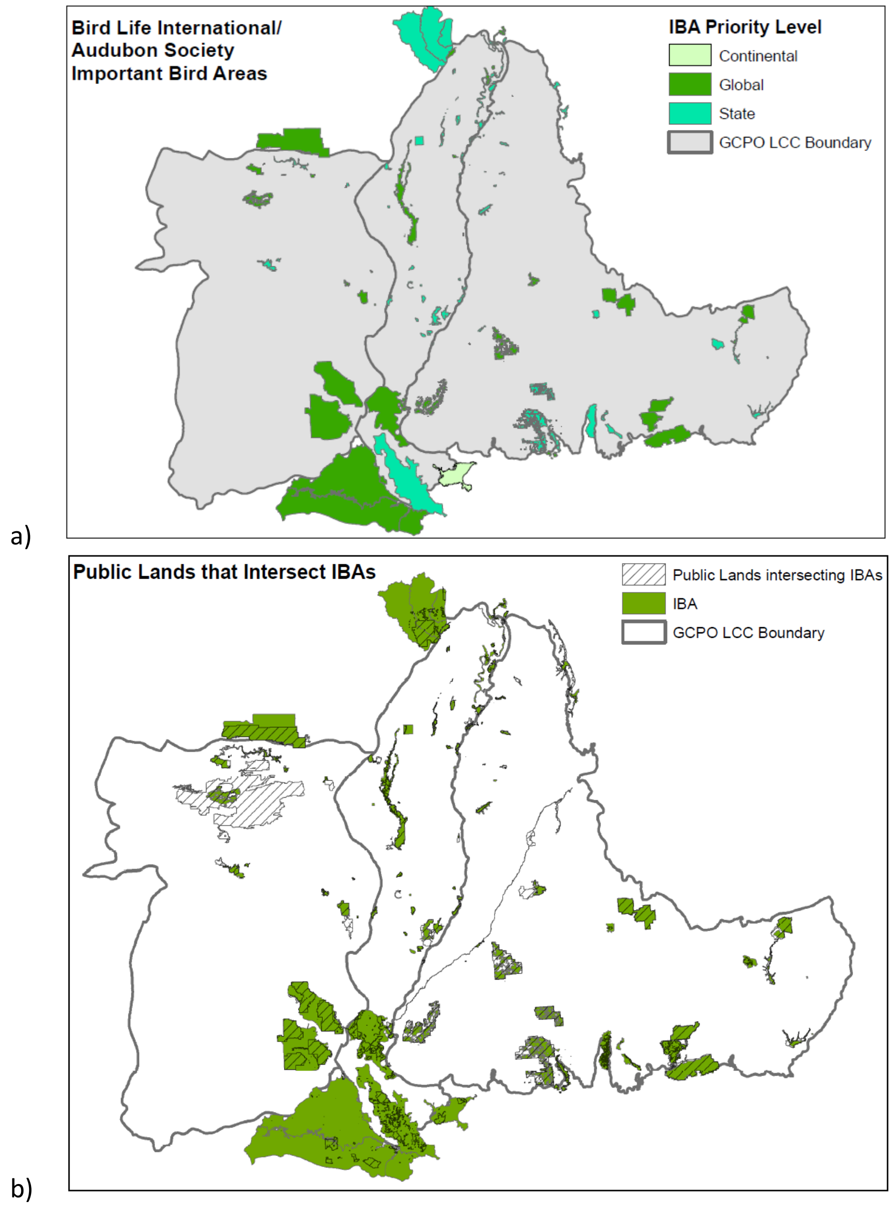
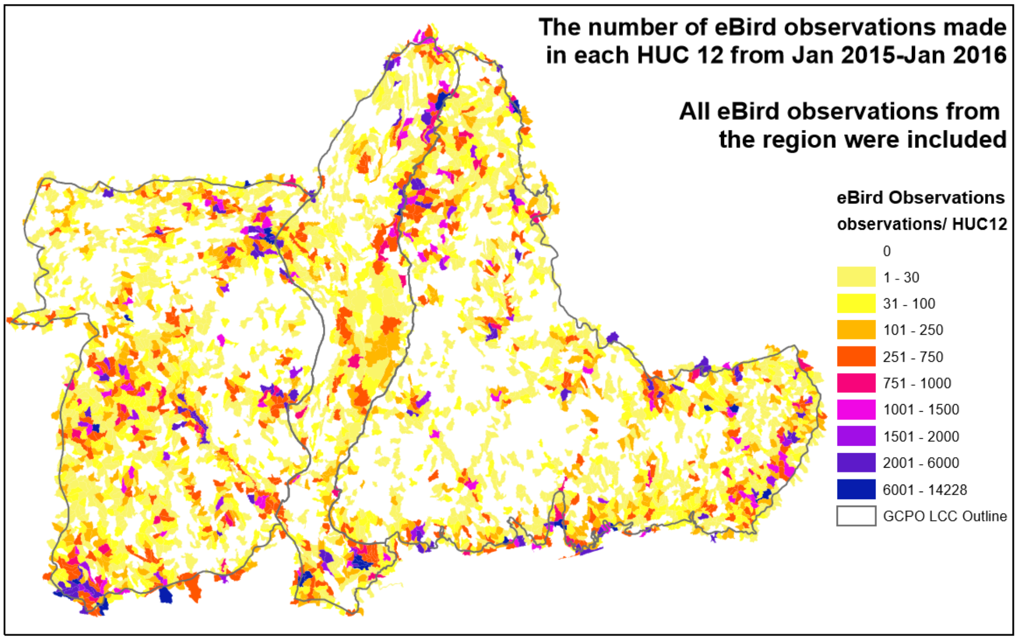


Figure 30: a) Important Bird Areas, and **b)** overlap between Important Bird Areas and public lands in the GCPO LCC subregion.

