Examining the southern Great Plains for hotspots of at-risk species and assessing efficacy of a decision support tool

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ABSTRACT

Resources for conservation efforts are lacking across the world. There are many species at risk due to anthropogenic landscape development and other stressors, but not enough money or time to deal with conserving each species on an individual basis. Though individual target species warrant protection, conservation efforts that address many at-risk species simultaneously maximize efficiency of time and money spent. By identifying areas where we find dense concentrations of at-risk species (i.e., hotspots), we can efficiently target our conservation efforts and resources, thus maximizing the number of species and habitat protected by a single conservation plan.

This is particularly problematic in the southern Great Plains, where land cover conversion to agriculture and energy production has altered habitat for many species. Given a growing human population and therefore increasing need for food and energy production, this area is of critical conservation importance to protect over 1000 currently listed at-risk species. In the southern Great Plains, the Lesser Prairie-Chicken (*Tympanuchus pallidicinctus*) range-wide conservation plan exists along with a decision support tool, known as the Crucial Habitat Assessment Tool (CHAT), to protect this at-risk species. The Lesser Prairie-Chicken, already having a conservation plan in place, could act as an umbrella species if this plan subsequently protects non-target at-risk species within its range. Identifying the range-wide plan and CHAT as a multi-species approach could bolster its importance and efficiency.

In Chapter I, I provided an overview of previous biodiversity hotspot research, agricultural land conversion, and at-risk species in the southern Great Plains. I discussed how anthropogenic pressures have resulted in land conversion and habitat loss or

fragmentation, which are the leading causes of species declines. These pressures have resulted in many species being designated at a state level as Species of Greatest Conservation Need (SGCN). I posited how identifying areas of dense concentrations of SGCNs can create a biodiversity hotspot map that will be useful for management agencies in considering where to target future conservation efforts. I also explained the use of umbrella species and create a framework of how the Lesser Prairie-Chicken (LPC) and the range-wide plan and decision support tool (CHAT) could potentially serve dual purpose protection for non-target SGCNs.

Chapter II focuses on defining hotspots of biodiversity – defined as dense concentrations of Species of Greatest Conservation Need – in my study area. Existing range files for at-risk vertebrate species were overlaid to identify these biodiversity hotspots. I discussed general areas where these hotspots occur and examined the land ownership underlying these hotspots. Maps of biodiversity hotspots and land ownership analyses were produced so that land managers may have valuable information that helps them approach how to address conservation of at-risk species in the Great Plains. Hotspots for current, pending, and combined (current and pending) Species of Greatest Conservation Need were found to occur mostly on state or federal managed land and high density hotspots occur along eastern New Mexico and Colorado.

In Chapter III, I assessed whether the Lesser Prairie-Chicken, through its habitat protected by an existing range-wide plan, acts as an umbrella species. I addressed habitat use and ecoregion occupation on a per-species basis to determine if habitats were overlapping with the LPC by chance or by similar habitat requirements in a focal area of Bird Conservation Regions 18 and 19. In this way I assayed whether the CHAT tool serves in protecting non-target species and can be considered a multi-species support tool for conservation. It turns out that the CHAT tool also covers more than 100 at-risk species ranges, some of which have similar habitat requirements as the LPC. This information will help management agencies in future planning for the conservation of all species at risk in the southern Great Plains.

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CHAPTER I

Examining the southern Great Plains for hotspots of at-risk species and assessing efficacy of a decision support tool: Literature review and project overview

Abstract

Resources for conservation are lacking across the world, though preserving biodiversity is critical to maintain proper ecosystem function. Many conservation plans exist to protect a single target species that is at risk. Conservation goals are met when they preserve the habitat and increase the populations of target species, so plans can be considered dually effective if they simultaneously preserve habitat for non-target species. The southern Great Plains region has experienced a large amount of land conversion to agriculture, resulting in habitat loss and fragmentation for many species, making it increasingly important and difficult to preserve many at-risk species. Using the Lesser Prairie-Chicken (*Tympanuchus pallidicinctus*) as a potential umbrella species, an existing conservation plan for this species could have a multi-species approach, thus maximizing efficiency.

Biodiversity and Its Loss

Biodiversity is critical to ecosystem function (Loreau et al. 2001), with more diverse regions tending to be more secure in terms of ecosystem stability (McCann 2000, Krebs 2009). Ecosystem stability, as defined by Lewontin (1969), is the ability of an ecosystem to maintain resilience to or recover quickly after disturbances. A large number of species (species richness) is key to maintaining ecosystem functioning, particularly in intensively used landscapes (Naeem et al. 1994, McGrady-Steed et al. 1997, Loreau et al. 2001). Removal of species from an ecosystem often has systemic effects; for instance, wolves (*Canis lupus*) were extirpated from Yellowstone National Park and other communities were affected. The preferred diet of wolves is elk (*Cervus canadensis*), and elk browse on aspen (*Populus tremuloides*) trees, which led to aspen decline. Since wolves have been reintroduced into Yellowstone National Park, there has been an increase in aspen, indicating how the presence or absence of a single species can alter an entire trophic web. The wolf population keeps the elk population in check by predation as well as by altering behavior and distribution of elk, resulting in elk consuming aspen bark less frequently (Ripple et al. 2001, Fortin et al. 2005). Furthermore, a study in Yellowstone, Olympic, and Zion National Parks demonstrated that when plant browsing by ungulates went unregulated due to lack of an apex predator, morphology of streams was altered (Beschta and Ripple 2011). Yet another example of how biodiversity loss affects ecosystems is the decline of the mantled howler monkey (*Allouatta palliata*) leading to a decline in tree density in Mexico. Howler monkeys eat seeds that pass through their digestive tracts and then are deposited on the forest floor and subsequently germinate; the fewer howler monkeys, the lower the density of trees (Anzures-Dadda et al. 2011). Finally, several replications of a study by Tilman et al. (1994) showed that grassland plant communities with higher biodiversity were more productive. These examples show how maintaining biodiversity within a given ecosystem subsequently maintains biotic and abiotic properties such as flow of nutrients, hydrological functions, and chemical composition of soil. When these functions are compromised, ecosystem productivity and stability are compromised, which affects biota and quality of human life.

Biodiverse ecosystems provide core benefits called ecosystem services that humans derive from their environment and are responsible for sustaining human civilization and culture throughout the world (Boykin et al. 2013). The Millennium

Ecosystem Assessment (MEA) describes these benefits as ranging from recreational to clean air and water to productive soils for sustainable food production, and sorts them into four categories: supporting, provisioning, regulating, and cultural services (MEA 2005). A supporting ecosystem service would be maintaining proper nutrient cycling in soil for primary production. A supporting ecosystem service would be the precursor to a provisioning ecosystem service such as food, wood, or fiber that can be grown in the soil. A regulating ecosystem service would be water purification or climate regulation to provide humans with potable water and a livable climate to sustain life. A cultural ecosystem service encompasses why humans value the natural ecosystem: for its provision of aesthetic, recreational, spiritual, and educational opportunities (MEA 2005). Economic value has been placed on the amount of goods and services ecosystems provide, such as food generated, revenue from recreation, etc. For example, in 1995, the total value of ecosystem services was estimated to be 33 trillion U.S. dollars per year. Updated values show that between 4.3 and 20.2 trillion U.S. dollars in ecosystem services have been lost between 1997 and 2011 due to land-use changes (Costanza et al. 2014). In other words, ecosystems can continue to function and provide humans with ecosystem services and economic benefit so long as biodiversity is not deleteriously altered.

Conservation biology is a considered a normative discipline, meaning it operates on certain inherent values. In addition to providing ecosystem services, preservation of the natural world is considered an ultimate good and a goal of conservation biology (Primack 2008). Aldo Leopold and John Muir, two of the founders of the field, advocated for preserving the natural world on the basis that it maintained ecosystem health. This idea was expanded on by Gifford Pinchot as the first head of the U.S. Forest Service when he held that the goal of land management is to use natural resources for the greatest good for the longest time (Callicott 2000). The notion of conservation as an ultimate good also has philosophical roots in nearly all major religions: from Islam to Christianity, humans are charged with being good stewards of the environment, and humans have long had a cherished relationship with the natural world (Berkes 2001, McNeely 2001). Similarly, Henry David Thoreau and Ralph Waldo Emerson posited that sound moral and spiritual development for humans stemmed from interactions with nature (Merchant 2002). Thus, protection of biodiversity is a central component of conservation biology and is especially important in modern times as we face an intense loss of biodiversity (Primack 2008).

Several things can cause biodiversity loss, such as the spread of disease, invasion by non-native species, pollution, habitat loss and fragmentation, and overharvesting (Wilcove et al. 1998). Many of these processes by which biodiversity is lost are natural or unavoidable. However, global biodiversity is being lost at an alarming rate, about a thousand times faster than the past trend in the fossil record indicates (MEA 2005, Barnosky et al. 2011). The International Union for Conservation of Nature (IUCN) Red List of threatened and endangered species tracks and confirms this accelerated rate of species extinctions (IUCN 2009).

It is well-accepted that habitat loss is a main driver of declines in biodiversity (Ehrlich 1988, Secretariat of the Convention on Biological Diversity 2010). Throughout the world, land conversion has resulted in the loss of natural land cover and the increasing fragmentation of that which remains (Lambeck 1997, Tilman et al. 2001, Foley et al. 2005). Ecosystem function and stability are thus being affected globally by anthropogenic activities that incur biodiversity losses, particularly by land conversion that induces habitat fragmentation and/or habitat loss (Samson et al. 2004, Secretariat of the Convention on Biological Diversity 2010, Galatowitsch 2012). Per indicators such as population trends and management responses to threats, global biodiversity has declined steeply over the past four decades (Butchart et al. 2010) as humans have cleared more and more land for agriculture and forestry (Krebs 2009).

Because biodiversity is critical for supporting ecosystem function and thus human society, the global conservation community has formed a number of initiatives to monitor and preserve biodiversity. For example, DIVERSITAS (Larigauderie et al. 2012), the Group on Earth Observatory Biodiversity Observation Network (GEO BON 2010), and the Convention on Biological Diversity (Secretariat of the Convention on Biological Diversity 2005) are all aimed at addressing biodiversity loss, with emphasis on conserving ecosystem services provided to humans (MEA 2005, IPBES 2011). Similar but smaller efforts such as the Butte Regional Conservation Plan (BRCP 2011) have likewise been created to identify at-risk species on a local level (city, county, or other small area) and work with industry and private landowners to site new development responsibly to preserve species' habitat. At all scales, conservation plans are formulated with the same goals of sustaining populations for the benefit of at-risk species as well as humans using the ecosystem.

A challenge in formulating effective conservation plans is assessing biodiversity, as it can be quantified in a multitude of ways (Magurran 1988). Species richness, or the number of different species in a given area, is perhaps the most common metric used to measure biodiversity. Although richness does not include assessments of species abundances (evenness or its converse, dominance), it is relatively straightforward in calculation (Magurran 1988). Therefore, richness (especially of endemic species) is a good assay of the conservation value of an area, particularly when dealing with known ranges of species. However, information on ranges and occurrence of many species is lacking; for example, there is a lack of information on invertebrate ranges, despite the fact that invertebrates account for the majority of known species (Ward et al. 2004). Therefore, any statistics or calculations based off incomplete information are estimates. When dealing with data in the form of species ranges, it has long been assumed that the abundance of species is densest at the center of the range and less so as one progresses towards the edge of the range (Sagarin et al. 2006). This assumption can simplify any subsequent analyses done on said ranges. Measurements of diversity combined with existing data prove useful in helping managers formulate conservation plans to protect species, especially for a multi-species approach.

One approach to conservation is to identify where dense concentrations of species occur. Areas with large numbers of species are commonly called hotspots and are of high conservation value (Myers et al. 2000). The biodiversity hotspot approach is increasingly being used to address multi-species conservation needs (Marchese 2015). Using endemic species richness as the strictest definition of biodiversity hotspots, areas of conservation need have been defined globally, with tropical regions being the hottest hotspots (Myers et al. 2000). Several resources exist to identify biodiversity and provide information for conservation planning. Precious Heritage: The Status of Biodiversity in the United States, is a thorough general reference for understanding what biodiversity is, its ecological importance, and loss rates (Stein et al. 2000). NatureServe (natureserve.org) is a recently developed online information hub for data on species distributions, ecosystem functions, and conservation efforts. These resources are useful overviews, but on state or smaller regional levels less work has been done to identify biodiversity hotspots.

Not all species are equivalent in terms of ecosystem function or conservation value or appeal, however, threatened and endangered species, harvestable or game species, and unique endemic species all have greater legal or social value than do other species (Boykin et al. 2013). The Endangered Species Act of 1973 (ESA) was designed to protect imperiled species and their habitat, recognizing the value of biodiversity in regards to ecosystem services. The ESA guides work with private landowners, states, tribes, and corporations to form habitat assessment plans and incentivize conservation of threatened and endangered species (Evans et al. 2016). In addition to federally threatened or endangered species, state-level designations of at-risk species exist. Species of Greatest Conservation Need, or SGCNs, are a state-level designation of flora and fauna species that have been deemed at-risk due to some threat or combination of threats leading to decreasing population trends. All federally threatened and endangered species occur on state-level designation of SGCNs. Since many conservation efforts are made at the state or regional level, the SGCN designation is particularly important for managers and policy-makers and would be useful in designating biodiversity hotspots for a multi-species approach.

In many instances, a single at-risk species may become the focus for conservation in a given area. Species that serve as such ambassadors are often well known, valued, and/or more easily researched and funded than landscape-level multi-species conservation efforts or efforts that focus on less charismatic species. These single species serve as surrogates for biodiversity in the area, conferring a protective umbrella to numerous co-occurring species, thereby offering a shortcut to multi-species conservation efforts where funding is limited (Fleishman et al. 2000, Rodrigues and Brooks 2007). Management of these so-called "umbrella species" has been a useful conservation tool (Caro and O'Doherty 1999, Favreau et al. 2006). For example, the conservation plan of the Bay Checker-Spot Butterfly (*Euphydryas editha bayensis*) also covered 98% of at-risk plant species (Launer and Murphy 1994). The European Nuthatch (*Sitta europaea*) has been used as an umbrella species to plan reserve networks for other birds (van Langevelde et al. 200). Approaches like these that can use umbrella species may be particularly expedient and cost-effective, and those that can identify hotspots of biodiversity would be especially valuable in protecting multiple species at once.

Biodiversity Loss on the Great Plains

The Great Plains are comprised of several unique ecoregions—the tallgrass prairie, the mixed-grass prairie, and the shortgrass prairie—all of which contain unique biodiversity that has been affected by land-cover changes stemming from agricultural activities and energy production. Agricultural cultivation is one of the primary forces inducing habitat fragmentation and loss around the world (Vitousek et al. 1997). As a necessary activity and a cosmopolitan form of land conversion, agriculture is a key conservation focus. In the U.S., the nation's breadbasket, corn, and cotton belts all converge in the Great Plains. The Great Plains region has largely been converted to agriculture, losing 20-99% of its original land cover in various states (Samson and Knopf 1994). Although some of this conversion began with large-scale settlement of the Great Plains in the 19th century, almost 93,000 square kilometers of United States grasslands have been lost more recently (between 1982 and 1997), primarily from conversion to agriculture (Samson et al. 2004). These losses have resulted in declines in number of species and the genetic diversity of the remaining species in the Great Plains (Sieg et al. 1999).

The Great Plains have also experienced land-cover changes from the development of oil and gas as well as wind energy infrastructure. The southern Great Plains states are the leading U.S. producers of petroleum products (Paxton 2001). By its very nature, energy development on the Great Plains causes habitat loss and/or fragmentation. This raises concerns in regards to wildlife habitat. For example, several studies have shown Sage Grouse avoid nesting within three kilometers of oil and gas developments as well as having lower survival rates near these developments (Walker et al. 2007, Holloran et al. 2010). As the human population increases, the need for energy development is likely to increase as well, which has implications for furthering biodiversity declines.

As a result of these forces, the Great Plains ecoregions are among the continent's most endangered biomes (Rickletts et al. 1999). The Great Plains have endured vast land-cover changes from grasslands to large-scale agriculture and rangeland since being settled (Drummond et al. 2012). The three ecoregions have not sustained equivalent losses, however. Tallgrass prairie has fared the worst, with losses well over 90% (Samson and Knopf 1994). Estimated declines in native mixed-grass prairie area, although less than the tallgrass declines, range from 30% in Texas to 99% in Manitoba. Finally, the shortgrass prairie has likewise decreased in area, ranging from an estimated 20% decline in Wyoming to 85% in Saskatchewan (Samson and Knopf 1994). Having retained relatively more intact habitat, the mixed-grass and shortgrass prairies may be the ecoregions with the greatest potential for preservation of their remaining biodiversity from multi-species conservation plans designed to work with existing and projected future land-use changes. The short and mixed-grass prairie eco-regions correspond to Bird Conservation Regions (BCR) 18 and 19 (U.S. North American Bird Conservation Initiative 2017).

Given extreme habitat declines in every ecoregion of the Great Plains, combined with biodiversity richness and continued propensity towards agricultural conversion, the Great Plains are of great conservation concern. There are over 1000 SGCNs in BCR 18 and 19, and as land is converted to agriculture and habitat is lost, biodiversity is likely to continue to decline. Grassland bird species have well-documented population declines throughout the Great Plains (Stein et al. 2000, Vickery and Herkert 2001, Brennan and Kuvlesky 2005), and other biodiversity is declining as well (Benedict et al. 1996, Corn and Peterson 1996). With the negative effects of climate change, these species are predicted to continue declining and have an impaired ability to disperse to new habitat (Peterson 2003).

In the southern Great Plains, at-risk species are plentiful but conservation plans are lacking. Though state-level efforts exist, there has not been a regional effort to include the short and mixed-grass prairie ecoregions as a whole. The U.S. Fish and Wildlife Service has a Mountain-Prairie Region directive that works with multiple federal agencies and other landowners to preserve habitat and biodiversity (U.S. Fish and Wildlife Service 2016). This region is delineated by state boundaries of northern U.S. mountainous and plains states and does not include all of the short- and mixed-grass ecoregions. Since protection of endangered species is legally mandated but funding to do so is limited, approaches designed to protect a single threatened species are often cost-ineffective (Waldron et al. 2013). A financially and practically beneficial approach to conservation can be to use a multi-species approach (Root et al. 2003).

Use of umbrella species is most appropriate in landscapes where managers are faced with a large number of species who only have remnants of habitat left in need of conservation (Fleishman et al. 2000). Large mammals have commonly been used as surrogate species, any species that occupies areas also critical to the existence of other species could feasibly function as an umbrella. For example, the Lesser Prairie-Chicken (LPC, *Tympanuchus pallidicinctus*), an endemic of the mixed-grass ecoregion of the southern Great Plains BCRs 18 and 19, has an existing landscape-level conservation plan that has the potential to be used as a framework to protect other at-risk species in this system that has experienced great habitat loss. Populations of Lesser Prairie-Chicken have declined significantly from historic levels (Crawford 1980, Garten et al. 2016). Once land cover is changed from original short- and mixed-grass prairie, grassland bird species such as the Lesser-Prairie Chicken decline (Fuhlendorf et al. 2002); the main causes of Lesser Prairie-Chicken decline have been habitat fragmentation and loss due to agricultural development (Hagen et al. 2004). Furthermore, Lesser Prairie-Chickens have been documented to avoid areas of human developments such as roads, power lines, and oil wells (Hagen et al. 2011). Since the Lesser Prairie-Chicken is up for listing as an endangered species, its conservation plan is likely to become even more important and enforceable, thus being more effective for potential non-target species as well.

The LPC Initiative is a partnership among the five current LPC range states (Texas, New Mexico, Oklahoma, Kansas, and Colorado), private landowners, and regional industries with activities that may negatively affect the LPC, such as energy production. The Lesser Prairie Chicken Interstate Working Group created the Lesser Prairie-Chicken Range-wide Conservation Plan in October 2013 in an effort to preclude the species from being listed as threatened under the U.S. Endangered Species Act (Van Pelt et al. 2013). From this plan, the Working Group in association with the Western Association of Fish and Wildlife Agencies (WAFWA) created the Southern Great Plains Crucial Habitat Assessment Tool (CHAT), intended to help industry make informed decisions about building energy infrastructure and mitigating for the loss of Lesser Prairie-Chickens and their habitat. The CHAT tool assigns a gradient of conservation priorities to the landscape and identifies the most important Lesser Prairie-Chicken habitat areas, which include areas of short vegetation for lekking, taller grass for nesting, connectivity zones between habitat patches, and a buffer zone surrounding known habitat (WAFWA 2017). A particularly unique aspect of the CHAT tool is that it uses geospatial technology to delineate areas of conservation priority. My project examined whether the range-wide plan (visualized via the CHAT) can serve to protect other at-risk, non-target species, capitalizing on areas that have been deemed high priority for protection and identify other SGCN species ranges that also occur in these areas to definitively say whether the CHAT tool serves as a multi-species conservation effort. Although it was not designed as one, there is considerable potential for added-on value from such a designation.

The rich biodiversity of the Great Plains as well as its energy and food production make this region an important provider of ecosystem services and thus of conservation concern. Provisioning ecosystem services such crop and fiber production and energy production are important to humans but reduce grassland biodiversity on the Great Plains (Power 2010). This reduction in biodiversity compromises the ability of the ecosystem to provide services, such as supporting services that benefit agricultural production. Services such as nutrient cycling, water provisioning, soil fertility, and genetic diversity for breeding crops and livestock all support agricultural production (Power 2010). In other words, preserving biodiversity and ecosystem function preserves ecosystem services in the southern Great Plains region.

Agricultural lands are expanding globally but also becoming more productive in response to the exponentially growing human population. Some negative consequences of intensive production are lower biodiversity, lower soil fertility, and pollution of groundwater due to pesticides and fertilizers (Matson et al. 1997). The rates of environmental degradation in the form of eutrophication and water shortages are predicted to increase in agriculturally intensive areas over the next fifty years, simplifying ecosystems and resulting in biodiversity loss and thus a loss of ecosystem services (Tilman et al. 2001). Freese et al. (2014) call for a conservation management approach to support ecological processes and thus maintain ecosystem services throughout Great Plains rangelands. Conservation of biodiversity throughout the southern Great Plains results in services benefiting land managers, private landowners, and industry alike, and therefore should be a top priority for all.