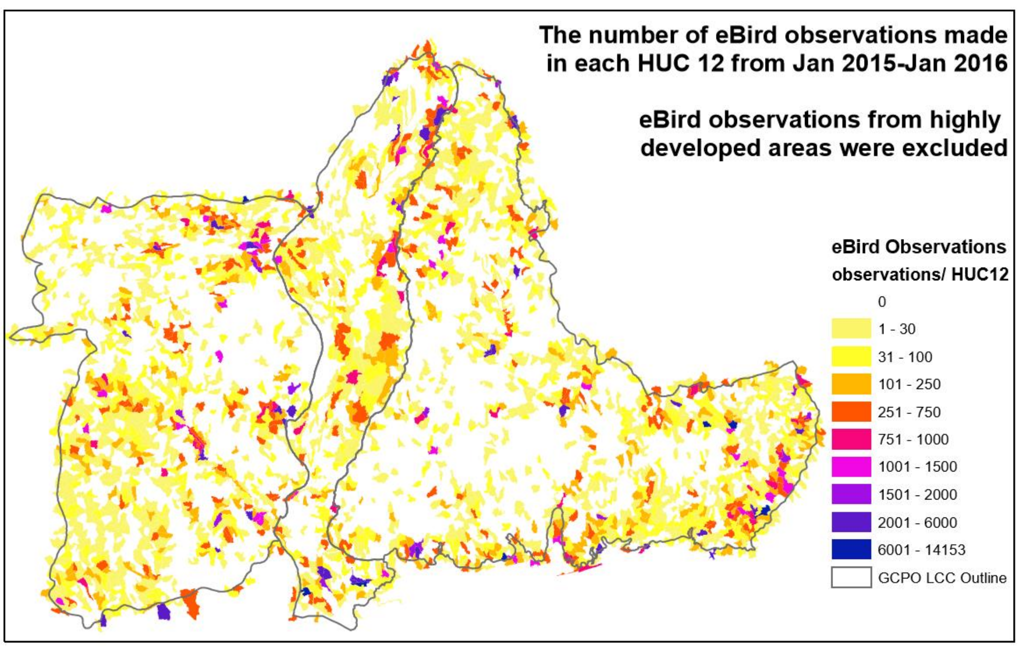
eBird. The maps created using eBird data can be seen in figure 31. Figure 31a includes all eBird observations taken in the GCPO region from January 2015 – January 2016 (964,986 observations total).

Upon examination of this data it became clear that developed, urban areas were highlighted as birding hotspots. This is unsurprising as developed areas contain concentrated human populations, and many urban birders use eBird. This results in a disproportionate number of observations in and around cities. eBird observations falling within highly developed areas were then masked out to try and examine birding hotspots outside of urban centers (Figure 31b).

The NLCD impervious surface layer was used as a proxy for development, and any cell classified as containing ≥30% impervious surface cover was considered "developed." (See the infiltration capacity section of this report for more details on the NLCD impervious surface data and creation of the layer reflecting cells with ≥30% impervious surface cover). The region group tool was used on the ≥30% impervious surface layer to eliminate any patch of development smaller than 5 100x100m pixels—this was done so that only those eBird observations falling within large urban centers were removed. A 1km buffer was created around the remaining impervious surface cover, and this buffer was used as a mask. Any eBird observation falling within this mask was removed from the dataset. This left only eBird observations falling in relatively un-developed areas (558,217 observations total), allowing the creation of Figure 31b.



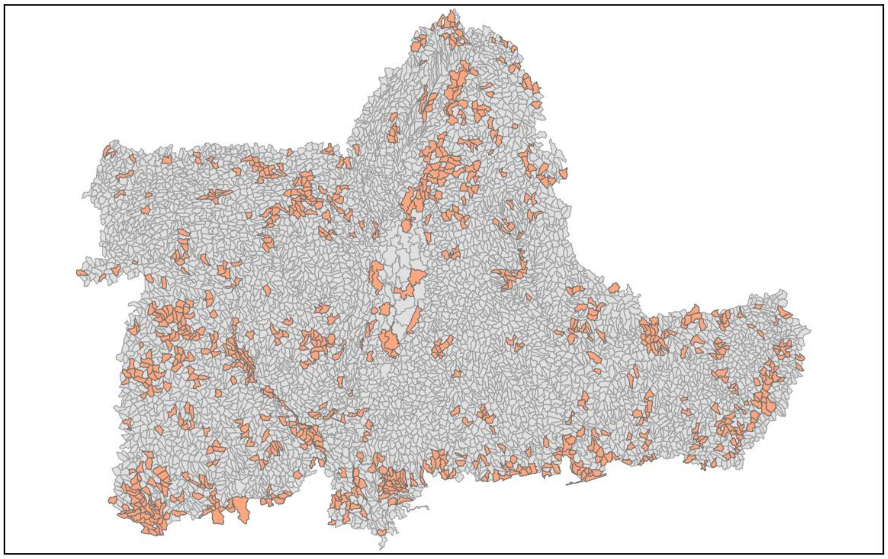
a)



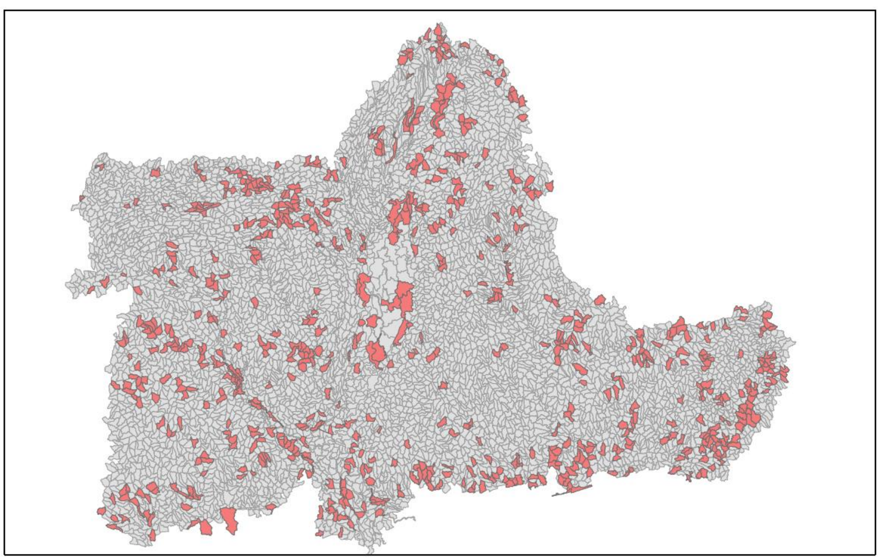
b)

Figure 31: the number of eBird observations falling within each HUC 12 of the GCPO LCC study area **a)** including all observations, and **b)** excluding observations which fall in highly developed areas.

Birding Priority Areas. HUC 12s with the highest number of birding observations for both the entire downloaded eBird dataset (Figure 32a) and the dataset using only observations outside of developed areas (Figure 32b) were highlighted as priority areas for birders. The top 25% of non-zero HUCs were included in each map; the threshold for figure 32a was 165 observations/ HUC (a total of 824 HUC 12s) and the threshold for figure 32b was 102 observations/ HUC (a total of 683 HUC 12s). There are 532 HUCs that overlap between maps 32a and 32b.



a)



b)

Figure 32: Priority HUC12s for birders; the areas highlighted are the HUCs within the GCPO LCC study area containing the top 25% of eBird observations including, **a)** all the eBird observations from Jan 2015-Jan 2016, and **b)** only eBird observations falling outside of highly developed areas from Jan 2015-Jan 2016.