The main objectives of my project were thus to identify biodiversity hotspots in terms of species richness for species at risk in the Great Plains, and to determine whether the Lesser Prairie-Chicken can serve as an umbrella species for other at-risk species in the mixed- and short-grass prairie ecoregions, based on locality and habitat similarities.

The Great Plains has gone through large changes in land use, including increases in agriculture, energy infrastructure, and other forms of development (Samson and Knopf 1994). These changes will continue to increase, fragmenting and changing wildlife habitat as the human population continues to grow, unless conservation of habitat is deemed a priority. My project aims to help natural resource managers deal with this conservation need by identifying areas and species that are receiving conservation coverage based on current efforts, the Lesser Prairie-Chicken Range-wide Conservation Plan, and those species and areas that need additional conservation efforts.

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CHAPTER II

Hotspots of at-risk species in the Great Plains and implications for future management efforts

Abstract

Biodiversity is being lost at an unprecedented rate, and resources for conservation efforts across the globe are lacking. This is particularly problematic in the Great Plains, where land-cover conversion to agriculture and energy production has altered habitat for many species. Given a growing human population and therefore increasing need for food and energy production, this region is of critical conservation importance to protect over 1000 currently listed at-risk species. To be most effective in terms of conserving at-risk species, identifying hotspots of biodiversity offers an opportunity to take a multi-species approach to areas of conservation concern. This study defines hotspots of biodiversity as dense concentrations of Species of Greatest Conservation Need identified by states in the southern Great Plains short- and mixed-grass ecoregions. I overlaid existing range files (USGS GAP Analysis Program) for at-risk vertebrate species in ArcMap 10.3.1 to highlight hotspots. I also identified land ownership types underlying hotspots so that land managers may have valuable information to address conservation of at-risk species in the Great Plains. Hotspots for current, pending, and combined (current and pending) Species of Greatest Conservation Need occur mostly on state or federal-managed land along eastern New Mexico and Colorado.

Introduction

Biodiversity is critical to maintaining ecosystem function and stability (Loreau et al. 2001, Hector and Bagchi 2007, Cardinale et al. 2012). A plethora of studies demonstrate that the loss of biodiversity can compromise an ecosystem’s ability to cycle nutrients, produce biomass, and maintain overall function and stability (Cardinale et al. 2012). Loss of biodiversity and therefore stability within an ecosystem can make that ecosystem more vulnerable to invasion and further environmental degradation (Chapin et al. 2000, Hooper et al. 2005). Environmental degradation reduces the ability of a system to provide goods and services such as food production, building materials, fuel, and recreational opportunities (Hooper et al. 2005). It is imperative to preserve biodiversity and ecosystem function so that these systems can continue to provide for human well-being and environmental health.

Maintaining biodiversity is so important that global partnership as well as federal and state governments have created protections for at-risk species. For example, the Millennium Ecosystem Assessment is a global effort developed to identify biodiversity trends around the world for conservation planning (MEA 2005). Another global effort, the International Union for the Conservation of Nature (IUCN), identifies at-risk species and their threats on a global scale (IUCN 2008). U.S. federal efforts include the Endangered Species Act (ESA) of 1973 that identifies threatened and endangered species and provides the framework and regulatory authority for habitat conservation. In addition to federal protections, state wildlife agencies designate Species of Greatest Conservation Need, which are species deemed to be at-risk within the state boundary for various reasons. This allows individual state agencies to develop land management and conservation plans specific to the needs of their local species, habitats, and economies. At all levels of government, protection of biodiversity is a priority.

Despite emphasis on biodiversity conservation, biodiversity loss is at an all-time high (IUCN 2008, Butchart et al. 2010). Both anthropogenic and stochastic factors contribute to biodiversity loss, the main driver being habitat loss and/or fragmentation by human alteration of the environment (Secretariat of the Convention on Biological Diversity 2010, Pereira et al. 2012). These anthropogenic factors reduce populations to the point that stochastic factors leading to extinction can have a large influence. Areas that experience high levels of fragmentation or land-cover conversion tend to be those developed for use by humans, particularly for agricultural use (Foley et al. 2005). Humans are thus forcing an unprecedented rate of biodiversity loss (Periera et al. 2012). In areas where habitat is being lost, degraded, or heavily fragmented, conservation plans are key to reducing rates of biodiversity loss and protecting at-risk species.

The Great Plains region has lost 20-99% of its original landscape cover to agricultural conversion (Samson and Knopf 1994), resulting in declines in species richness and abundance and in range contractions (Sieg et al. 1999). The Great Plains has distinct ecoregions of tallgrass, shortgrass, and mixed-grass prairies, is home to over 1,000 at-risk species, and is among North America's most endangered biomes (Rickletts et al. 1999). The Great Plains have lost over 90% of the tallgrass prairie (Samson and Knopf, 1994), and 30% of the mixed-grass prairie in Texas to 99% in Manitoba. The shortgrass prairie has declined from around 20% in Wyoming to 85% in Saskatchewan (Samson and Knopf 1994). This region is the primary provider of food for the U.S. and is home to oil, gas, and wind energy development (Samson and Knopf 1994, Paxton 2001). With an ever-expanding human population, the Great Plains region is of important for conserving biodiversity in the wake of the growing need for crop and energy production. With this growing population, it is more important now than ever to expand energy production responsibly, while protecting habitat for at-risk species.

Resources for conservation efforts are lacking, making it difficult to address all species in need of protection. In many instances, single target species conservation plans exist for charismatic or threatened/endangered species. This single-species approach is driven by the Endangered Species Act (ESA) of 1973, which offers protection for any federally listed threatened or endangered species. This approach has received both praise for its successes and criticisms for its shortcomings when many species still go extinct even under protection (Simberloff 1998). Although individual species certainly warrant attention, since resources are limited for management it would be beneficial to address multiple species with existing conservation plans to have a larger positive impact on biodiversity and ecosystem services (Root et al. 2003).

In addition to number of species that can be protected, it is also important to know the type of land management of an area in order to apply the most appropriate conservation strategy. For example, land trusts and conservation easements are suitable for private lands and consider both the needs of conserving habitat and of the landowner (Merenlender et al. 2004). Federal efforts such as the ESA mentioned above can promote no-take efforts on any listed species on any type of land but can only employ conservation plans on federal lands, or through special voluntary agreements with private landowners. State conservation efforts can include state wildlife action plans to help species threatened at the state-level before they are listed by the ESA (USFWS 2016). Moreover, regional conservation strategies may use a combination of these efforts. When combined with land ownership information, identifying biodiversity hotspots is a conservation approach that may address multiple species needs at once (Myers et al.

2000, Marchese 2015) and could offer land managers valuable insight on how to employ effective conservation strategies.

Identification of biodiversity hotspots of at-risk species throughout the Great Plains is valuable for planning conservation and integrating private, state, and federal efforts. Using hotspots of at-risk species and information on land ownership underlying these areas, state and federal land managers can plan conservation efforts that will protect many species at once to maximize financial and labor efficiency for such projects. My project identifies hotspots of at-risk biodiversity in the southern Great Plains and the land ownership underlying those hotspots to provide state and regional land managers with valuable information to be considered when formulating conservation strategies.

Methods

The three ecoregions that comprise the Great Plains are the tall-, short- and mixed-grass prairie ecoregions. The short- and mixed grass prairie ecoregions cover parts of Texas, New Mexico, Oklahoma, Nebraska, Colorado, Kansas, Wyoming, and South Dakota. I chose the short- and mixed-grass ecoregions because these areas have not been decimated as drastically as the tallgrass prairie and continue to offer unique habitat for many species (Samson and Knopf 1994). I defined the study area as Bird Conservation Regions 18 and 19 as delimited by the Commission for Environmental Cooperation (http://nabci-us.org/resources/bird-conservation-regions/), which correspond to the short- and mixed-grass prairie ecoregions (Figure 2.1).

I used at-risk species by state-level designation of Species of Greatest Conservation Need (SGCN), as this designation is most applicable to state agencies for management and includes species that may not be federally protected. I compiled lists of current SGCNs from state agencies for the eight states in my study area: Texas Parks and Wildlife Department, New Mexico Game and Fish, Oklahoma Department of Wildlife Conservation, Nebraska Game and Parks Commission, Colorado Parks and Wildlife, Kansas Department of Wildlife and Parks, Wyoming Game and Fish Department, and South Dakota Game, Fish, and Parks.

There were 1763 total currently listed SGCNs across the study area at the time information was collected. I included vertebrate species only for the analysis because vertebrate range files were readily available whereas the majority of invertebrate range files do not exist digitally. Of the currently listed 710 vertebrate SGCNs in the study area, range files from USGS Gap Analysis program exist for 347 species. Digitized fish species ranges were generally unavailable and many range files were "in progress" or not yet completely digitized. I used all files form GAP to be consistent and because GAP has the most complete collection of range files. Of these 347 range files, 81 ranges did not overlap with the study area. I also compiled lists of pending SGCNs for the eight states. New Mexico and Kansas recently reviewed and updated their SGCN list and did not have any pending species. I consolidated any overlap in listings between states, including states that had a pending SGCN that was already listed as a current SGCN elsewhere. In total, there were 120 at-risk species pending listing for SGCN in the study area, 53 of which were vertebrate species. Range files exist for 26 of these species (USGS Gap Analysis) and of those species, three ranges did not overlap with the study area. I transformed the remaining 266 current SGCN range files (Appendix 2.1) and 23 pending SGCN range files (Appendix 2.2) from .dbf (database) files into raster format (Appendix 2.3), an appropriate format for these analyses to calculate cell overlap and thus species richness. For rasterization of .dbf files, cell size was set to 5km by 5km, a biologically reasonable maximum distance for at least some of the less-vagile species such as amphibians (Griffis-Kyle et al. 2011), but large enough to be computationally efficient.

I then overlaid the raster files in ArcMap 10.3.1 to create a hotspot density surface based on species richness from range maps using the projection NAD 1983 for all layers involved, as it is the projection used by USGS GAP Analysis program. The "0" category was eliminated, as it represented cells outside the study area. I designated remaining categories of hotspots using a mix of natural breaks (Jenks) and visual histogram evaluation. I identified obvious breaks and rounded to the nearest whole number, as in this study I was interested in species richness, counting whole numbers of species. I used a color ramp with a gradient from cool to warm tones to indicate areas of lower to higher species richness, respectively. I used the raster to polygon tool, dissolved the category polygons, and exported the attribute table to Microsoft Excel to gather number of square kilometers per hotspot category. I combined current and candidate species range files into a single hotspot surface layer. Current and pending SGCNs were used for a temporal comparison between existing areas with dense concentrations of at-risk species and areas likely to be of conservation interest in the future. I combined these two layers to highlight shifts in current hotspots and future hotspots, so management can plan preemptively. I used the raster to polygon tool, dissolved the category polygons, and exported the attribute table of the combined hotspot layer to Microsoft Excel to calculate square kilometers per hotspot category.

I identified land ownership under each hotspot category using the PADUS 1.4 layer from USGS (USGS 2017), which is a compilation of protected areas surveyed at federal and state levels and formatted into one usable feature class. I overlaid the PADUS 1.4 layer onto each hotspot map and extracted land ownership values by attribute "MangType" or management type, which I also refer to as land ownership (Appendix 2.4). There were eight categories of management type: district, federal, joint (joint ownership between any two or more entities), local, non-governmental organization, private, state, and unknown (abbreviated DIST, FED, JNT, LOC, NGO, PVT, STAT, and UNK, respectively). I also included a "Not Surveyed" category for lands that were not protected areas and therefore not included in the PADUS 1.4 layer. The attribute table produced from the model yielded values in square meters for type of land ownership of each hotspot category. I copied these values into Microsoft Excel (version 2013) to identify areas of land ownership in square kilometers. I repeated this methodology for current SGCN hotspots, pending SGCN hotspots, and the combined current and pending hotspot layer. This land ownership analysis identifies the agencies responsible in each hotspot area so that land managers may know with whom to work to formulate conservation plans.

To determine whether land ownership had an effect on species richness, I created a weighted average of species richness by dividing species richness by land area per land ownership type. I used the high end of the hotspot categories, as SAS 9.4 did not recognize species richness as string variables (e.g.- hotspot category 106-113 was entered as 113). To determine if my land ownership data met the assumptions of normality and equality of variances, I ran Shapiro-Wilk and Levene tests. Since the data for the three hotspot layers did not meet assumptions of normality (p values < 0.004 for Not Surveyed, NGO, State, and Unknown, whereas Private, Federal, and District, Local, and Joint $p >$

0.056). I used a log transformation and tested again, and assumptions were met (all $p > 0.05$, except State and Not Surveyed). My data for the current, pending, and combined hotspot layer did not meet assumptions of homoscedasticity as per Levene's test (all $p > 12.35$). However, ANOVA is robust to violations of assumptions, so we used the log transformed data. To assess whether there was any statistical difference in whether hotspot categories were more likely to fall on any given land ownership type, I ran an ANOVA (SAS 9.4) as I had one class variable for comparison. I used land ownership area totals in km^2 in Microsoft Excel (2013) as per extracted from the attribute tables of current, pending, and combined SGCN hotspot maps. I ran the ANOVA for data from each of the three hotspot layers to plot weighted species richness against land ownership. To determine where the statistical differences lied between categories of land ownership, I ran a Tukey's post-hoc test. I used SAS English version 9.4 for all statistical analyses.

Results

I included a total of 266 current SGCN and 23 pending species of existing vertebrate range files that overlapped with the study area. Hotspot categories for the current SGCN layer were: 106-113, 114-120, 121-125, 126-131, 132-135, 136-140, 141-146, 147-154, and 155-164 species (Figure 2.2). Pending SGCNs resulted in seven categories: nine, 10-11, 12, 13, 14, 15, and 16-18 species (Figure 2.3). The mix of natural breaks (Jenks) method and visual histogram evaluation resulted in nine categories for the combined layer: 115-123, 124-128, 129-134, 135-141, 142-147, 148-153, 154-160, 161-169, and 170-179 species (Figure 2.4). The entire study area measured 782,812 km^2. Total area in kilometers squared for current, pending, and combined layer hotspot categories is summarized in Tables 2.1, 2.2, and 2.3, respectively.

Fifteen percent of the study area had over 140 species currently assessed as being at risk. The areas with fewest species at risk, 10% of the total area, still had a minimum of 106 species at a resolution of 5 km by 5 km (Table 2.1, Figure 2.5). For current SGCNs (Figure 2.6), warm (orange and red) colors representing the densest hotspots (141 to 164 species) lie in the southeast portion of Colorado, the westernmost portion of the panhandle in Oklahoma, and a small portion of northeast New Mexico. Yellow and green colors representing mid-range density hotspots (121 to 135 species) occur across the panhandle of Texas into central Texas and the western portion of Oklahoma. Mid-density hotspots also cover parts of eastern Colorado and eastern New Mexico to the east of the mountain ranges. Cooler shades of blue, or less dense hotspots (106 to 120 species), lie across much of Nebraska, northern Kansas, and northeast Colorado. There is also a portion of low-density hotspots along the western border of Texas with New Mexico. It is worth noting that the coolest hotspots still contain between 115 and 123 SGCNs.

Fifteen percent of the study area had over 14 species pending assessment for at-risk status. Areas with the fewest at-risk species, 31% of the area, still had a minimum of nine species at a resolution of 5 km by 5 km (Table 2.2, Figure 2.7). Pending SGCNs (Figure 2.8) show the warmest colors or densest hotspot (14 to 18 species) over the southeast Colorado and along the western border of the Texas panhandle (stopping just before the border), which includes part of the Permian Basin. Green shades or mid-density hotspots (12 to 13 pending species) cover the central and eastern Texas panhandle, the southwestern portion of Oklahoma, and the eastern border of New Mexico. Mid-density hotspots outline the densest hotspots over the Permian basin area of Texas and southeast Colorado. There are also mid-density hotspots that run north to south through eastern Colorado to the southeastern corner of Wyoming. Blue shades or low-density hotspots (9 to 11 pending species) cover most of central Nebraska, eastern Kansas, and a small portion of northeast Colorado.

Thirty-four percent of the study area had over 148 current and pending SGCNs. Areas with the fewest species at risk, or 12% of the area, had a minimum of 115 species at a resolution of 5 km by 5 km (Table 2.3, Figure 2.9). The combined hotspot layer of current and pending SGCNs (Figure 2.10) follows somewhat similar trends as the current SGCN layer. Reds and oranges or the densest hotspots (154 to 179 species) for the combined layer occur in the southeast portion of Colorado and along the eastern side of the mountains in New Mexico. Dense hotspots also occur along the southeastern edge of the study area over north-central Texas and south-central Oklahoma. Small patches in the Texas panhandle and central Oklahoma emerge as well. Yellow and green or mid-density hotspots (135 to 153 species) occur throughout west Texas and eastern New Mexico. The panhandle of Oklahoma up into central Kansas are also mid-density areas. A thin strip of mid-density hotspots runs north to south along eastern Colorado up to the southeast corner of Wyoming. Blue shades representing low-density hotspots (115 to 134 species) can be seen in central Nebraska and central northern Kansas. Again, low-density hotspots still consist of 115-123 species.

Land ownership type for current, pending, and combined SGCNs is summarized in square kilometers per hotspot category in Tables 2.4-2.6 and visualized in Figures 2.11-2.13. The total area of the study site is 782813 km^2 distributed across land ownership as follows in order from greatest area to least: 23,250 km^2 State, 19,012 km^2 Federal, 8,783 km^2 Joint, 3,075 km^2 NGO, 2,846 km^2 Local, 334 km^2 Private, 305 km^2

Unknown, and 33.33 km^2 District. Figures 2.14 and 2.15 show the highest species richness hotspot category and the top three surveyed landowner groups that have the most currently listed at-risk species and most combined species (current and pending at-risk species). The PADUS 1.4 layer (Figure 2.16) shows the eight landownership types plus the land that hasn't been surveyed. This information highlights areas with the highest risks to provide land managers information on where to target species for protection.

I ran an ANOVA (SAS 9.4) which revealed a significant difference ($F_{8,63}$=13.1, p < 0.0001) between hotspot occurrence across various land ownership types for the current SGCN layer. Tukey's post-hoc tests indicated that there was considerable overlap among eight of the nine land ownership categories (Figure 2.17). The pending SGCN layer revealed a statistically significant different in land ownership types hosting species richness. ($F_{8,54}$=10.96, p < 0.0001) Tukey's post-hoc tests show overlap among seven of the nine categories (Figure 2.18). The combined SGCN layer revealed a statistically significant difference ($F_{8,64}$=11.8, p < 0.0001) in whether various land ownership types were more likely to host certain hotspot categories (species richness). Tukey's post-hoc tests indicated that again there was considerable overlap among all nine categories (Figure 2.19). When species richness was divided by area of each land ownership type, smaller land ownership areas reveal an inflated average of species richness. This is to be expected as I was dividing a large number of species richness over a small amount of land area. Thus, District showed the highest values of species richness and Not Surveyed exhibited the lowest.

Discussion

Mountainous areas in the study region generally had more at risk species than the plains. Current (266 species) and current and pending combined (266 current and 23 pending species) hotspots primarily occur in the mountainous regions of Colorado and New Mexico. Pending SGCN hotspots are chiefly along the mountains of southeastern Colorado and northeastern New Mexico. This relationship between mountainous areas and hotspots may be a result of topography and/or landscape heterogeneity. Topography in this context refers to elevational change, and how areas with greater change in elevation have a greater amount of absolute surface area than flatter areas, potentially supporting more species (Connor and McCoy 1979, Hill et al. 1994). Maps are two-dimensional whereas mountainous regions are three-dimensional and therefore have more surface area. Another possibility is that landscape heterogeneity and related habitat heterogeneity may support a larger number of species because of a greater diversity of resources (Connor and McCoy 1979, Hill et al. 1994). Topographically diverse landscapes (i.e., mountainous regions) have landscape and habitat variability that translates into more available niches and therefore greater plant biodiversity (Hofer et al. 2008). On the other hand, modified agricultural lands that lack native vegetation have less species richness of mammalian, avian, amphibian, and reptilian taxa than forest plantations (Felton et al. 2010) with greater landscape heterogeneity. Landscape heterogeneity in agricultural lands may be necessary for biodiversity (Fahrig et al. 2011) and therefore should be of consideration when managing agricultural landscapes (Benton et al. 2003).

The pending SGCN hotspot layer exhibits highest species richness around the northwest border of the Texas panhandle, the Permian Basin region, and just south of the Permian Basin region. Declining populations in this area and other areas of may be a function of intense energy development (Ruppel and Hovorka 1995, Walker et al. 2007). In areas where human development is occurring, it is important to allow for energy expansion while simultaneously protecting habitat for at-risk species. For example, the range-wide plan for the Lesser Prairie-Chicken (www.wafwa.org/initiatives/grasslands/lesser_prairie_chicken/) places significant fees on any development impacting crucial chicken habitat, incentivizing industry to site elsewhere (Van Pelt et al. 2013). Similarly, Doherty et al (2008, 2011) developed a framework for wind and natural gas companies to maintain Greater Sage-Grouse (*Centrocercus urophasianus*) numbers in the northern Great Plains by identifying leks and critical nesting habitat. Identification of emerging hotspots of at-risk biodiversity and efforts such as those for the Lesser Prairie-Chicken and the Greater Sage-Grouse can help energy developments responsibly site infrastructure as well as provide land managers with areas of conservation priority.

Effective management will be influenced by type of land ownership. For the southern Great Plains, private, local, and district lands had the greatest concentration of at-risk species. In these areas, programs such as conservation easements and land trusts may be most useful (Merlender et al. 2004, Rissman et al. 2007). This information can be used to help land managers determine what agencies or land owners may be most beneficial to partner with in terms on formulating conservation strategies. However, the PADUS land ownership layer, while useful, lacks information on large swaths of land (the "Not Surveyed" category). Since this layer is a compilation of federal and state surveys of publicly administrated lands, it is likely that most of the unsurveyed lands are private. This leaves a large information gap, and conservation plans for private lands are likely under-emphasized in this area. Additionally, the statistics I ran, by nature of the weighted species richness Y variable, inflate results for land ownership types with small areas.