Though this data is aggregated to the HUC 12 level to better match other data collected for this report, it could be examined at a finer scale for future, more specific analyses. Using the point density tool in arcmap or creating a simple distribution model from the eBird observations could give a more detailed and finer scale look at where birders are birding across the landscape.

Citations

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Water Filtration (proxy for potential water quality improvement)

The goal of this analysis is to map water quality services within three subgeographies of the Gulf Coast Plains and Ozarks LCC (East Gulf Coastal Plain, West Gulf Coastal Plain, and Mississippi Alluvial Valley). We approximate this ecosystem service using an analysis that assesses the amount of grassland, wetland and forest buffer in the hydrological flowpath from non-point sources of pollution to streams. By comparing the natural habitat buffering potentials of each HUC 12 within the GCPO LCC region to known EPA impaired waters an approximate demand for water quality services can be made. This demand approximation can then help provide an estimation of where new natural habitat buffers might be most beneficial.

Data Sources

Digital Elevation Model

A filled 30m digital elevation model (DEM) of the GCPO LCC region was used as a basis for all hydrological applications used in this analysis.

Initial Data Processing. The filled DEM was used as an input for the 'flow direction' tool and indirectly for the 'flow accumulation' tool to create hydrological products used throughout the analysis.

USA Streams

The USGS and EPA have provided a map of detailed streams for the United States that is available through ESRI. These linear features were used to define stream locations within the GCPO LCC subregion.

Initial Data Processing. This linear streams layer was rasterized and clipped to the GCPO LCC study area.

NLCD 2011

The NLCD 2011 was used to identify land cover types of interest for this analysis. Non-point sources (NPS) and riparian buffers (buffers) were defined by specific landclasses.

Initial Data Processing. By using the 'con' tool an NPS and a buffer layer were created. NPS was defined by developed and agricultural areas (NLCD landclasses 21, 22, 23, 24, and 82) while riparian buffers were defined by forests, wetlands, and grasslands (NLCD landclasses 41, 42, 43, 71, 90 and 95).

EnviroAtlas

EnviroAtlas is an EPA product meant to allow users to discover and map data related to ecosystem services. The EnviroAtlas 'ImpairedWaters' dataset provides information on EPA 303(d) impaired waters including the stream length of impaired water in each HUC12, as well as a breakdown of stream length impairments by reason for impairment.

Analysis and Results

Analysis Note. We have performed two similar but distinct water quality analyses here. Analysis 1 examines all filtration pixels (wetlands, forests, grasslands) that fall within the flowpath of a NPS pixel, regardless of their adjacency to a stream. Analysis 2 alternatively examines the water quality service potential of riparian buffers only. These riparian buffers are defined as any natural habitat pixels deemed to have water filtration properties (wetlands, forests, grasslands) falling in a contiguous block adjacent to a stream, and within the flowpath of a NPS pixel. These two analyses were performed together to examine multiple facets of potential water quality services provided by the landscape. Any natural habitat cell containing vegetation is likely to perform some kind of water quality service, especially trapping sediments and other pollutants contained in surface flow (Lowrance et al 1997). However, riparian buffers are considered disproportionately more important for water filtration, given their relatively small extent (Vidon et al 2010). Though the amount of filtration performed by a riparian buffer can depend on many factors, including pollutant type, water table level, and groundwater flow (Lowrance et al 1997), riparian buffers are thought to be quite effective for absorption of many nutrients, especially nitrogen (Lowrance et al 1997, Mayer et al 2007). When managers aim to improve water quality, a common option is the creation or restoration of riparian buffers because of their acknowledged influence on the flow of solutes into streams (Lowrance et al 1997, Vidon et al 2010).

The following analyses are not meant to be interpreted as gauges for water quality throughout the GCPO LCC, only as relative measures of filtration potential. We realize that the analyses performed here are extremely basic, and ignore many of the factors incorporated into more sophisticated water models, including but not limited to: soil type, bank incision, water table level, temporal changes in water flow, quality of filtration habitat, pollutant type, pollutant source, pollutant location in the watershed, and biogeochemical conditions. The analyses presented here are only meant to be a general examination of the availability and/or lack of natural buffer potential across the landscape.

Mean Filter/ Buffer Length. Analyses 1 and 2 (referenced above) were performed to assess the amount of grassland, wetland, and forest buffer in the hydrological flowpath from non-point sources of pollution to streams to examine the supply of water quality provision services across the landscape. These analyses were inspired by Baker et al 2006 and interpreted from previous analyses performed by John Fay.

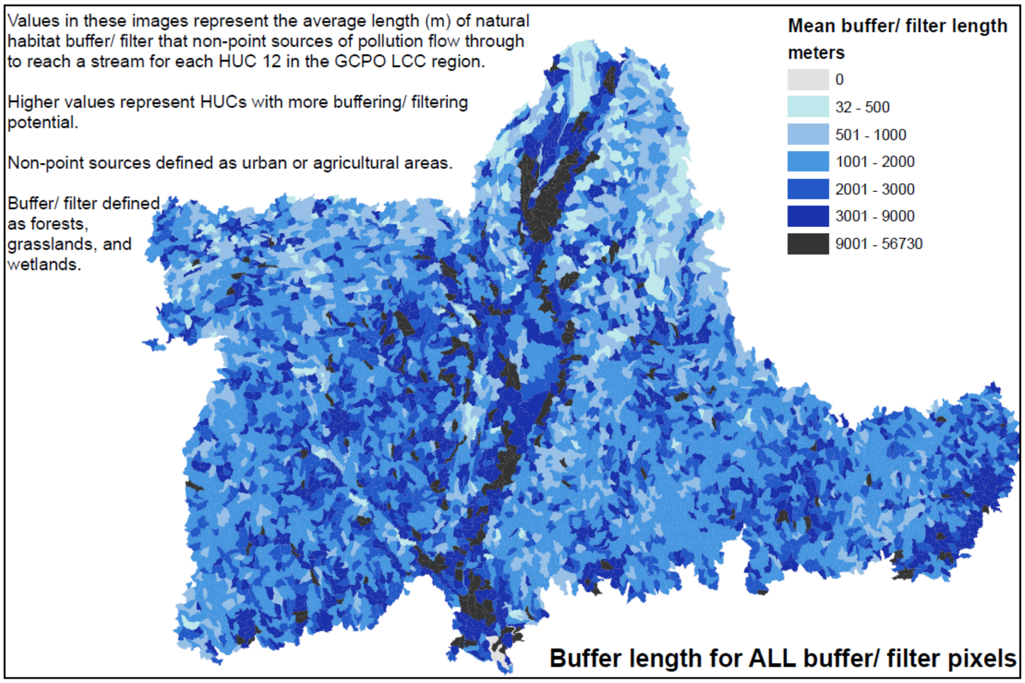
Using isolated NPS cells created from the NLCD 2011, a mask was created that only includes pixels that are NPSs or are in the hydrological flowpath from these NPSs to streams. This mask was then used to extract only those buffer cells that fall within an NPS flowpath, as these are the buffer cells that would be providing water quality services by filtering NPS pollutants. These buffer cells in the NPS flowpaths were saved in a raster as "buffers in flowpath."