My work is focused on vertebrates that have USGS GAP digital range files. Invertebrate species ranges were generally not available, which is why I included only vertebrate species in the analysis. Although 710 vertebrate species were listed for the states in the area, overlapping range files with the study area existed for only 266 species. Fish ranges in particular were lacking on available digitized range files. This makes my work a very conservative estimate of at-risk species richness across all hotspots. For my analyses, my raster cell size was 5 km by 5km, whereas many rasters have a cell size of 30 m by 30 m. This means my project lost some resolution, but likely not enough to make a huge difference, as I am working with range files that cover very large spatial extents. If a study were to look at specific occurrences of species, then this larger resolution may have a significant effect.

Using hotspot mapping to target conservation can increase efficiency of management actions. Depending on management goals, different variations of hotspots can be mapped (e.g. species richness, endemism, species at risk, etc.). For example, I mapped concentrations of state-listed SGCNs because these lists may cover species not federally listed, and because much of the wildlife management is done at the state level. For management agencies working at regional scales, mapping concentrations of at-risk species can identify and prioritize locations for active conservation. Other studies have used species endemism to identify concentrations of unique biodiversity (Myers et al. 2000, Roberts et al. 2002, Malcolm et al. 2006) or compared endemism to overall species diversity to identify areas where more species are at risk of decline (Kerr 1997). In the southern Great Plains, several studies have looked specifically at habitat complexity and land-cover change in regards to conservation (Coppedge et al. 2001, Pogue and Schnell 2001). Future studies could incorporate my study's siting of biodiversity hotspots into examinations of the role of agricultural or energy-developed lands on landscape heterogeneity for a more holistic picture of how hotspots of at-risk species are being or will be affected over time. Additional studies could also include indicators of species rarity or endemism to apply a different weight to hotspot categories.

Wildlife across the southern Great Plains is currently faced with many stressors causing population declines. Some issues causing biodiversity declines in this region are drought accompanied by compounding effects of climate change such as higher temperatures, less surface water, and earlier onset of spring (Bonfils et al. 2008, MacDonald 2010). These factors have triggered pathogen outbreaks and wildfires (Bentz 2008), leading to habitat destruction. As stressors increase with the compounding effects of climate change, efforts such as this project will become increasingly valuable for landscape planning to protect the greatest number of species or hotspots. Much of the dense hotspot areas throughout Colorado and New Mexico are National Forest lands. Implementing conservation or habitat/species monitoring is implicit when developing land management plans, and these areas may provide the only remnant habitat remaining in fragmented landscapes (J.A. Burns, National Endangered Species Program Leader, U.S. Forest Service, personal communication). With identification of current and emerging hotspots, land managers can continue to troubleshoot areas of high conservation priority.

With the rise of landscape or ecosystem-level conservation approaches, targeting multiple species is becoming a more popular practice (Hobbs 1994). Identifying biodiversity hotspots is one method of a multi-species approach that can be cost- and resource-effective (Marchese 2015). Since funding financial for conservation is limited (McDonald-Madden et al. 2008), it is of utmost importance to continue finding feasible and effective ways to implement efficient conservation plans. As the Great Plains continue to provide agricultural and energy services, it is important to preserve biodiversity and maintain ecosystem function (Naeem et al. 1994, Loreau et al. 2001) to glean the benefits of these services while being good stewards of the environment. My study provides valuable information on hotspots of at-risk biodiversity in a region where such information is lacking. The information provided in this study can assist land managers and conservation planners at the state and regional levels throughout the southern Great Plains to more efficiently apply their limited funding and other resources.

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Tables, Figures, Appendices

Table 2.1 – Area of currently listed Species of Greatest Conservation Need per designated hotspot category. Categories are based on natural breaks in the data.

Hotspot Category (Species Richness)	**Area Km^2**
106 - 113	77200
114 - 120	121200
121 - 125	95150
126 - 131	127875
132 - 135	98225
136 - 140	142800
141 - 146	77050
147 - 154	34750
155 - 164	7775

Table 2.2 – Area of state pending Species of Greatest Conservation Need per designated hotspot category. Categories are based on natural breaks in the data.

Hotspot Category (Species Richness)	**Area Km^2**
9	240000
10 - 11	195500
12	132850
13	80850
14	49525
15	37500
16 - 18	45800

Table 2.3 –Area of state pending plus currently listed Species of Greatest Conservation Need per designated hotspot category. Categories are based on natural breaks in the data.

Hotspot Category (Species Richness)	**Area Km^2**
115 - 123	96300
124 - 128	84325
129- 134	77825
135 - 141	111525
142 - 147	142975
148 - 153	158175
154 - 160	73475
161 - 169	30600
170 - 179	6825

Table 2.4 – Current state-listed Species of Greatest Conservation Need hotspot land ownership type (km^2) per hotspot category. There were eight categories of management type: district, federal, joint, local, non-governmental organization, private, state, and unknown, abbreviated DIST, FED, JNT, LOC, NGO, PVT, STAT, and UNK, respectively. Areas that fell outside of surveyed land ownership are labeled "Not Surveyed." Hotspot categories with no land on a given land ownership category have been eliminated (0.00 km^2/ Land Ownership Category).

Ownership	Area (km^2) per Hotspot Category (Species Richness)								
	106-113	114-120	121-125	126-131	132-135	136-140	141-146	147-154	155-164
Federal	3429	2673	1071	1384	1294	3942	1802	2235	0
State	157	689	5514	4376	1490	2318	4791	3365	551
Joint	142	373	120	92	1223	3759	2240	649	186
District	0	<1	0	0	4	20	9	0	0
Local	<1	13	23	259	864	1059	610	19	0
NGO	248	228	226	676	216	138	320	665	357
Private	17	2	6	27	0	< 1	21	261	0
Unknown	91	7	2	33	74	32	64	3	0
Not Surveyed	73172	117233	88203	121116	93214	131747	67307	27661	5521

Table 2.5 – Pending state Species of Greatest Conservation Need hotspot land ownership type (km^2) per hotspot category. There were eight categories of management type: district, federal, joint, local, non-governmental organization, private, state, and unknown, abbreviated DIST, FED, JNT, LOC, NGO, PVT, STAT, and UNK, respectively. Areas that fell outside of surveyed land ownership are labeled "Not Surveyed."

Ownership	Area (km^2) per Hotspot Category (Species Richness)							
	115-123	124-128	129-134	135-141	142-147	148-153	154-160	161-169
Federal	6467	1766	1258	4652	2206	1468	740	454
State	3511	5816	2481	3816	4299	2649	484	194
Joint	611	66	770	4884	1631	465	356	0
District	< 1	0	0	24	9	0	0	0
Local	33	23	785	1456	530	19	0	0
NGO	532	740	226	321	363	534	249	108
Private	19	32	1	2	122	158	0	0
Unknown	98	25	40	95	44	3	0	0
Not surveyed	245878	99283	120902	177762	52476	22163	5013	1697

Table 2.6 – Combined current and pending Species of Greatest Conservation Need hotspot land ownership type (km^2) per hotspot category . There were eight categories of management type: district, federal, joint, local, non-governmental organization, private, state, and unknown, abbreviated DIST, FED, JNT, LOC, NGO, PVT, STAT, and UNK, respectively. Areas that fell outside of surveyed land ownership are labeled "Not Surveyed." Hotspot categories with no land on a given land ownership category have been eliminated (0.00 km^2/ Land Ownership Category).

Ownership	Area (km^2) per Hotspot Category (Species Richness)								
	115-123	124-128	129-134	135-141	142-147	148-153	154-160	161-169	170-179
Federal	3871	2117	428	2000	1505	3988	1717	2201	0
State	170	397	1474	7481	2586	2807	4516	3153	665
Joint	159	252	205	79	1873	3962	1432	799	22
District	< 1	< 1	0	0	0	23	10	0	0
Local	< 1	12	1	38	177	1696	901	22	0
NGO	263	127	170	730	295	165	377	590	357
Private	17	2	3	30	1	< 1	124	158	0
Unknown	91	6	2	33	74	48	48	3	0
Not Surveyed	91788	81421	75549	101234	136620	145726	64448	23769	4619

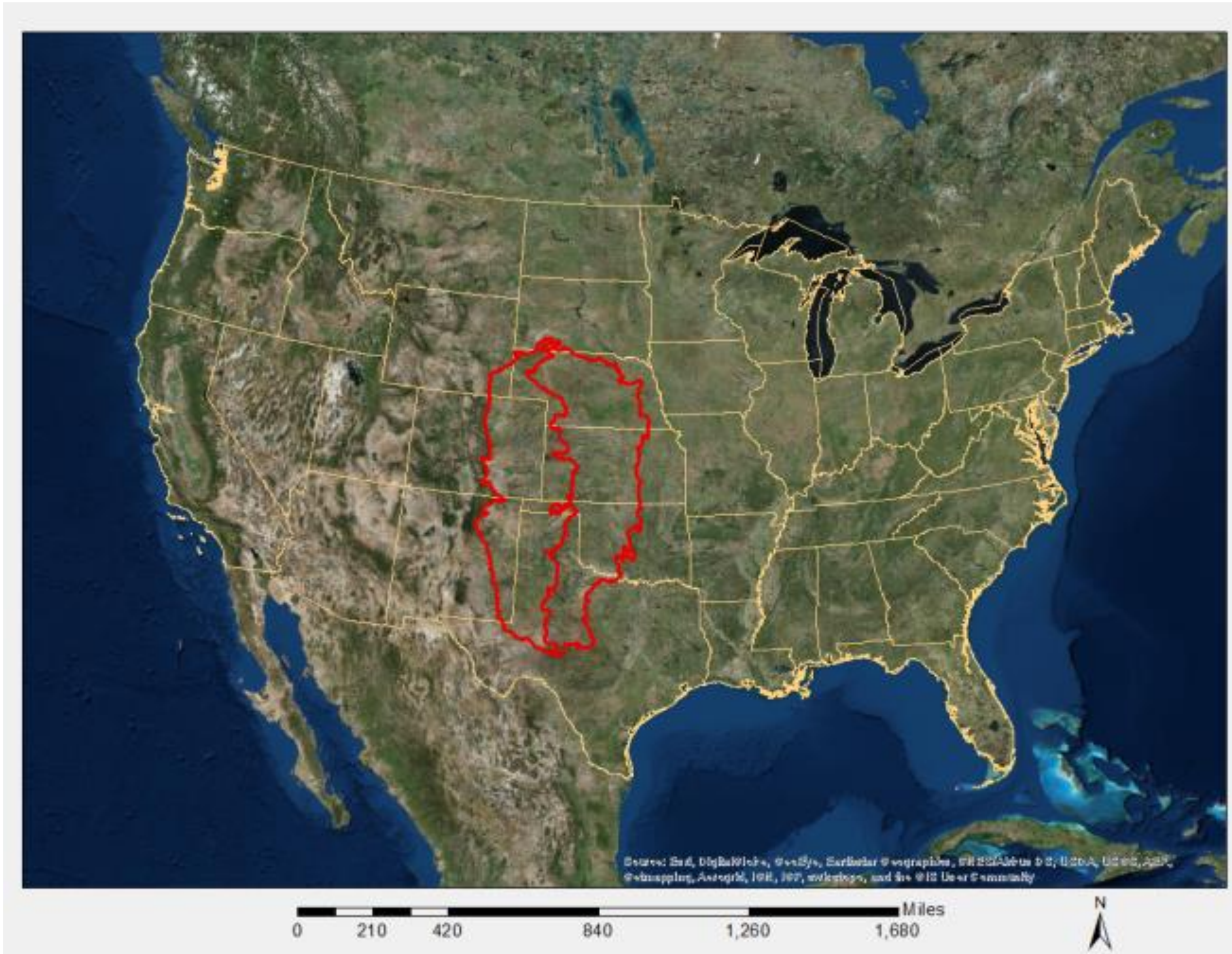


Figure 2.1 – The study area (Bird Conservation Regions 18 and 19) outlined in red. BCR 18 and 19 cover portions of eight states throughout the Great Plains: Texas, New Mexico, Oklahoma, Colorado, Kansas, Wyoming, Nebraska, and South Dakota.