Two flow length rasters were then created using the 'Flow Length' tool. The first established a flow length from any cell in the landscape to a stream, as defined by the USGS/ EPA USA Streams raster. The second flow length used the same inputs, however it used the "buffers in flowpath" raster as a weight in the 'Flow Length' tool. This weighted flow length only shows flow lengths that include relevant buffer cells. These two flow length outputs were compared, and only where they were equal did they represent contiguous buffer cells adjacent to streams and in an NPS flowpath. An output binary raster called "flow path buffer" contains cells only where the two flow lengths are equal. This "flow path buffer" is used in the next step of the analysis.

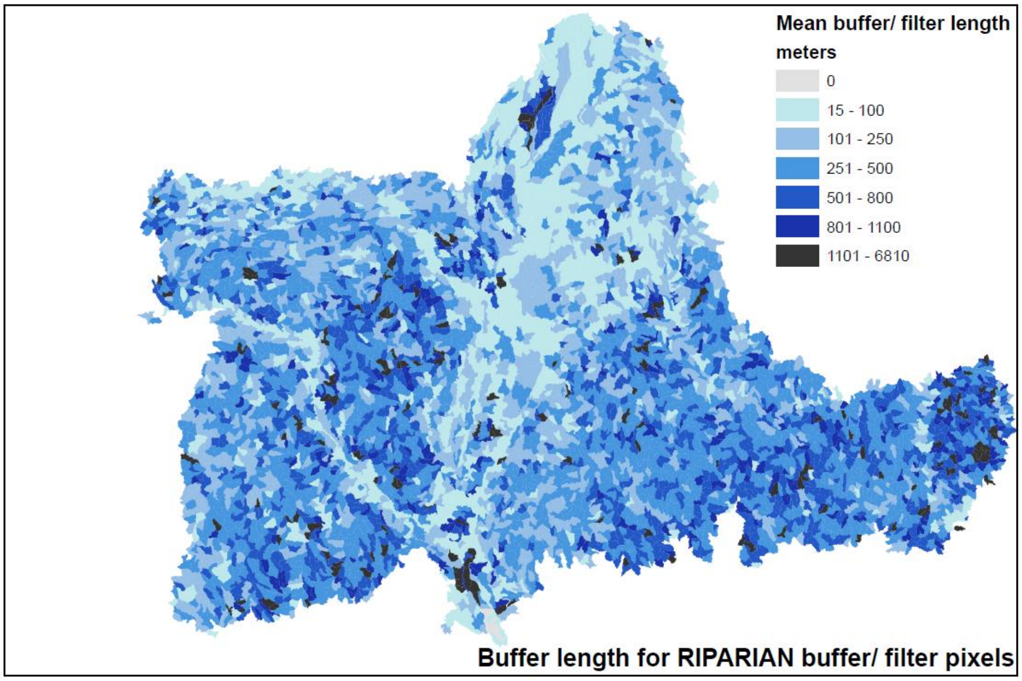
A final, third flow length was created using the "flow path buffer" as a weight. This produced an output, "flow through buffer," that displays a value for each pixel that represents the length of contiguous buffer cells adjacent to streams it flows through.

Analysis 1 used the output from the second flow length, which includes flow lengths from NPS cells through any buffer/ filter pixel. Analysis 2 used the output from the third flow length, which includes flow lengths from NPS cells through only riparian buffers.

Using the flow length outputs referenced above and the original isolated NPS cells created from the NLCD aggregated by HUC12, the 'zonal statistics' tool can produce an output that approximates water quality services provided across the landscape (Figure 33). This output provides one summary value for each HUC 12, and this number represents the mean length of buffer/filter cells that each NPS cell inside the HUC 12 flows through to reach a stream, or the mean buffer potential. It should be noted that this buffer potential value does not take into account the number of NPS pixels within the HUC 12, only the length of buffer that each NPS pixel flows through. Thus, a high buffer potential could result from a HUC 12 where there is only one NPS pixel, but many buffer cells that it flows through to reach a stream, or a high buffer potential could result from a HUC 12 where there are thousands of NPS pixels, but also a many buffer cells. For reference, a map displaying the proportion of NPS cells within each HUC is also provided (Figure 34).



a)



b)

Figure 33: The water quality buffering potential of each HUC 12 in the GCPO LCC subregion for **a)** all buffer cells, and **b)** riparian buffer cells only. The value of each HUC 12 represents the mean length (m) of buffer/ filter that each NPS pixel flows through to reach a stream.

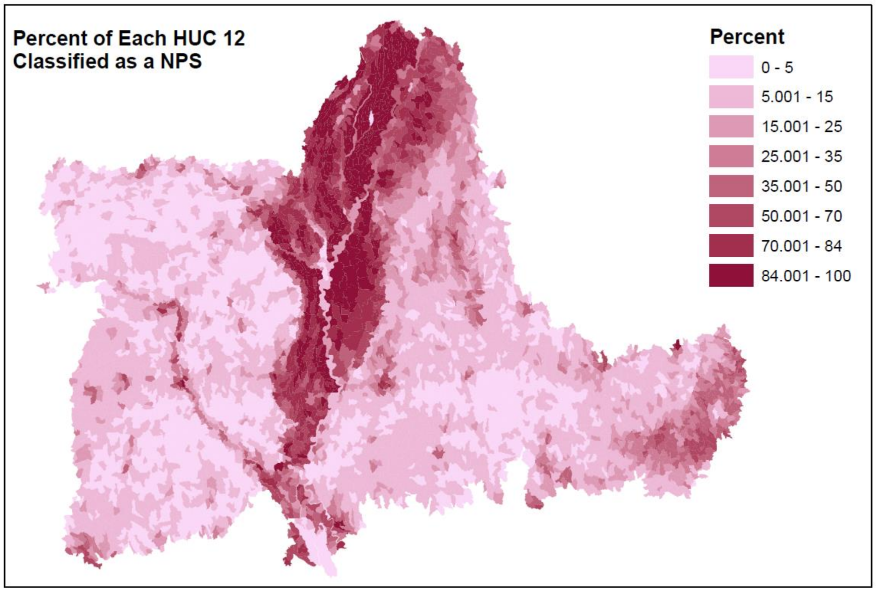


Figure 34: The percentage of each HUC 12 covered by NPS pixels.