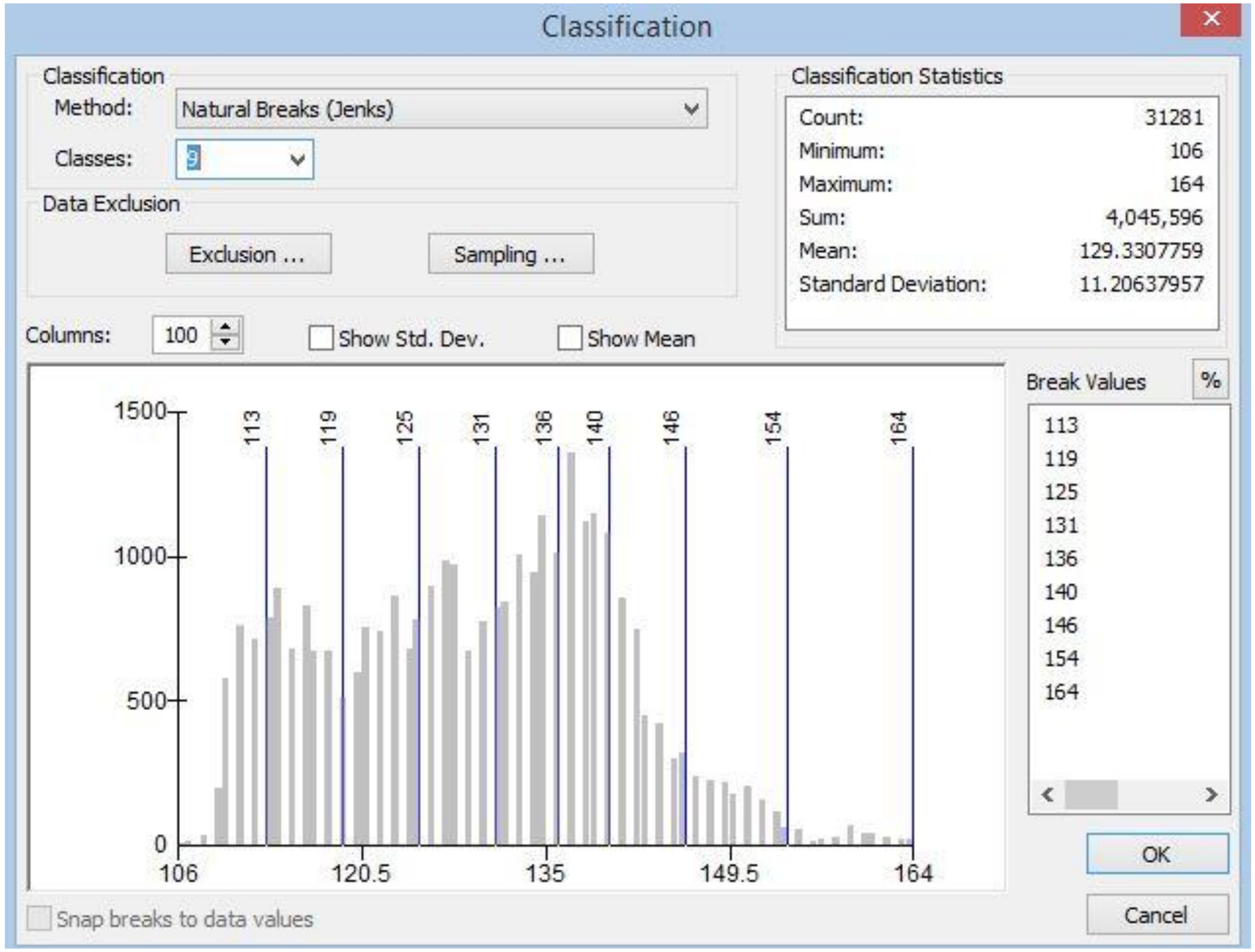


Figure 2.2 – Histogram from ArcMap 10.3.1 (Symbology, Classification tab) showing natural breaks (Jenks) rounded to determine hotspot categories for the current Species of Greatest Conservation Need hotspot layer.

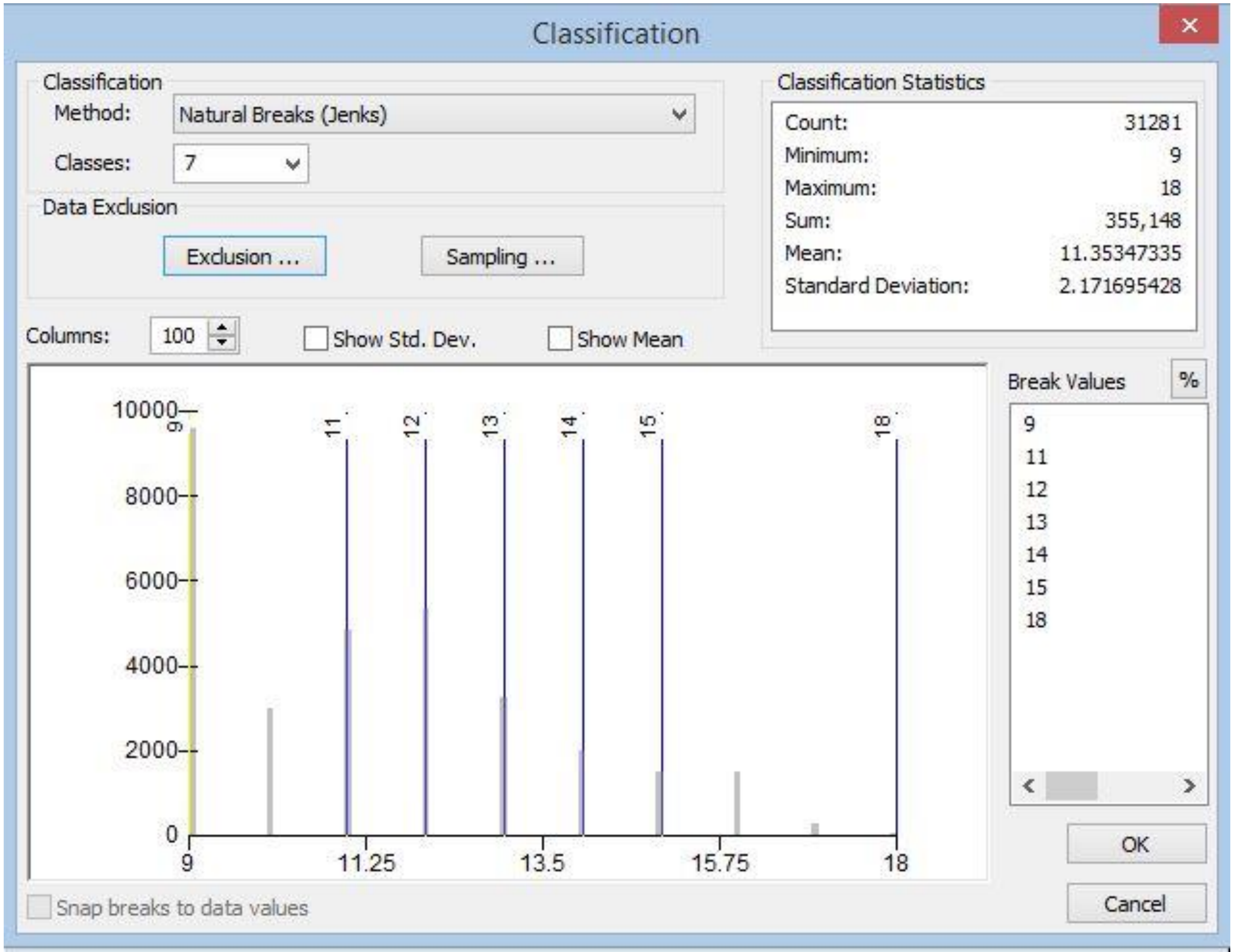


Figure 2.3 – Histogram from ArcMap 10.3.1 (Symbology, Classification tab) showing natural breaks (Jenks) rounded to determine hotspot categories for the pending Species of Greatest Conservation Need hotspot layer.

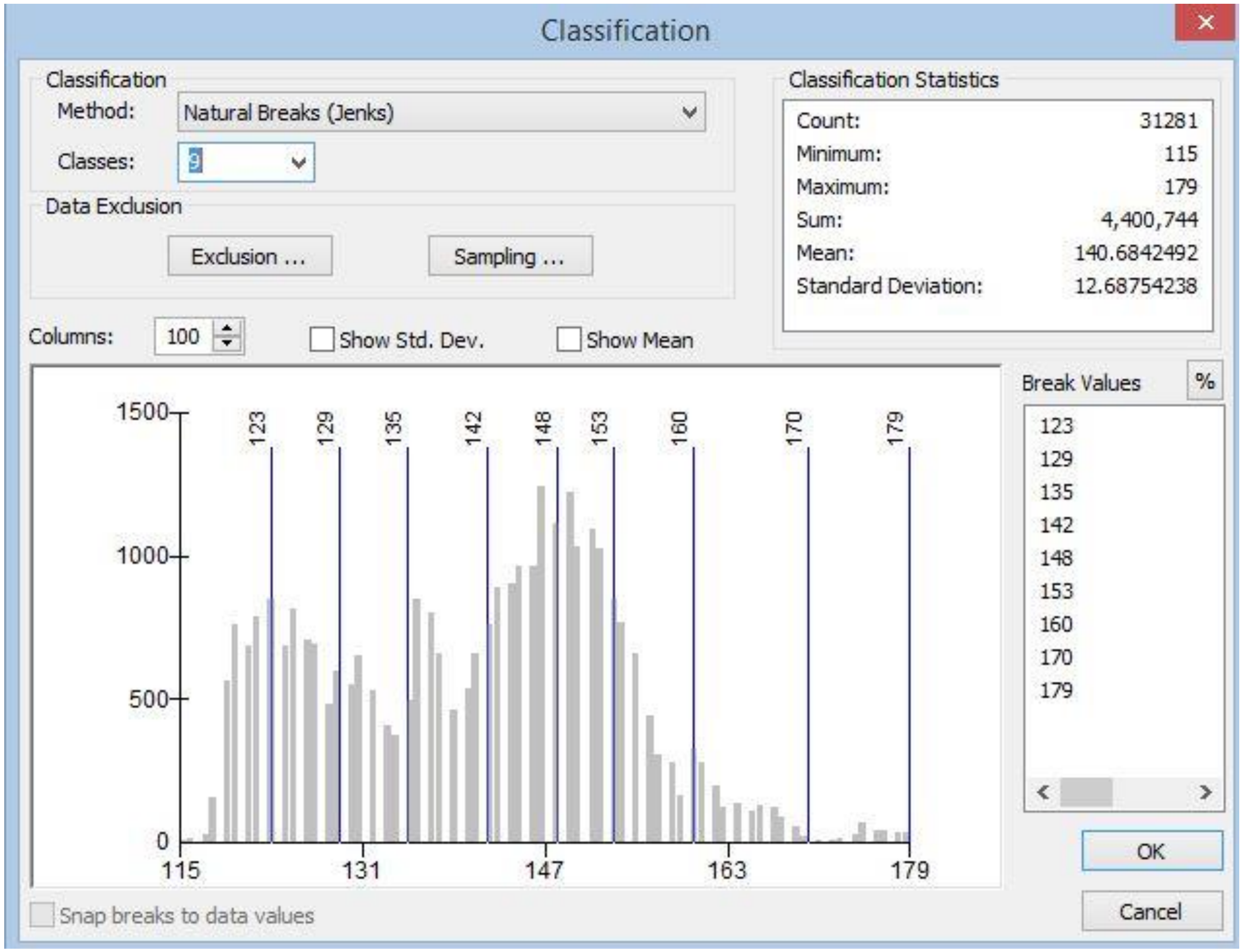


Figure 2.4 – Histogram from ArcMap 10.3.1 (Symbology, Classification tab) showing natural breaks (Jenks) rounded to determine hotspot categories for the combined (current and pending) Species of Greatest Conservation Need hotspot layer.