Stream Impairments. Using the EnviroAtlas 'ImpariedWaters' data, it is possible to visualize EPA 303(d) impaired waters (Figure 35). These areas are important to highlight because they represent one aspect of demand for water quality services; where water quality is poor there is a higher demand for increased water quality provision.

Due to the differences in state requirements for classifying 303(d) waters, it is hard to compare results across the entirety of the GCPO landscape because the region falls across 12 different states. However, the maps of 303(d) impaired water lengths may still provide useful information about where individual states are prioritizing their water quality projects.

Note: Not all water quality impairment classifications are available from EnviroAtlas. Thus, the total impairment length (which includes lengths from all impairment classifications) may not reflect a sum of the component water quality impairments shown here.

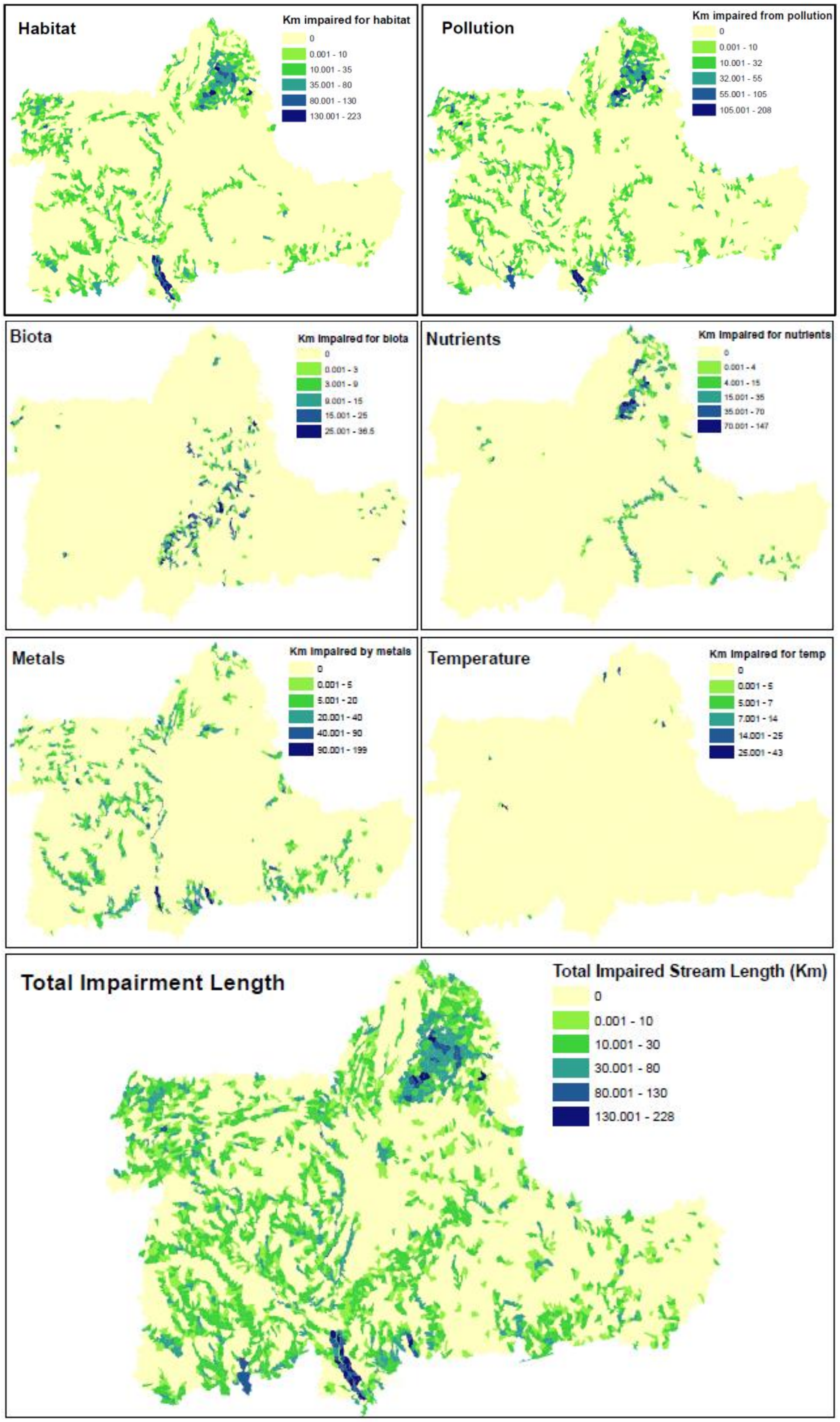


Figure 35: Length of impaired streams within each HUC 12 in the GCPO LCC subregion; the maps show the kilometer lengths of streams impaired for or by a) habitat, b) pollution, c) biota, d) nutrients, e) metals, f) temperature, and g) all impairments.

Priority HUCs. By assessing each HUC 12's buffering capacity and percentage of NPS coverage, it is possible to highlight priority HUCs for conservation and restoration.

NPS percent coverages range from 0-100%, and the 3rd quartile of these percentages is 26.2%, meaning that any HUC 12 with ≥ 26.2% coverage is in the top 25% of NPS coverages. Examining the buffer potential data reveals that the 1st quartile of the mean flow lengths through all buffers is 1055m and through riparian buffers is 134m, so any HUC 12 with a mean flow length ≤ 1055 or ≤134 is in the bottom 25% of buffer capabilities for all buffers or riparian buffers, respectively. Similarly, the 3rd quartile of the mean flow lengths through all buffers is 2719m and through riparian buffers is 481m, so any HUC 12 with a mean flow length ≥2719 or ≥481 is in the top 25% of buffer capabilities for all buffers or riparian buffers, respectively

Using these contrived thresholds priority HUC 12 layers were created (Figure 36). By selecting HUC 12s where mean buffer potential is either ≥2719 (Figure 36a) or ≥481 (Figure 36b) and NPS percent coverage is ≥ 26.2, it is possible to isolate the HUC 12s with highest buffer potential and highest NPS area. These are the HUCs that should be targeted for natural habitat buffer/ filter conservation, to protect the existing good natural filtration habitats. Alternatively, by selecting only HUC 12s where mean buffer potential is either ≤ 1032 (Figure 36c) or ≤129 (Figure 36d) and NPS percent coverage is ≥ 26.2, it is possible to isolate the HUC 12s with lowest buffer potential and highest NPS area. These are the HUCs that should be targeted for natural habitat buffer/ filter restoration.

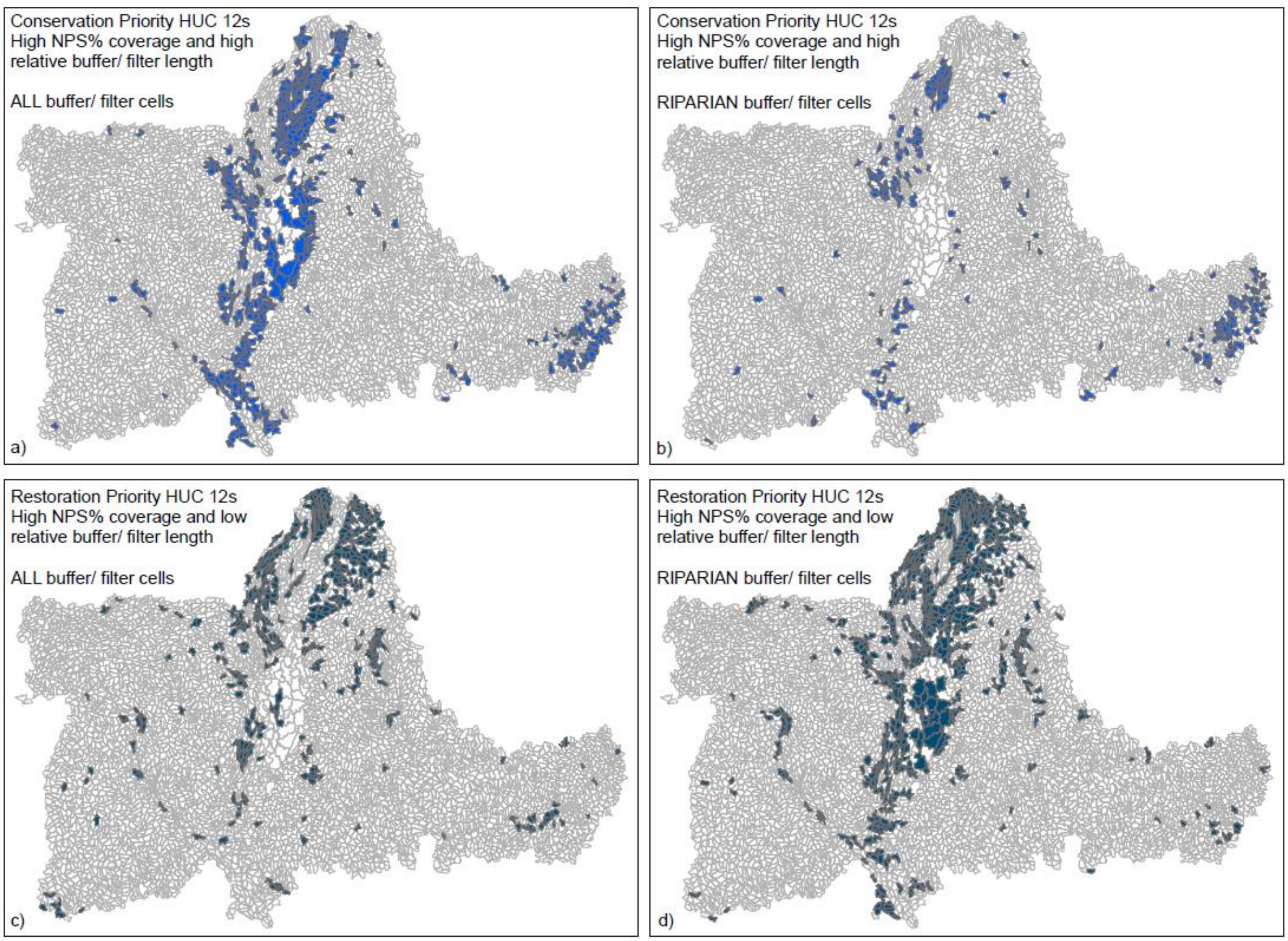


Figure 36: Priority HUC 12s for conservation and restoration of water quality services in the GCPO LCC subregion. Conservation HUC 12s are identified by high NPS coverage and high relative mean buffer/ filter length for **a)** all buffers/ filters, and **b)** riparian buffers. Restoration HUC 12s are identified by high NPS coverage and low relative mean buffer/ filter length for **c)** all buffers/ filters, and **d)** riparian buffers.

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Infiltration Capacity (proxy for flood mitigation potential)

The goal of this analysis is to map water infiltration capacity services within three subgeographies of the Gulf Coast Plains and Ozarks LCC (East Gulf Coastal Plain, West Gulf Coastal Plain, and Mississippi Alluvial Valley). The service mapped here is meant to be a basic proxy for examining flood mitigation potential. We approximate this ecosystem service using an analysis that assesses the amount of wetland, forest, and grassland in the hydrological flowpath from impervious surfaces to streams.

Data Sources

Digital Elevation Model

A filled 30m digital elevation model (DEM) of the GCPO LCC region was used as a basis for all hydrological applications used in this analysis.

Initial Data Processing. The filled DEM was used as an input for the 'flow direction' tool and indirectly for the 'flow accumulation' tool to create hydrological products used throughout the analysis.

USA Streams

The USGS and EPA have provided a map of detailed streams for the United States that is available through ESRI. These linear features were used to define stream locations within the GCPO LCC subregion.

Initial Data Processing. This linear streams layer was rasterized and clipped to the GCPO LCC study area.

NLCD 2011

The NLCD 2011 was used to identify wetlands for this analysis. The NLCD 'Percent Developed Imperviousness' data product was used to define impervious surfaces. Any pixel classified with ≥30% impervious surface cover was considered impervious surface for this analysis. At 30% impervious cover water reaching the ground is released as 30% runoff, as opposed to only 10% runoff on undeveloped land. 30% impervious cover within a watershed also marks the point at which streams within the watershed change from "impacted" to "degraded," due to influences from excess surface flow caused by impervious cover (Arnold and Gibbons 1996).