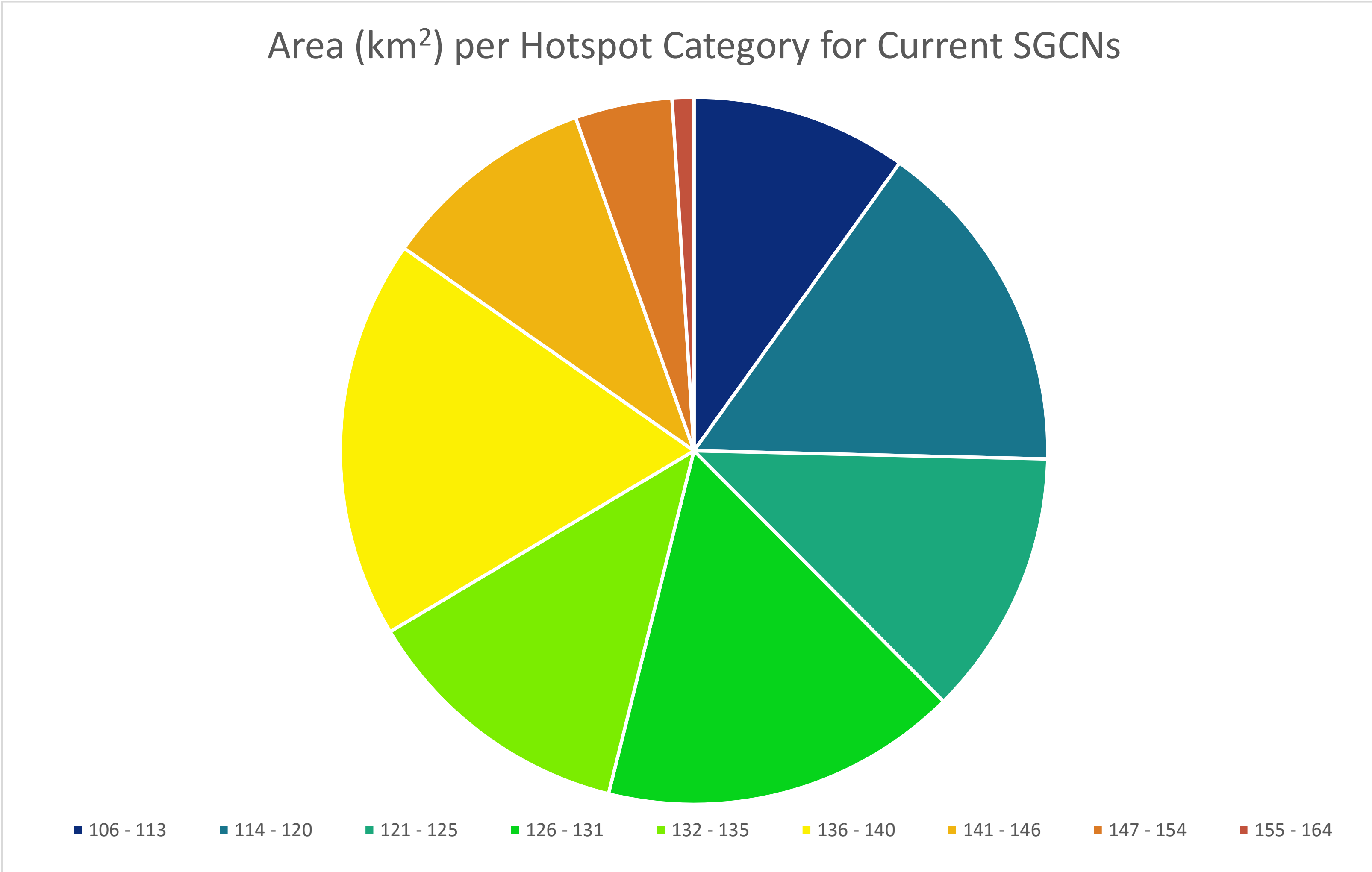


Figure 2.5 – Visual representation of total area (km^2) per hotspot category for current vertebrate Species of Greatest Conservation Need hotspot layer for the eight states in the study area of Bird Conservation Regions 18 and 19 (Texas, Oklahoma, New Mexico, Kansas, Colorado, Nebraska, Wyoming, and South Dakota) as of December, 2016.

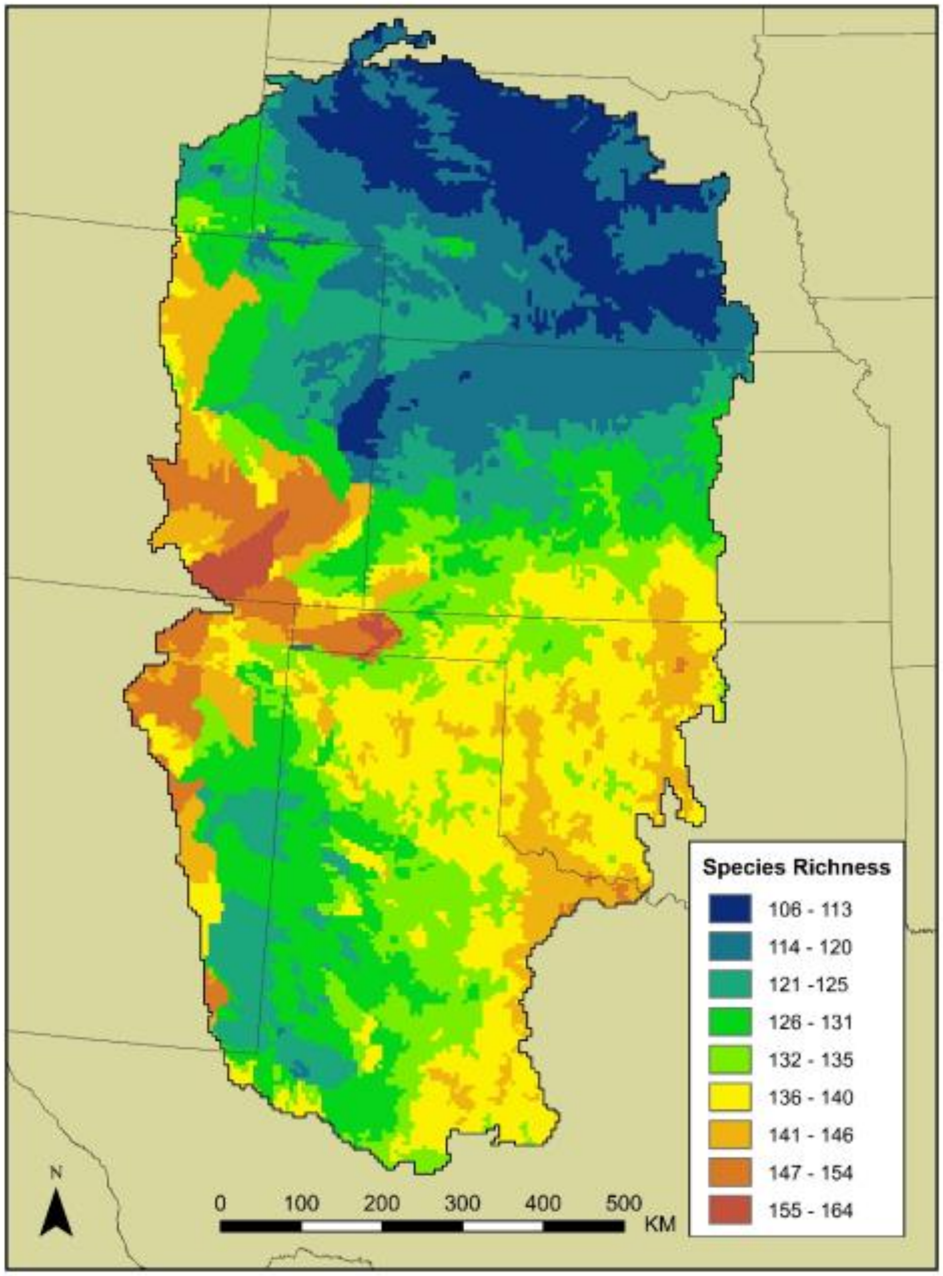


Figure 2.6 – Hotspots of state-listed at-risk vertebrate species for the eight states in the study area of Bird Conservation Regions 18 and 19 (Texas, Oklahoma, New Mexico, Kansas, Colorado, Nebraska, Wyoming, and South Dakota) as of December, 2016. Warmer to cooler colors indicate a decreasing gradient of at-risk species richness.