Initial Data Processing. By using the 'con' tool a "natural habitat infiltration" layer was created, defined by the NLCD land classes 41, 42, 43, 71, 90, and 95. The 'con' tool was also used on the 'Percent Developed Imperviousness' layer to isolate those pixels with ≥30% impervious surface cover.

Analysis and Results

Analysis Note. Wetlands and other natural habitats are known to offer effective protection from flooding events, and in some cases are more efficient and cost effective than traditional, man-made flood controls such as dikes and levees (EPA 2006). Percent impervious surface coverage is also linked to flooding events, as water in high impervious coverage areas has little chance to infiltrate the surface and enter the groundwater, thus flowing over the surface quickly and overfilling streams (Frazer 2005). Estimating the amount of natural habitat falling between impervious surfaces and stream features is therefore a way of examining the natural capabilities of the ecosystem to store excess water. However, the following analysis is not meant to be interpreted as a gauge for flood occurrence throughout the GCPO LCC, only as a relative measure of infiltration capacity potential. We realize that the analysis performed here is extremely basic, and ignores many of the factors incorporated into more sophisticated water flow models, including but not limited to: soil type, temporal changes in water flow, quality and/ or type of habitat, and impervious surface location in the watershed. The analysis presented here is only meant to be a general examination of the availability and/or lack of infiltration potential across the landscape.

Mean Flow Length. This analysis was performed to assess the amount of natural habitat in the hydrological flowpath from impervious surfaces to streams to examine the supply of infiltration capacity services across the landscape. These analyses were inspired by Baker et al 2006 and interpreted from previous analyses performed by John Fay.

Using isolated impervious surface cells created from the NLCD 'Percent Developed Imperviousness' layer, a mask was created that only includes pixels that are impervious surface, or are in the hydrological flowpath from these surfaces to streams. This mask was then used to extract only those natural habitat cells that fall within an impervious surface flowpath, as these are the habitat cells that would be providing water infiltration services by absorbing runoff from impervious surfaces. These habitat cells in the NPS flowpaths were saved in a raster as "habitats in flowpath."

A flow length raster was then created using the 'Flow Length' tool. The flow length output used the 'flow direction' raster as an input and the "habitats in flowpath" raster as a weight. This weighted flow length only shows flow lengths that include relevant habitat cells.

Using the flow length output and the original isolated impervious surface cells aggregated by HUC12, the 'zonal statistics' tool can produce an output that approximates water infiltration capacity services provided across the landscape (Figure 37). This output provides one summary value for each HUC 12, and this number represents the mean length of habitat cells that each impervious surface cell inside the HUC 12 flows through to reach a stream, or the mean infiltration potential. It should be noted that this infiltration potential value does not take into account the number of impervious surface pixels within the HUC 12, only the length of habitat that each impervious surface pixel flows through. Thus, a high infiltration potential could result from a HUC 12 where there is only one impervious surface pixel, but many habitat cells that it flows through to reach a stream, or a high infiltration potential could result from a HUC 12 where there are thousands of impervious surface pixels, but also a many habitat cells. For reference, a map displaying the proportion of impervious surface cells within each HUC (Figure 38) is provided.

To try and account for the number of impervious surface cells in each HUC, another map displaying the sum of the flowlengths from each impervious surface cell through habitats is provided (Figure 38). Because each HUC in Figure 39 is displayed by the total flowlength of all impervious surface pixels, HUCs with more impervious surface coverage will display with higher values.

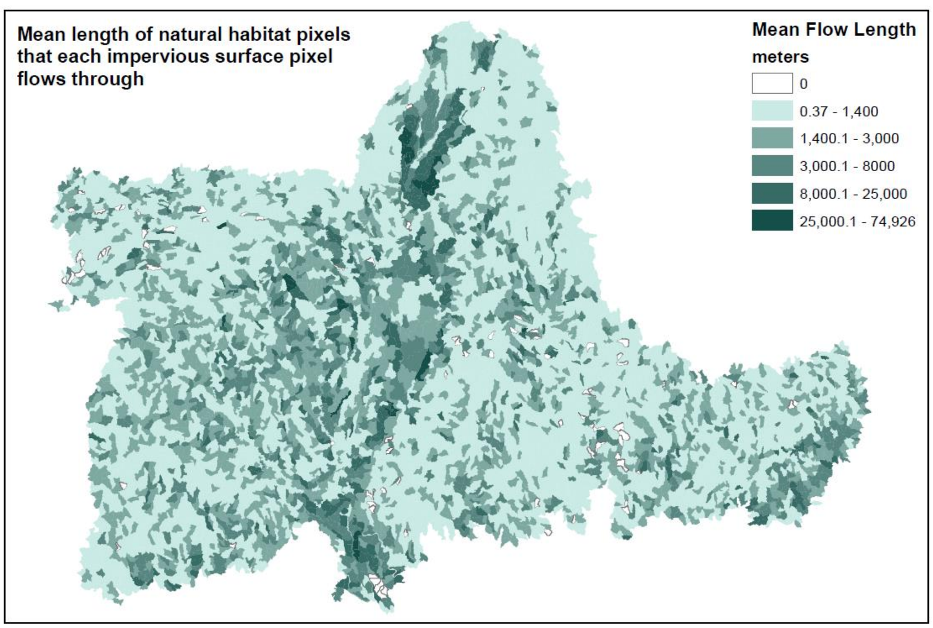

Figure 37: The mean water infiltration capacity potential of each HUC 12 in the GCPO LCC subregion. The value of each HUC 12 represents the mean length (m) of natural habitat that each impervious surface pixel in that HUC flows through to reach a stream.

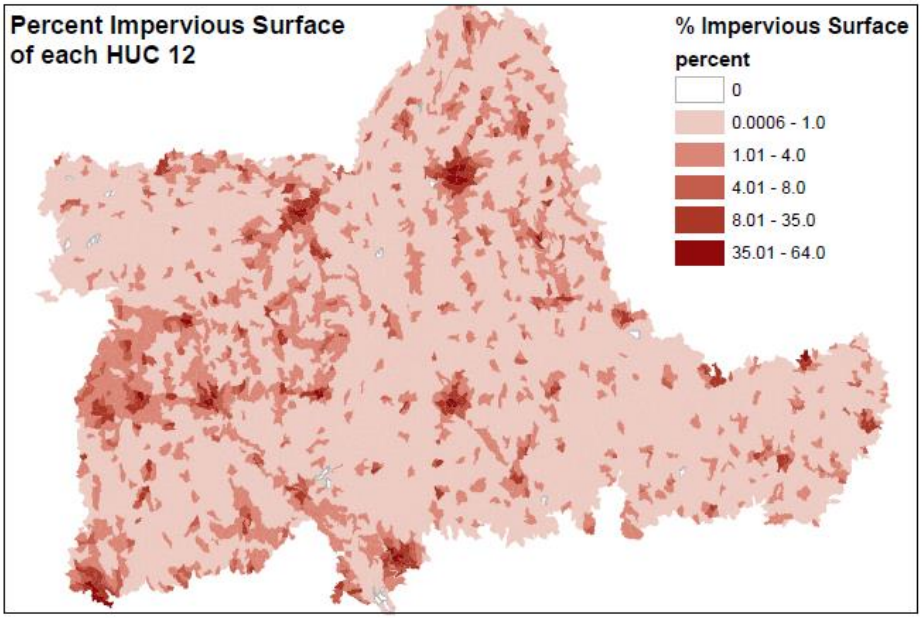

Figure 38: The percentage of each HUC 12 covered by impervious surface pixels.

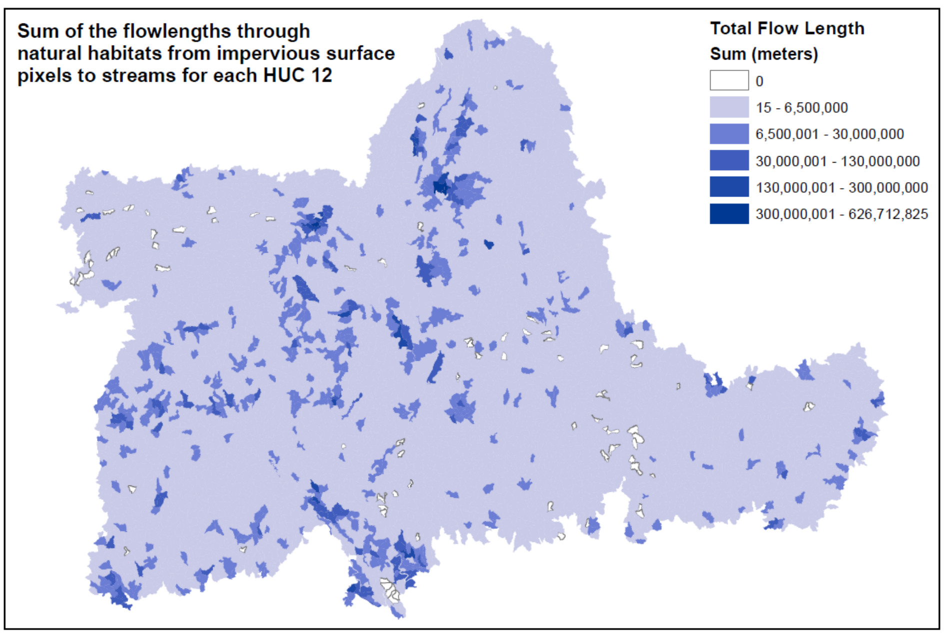

Figure 39: The water infiltration capacity potential of each HUC 12 in the GCPO LCC subregion. The value of each HUC 12 represents the summed length (m) of natural habitat that each impervious surface pixel in that HUC flows through to reach a stream.

Priority HUC 12s. To identify priority HUC 12s for conservation and restoration the percent coverage of impervious surfaces and the mean flow lengths through natural habitat were examined (Figure 40). The 3rd quartile of percent impervious surface coverage is 1.09%, therefore any HUC with ≥1.09 percent coverage is in the top 25% of impervious surface coverages. The 1st quartile of flowlengths through natural habitat is 532m and the 3rd quartile is 2368m, meaning that any HUC with a mean flowlength of ≤532m or ≥2368m is in the bottom, or top, 25% of mean flowlengths, respectively. These HUCs are therefore the ones with the least, or most, existing infiltration capacities. Those HUCs with the most existing capacity could be targeted for conservation of current infiltration habitat, while those HUCs with the least existing capacity could be targeted for restoration of infiltration habitat. If data becomes easily available, it would be helpful to combine these layers with flood zone and property data to help isolate those areas where demand is truly highest for these flood protection services.

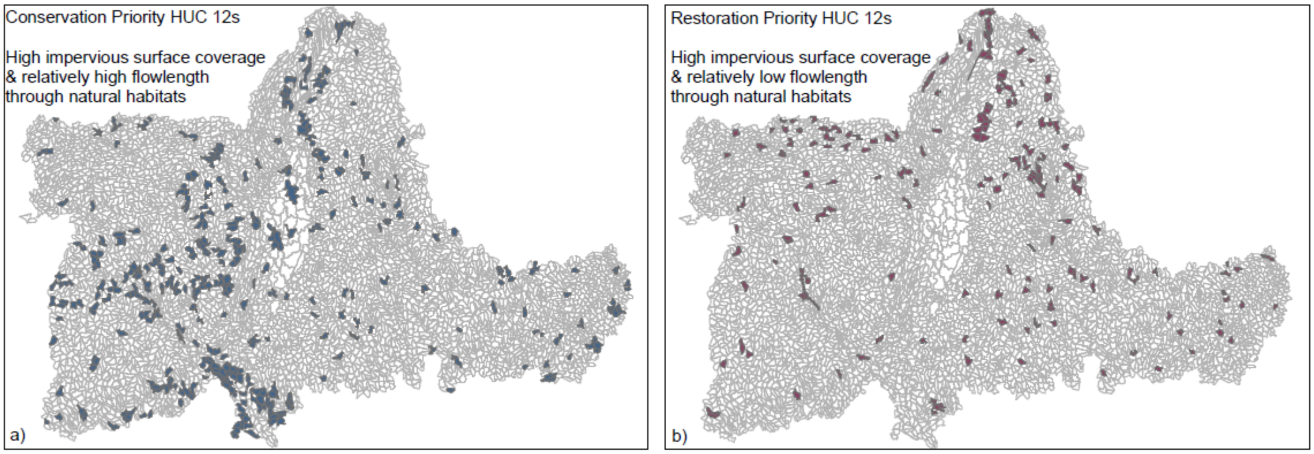

Figure 40: Priority HUC 12s for conservation and restoration of water infiltration capacity in the GCPO LCC subregion. **a)** Conservation HUCs are identified by high impervious surface coverages and relatively high flowlengths from impervious surfaces through natural habitat cells. **b)** Restoration HUCs are identified by high impervious surface coverages and relatively low flowlengths from impervious surfaces through natural habitat cells.

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