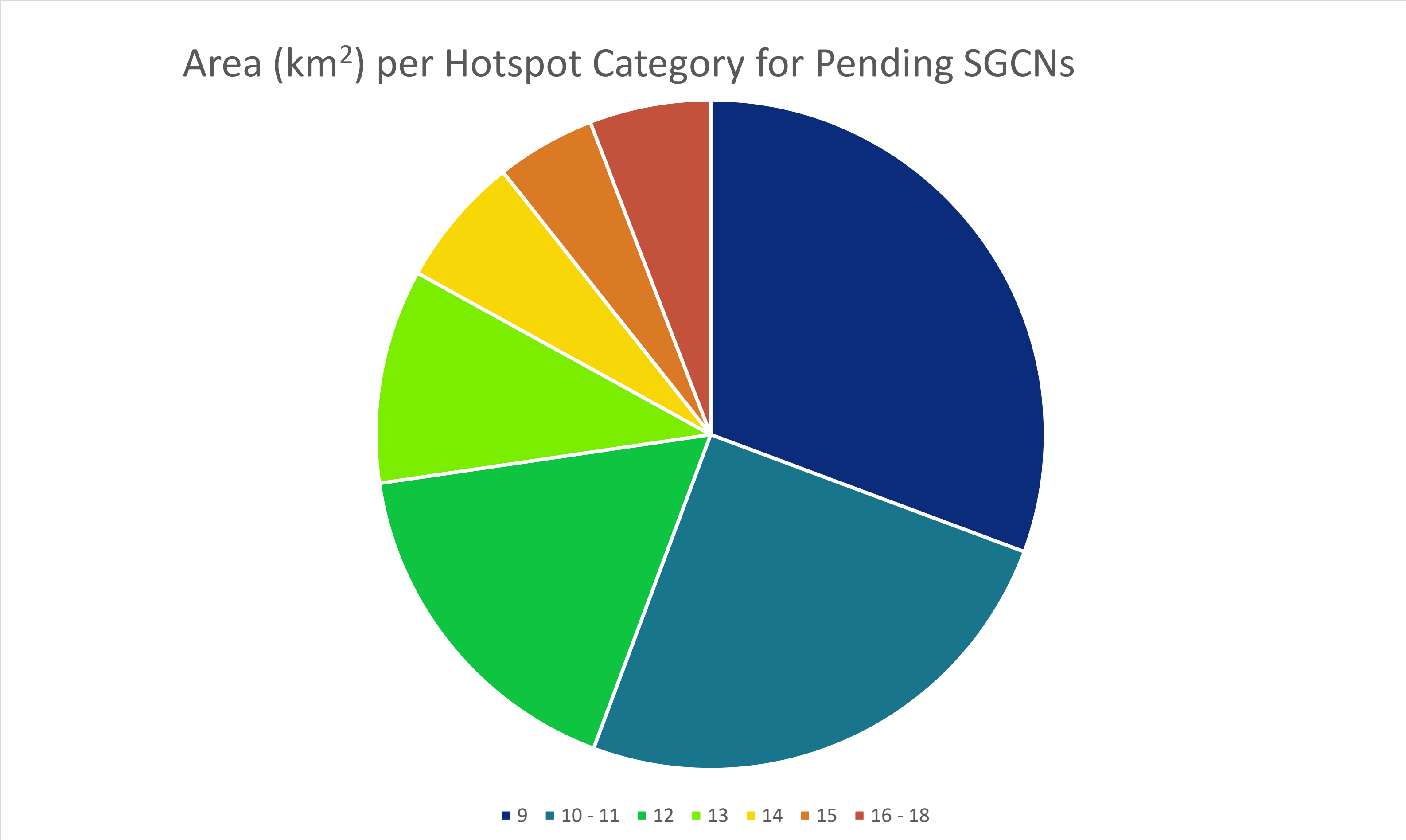


Figure 2.7 – Visual respresentation of total area (km^2) per hotspot category for pending vertebrate Species of Greatest Conservation Need hotspot layer for the eight states in the study area of Bird Conservation Regions 18 and 19 (Texas, Oklahoma, New Mexico, Kansas, Colorado, Nebraska, Wyoming, and South Dakota) as of December, 2016.

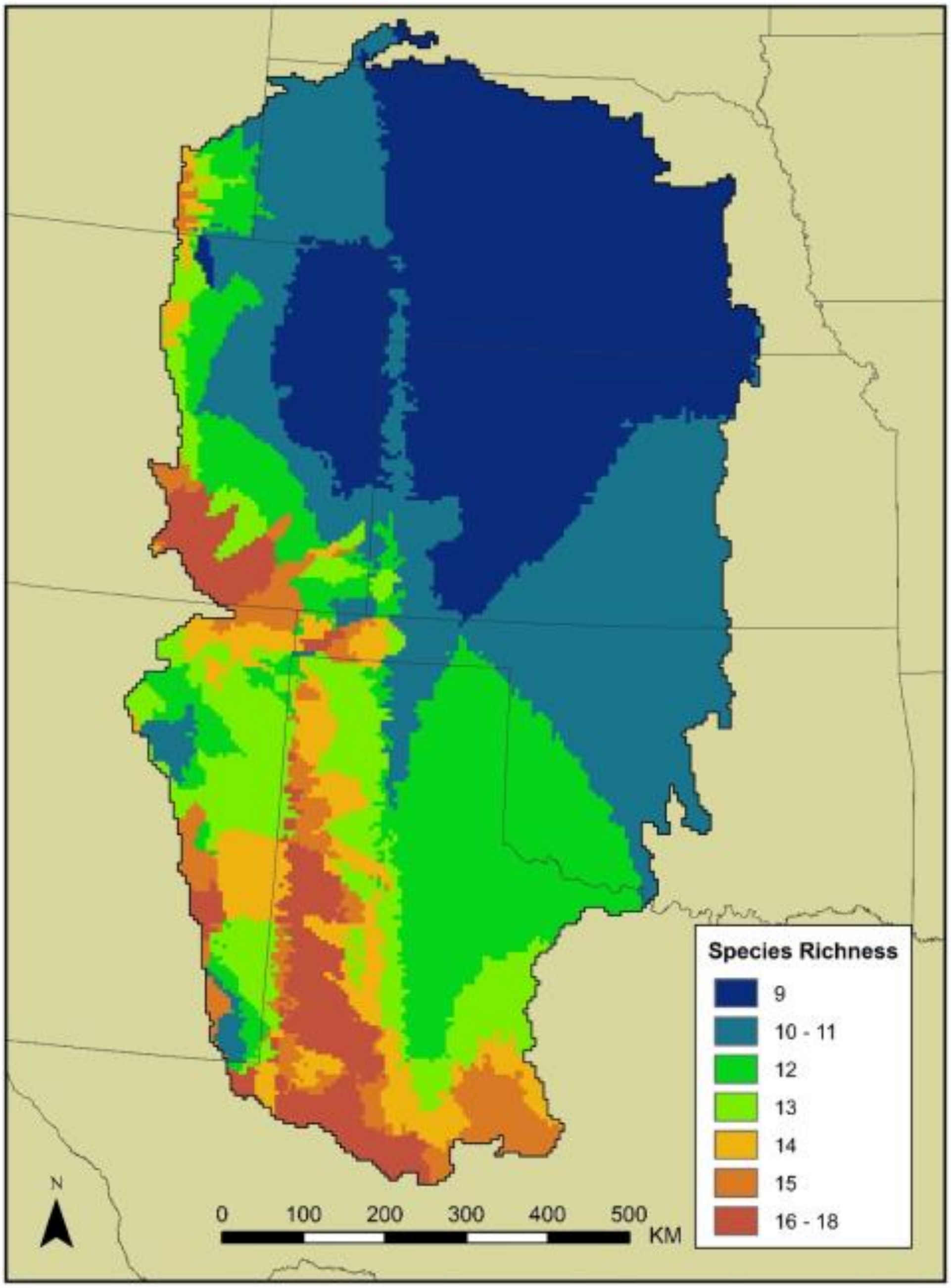


Figure 2.8 – Hotspots of state-pending at-risk vertebrate species for the eight states in the study area of Bird Conservation Regions 18 and 19 (Texas, Oklahoma, New Mexico, Kansas, Colorado, Nebraska, Wyoming, and South Dakota) as of December, 2016. Warmer to cooler colors indicate a decreasing gradient of at-risk species richness.

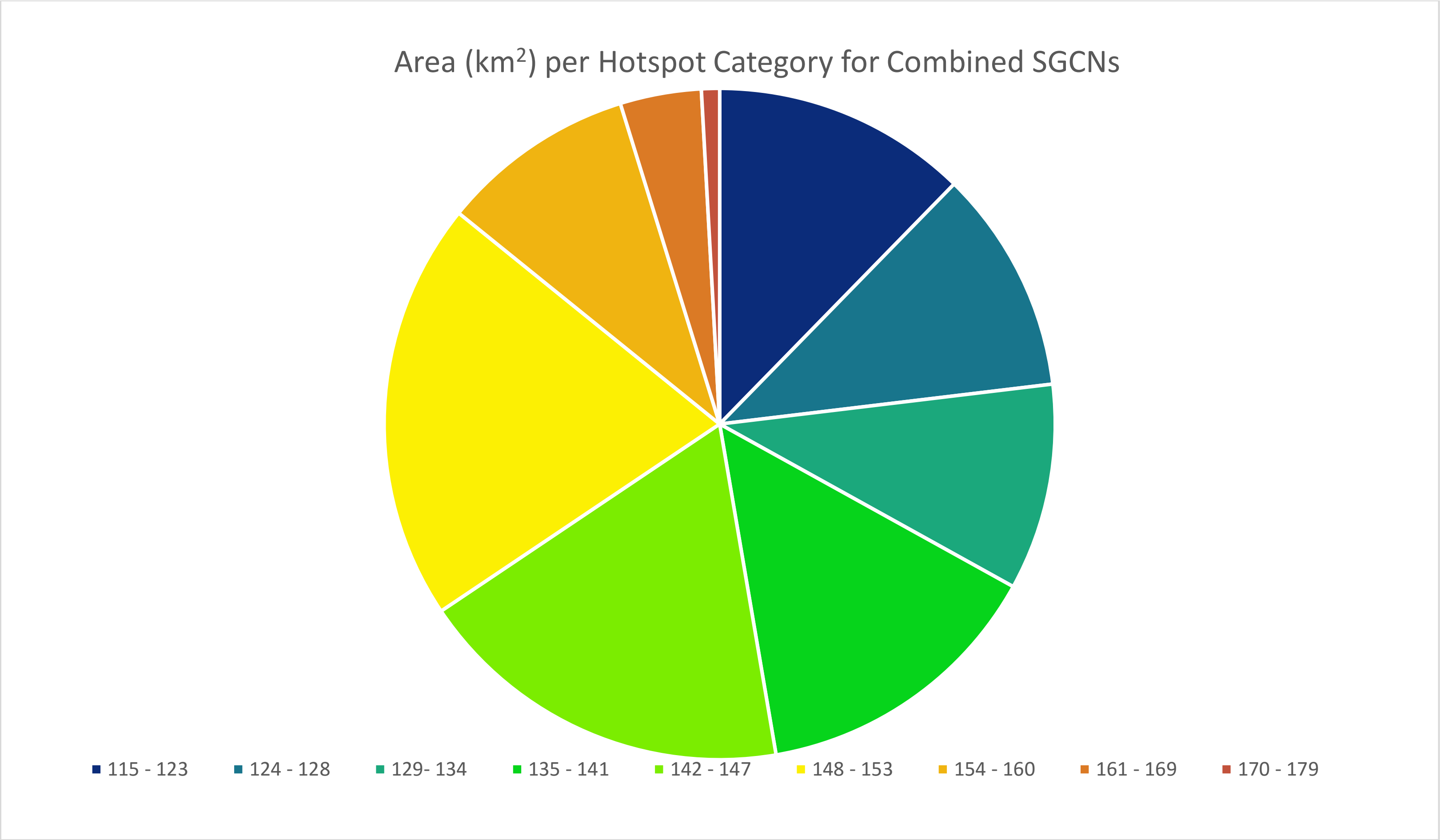


Figure 2.9 – Visual respresentation of total area (km^2) per hotspot category for currently listed and pending vertebrate Species of Greatest Conservation Need hotspot layer for the eight states in the study area of Bird Conservation Regions 18 and 19 (Texas, Oklahoma, New Mexico, Kansas, Colorado, Nebraska, Wyoming, and South Dakota) as of December, 2016.

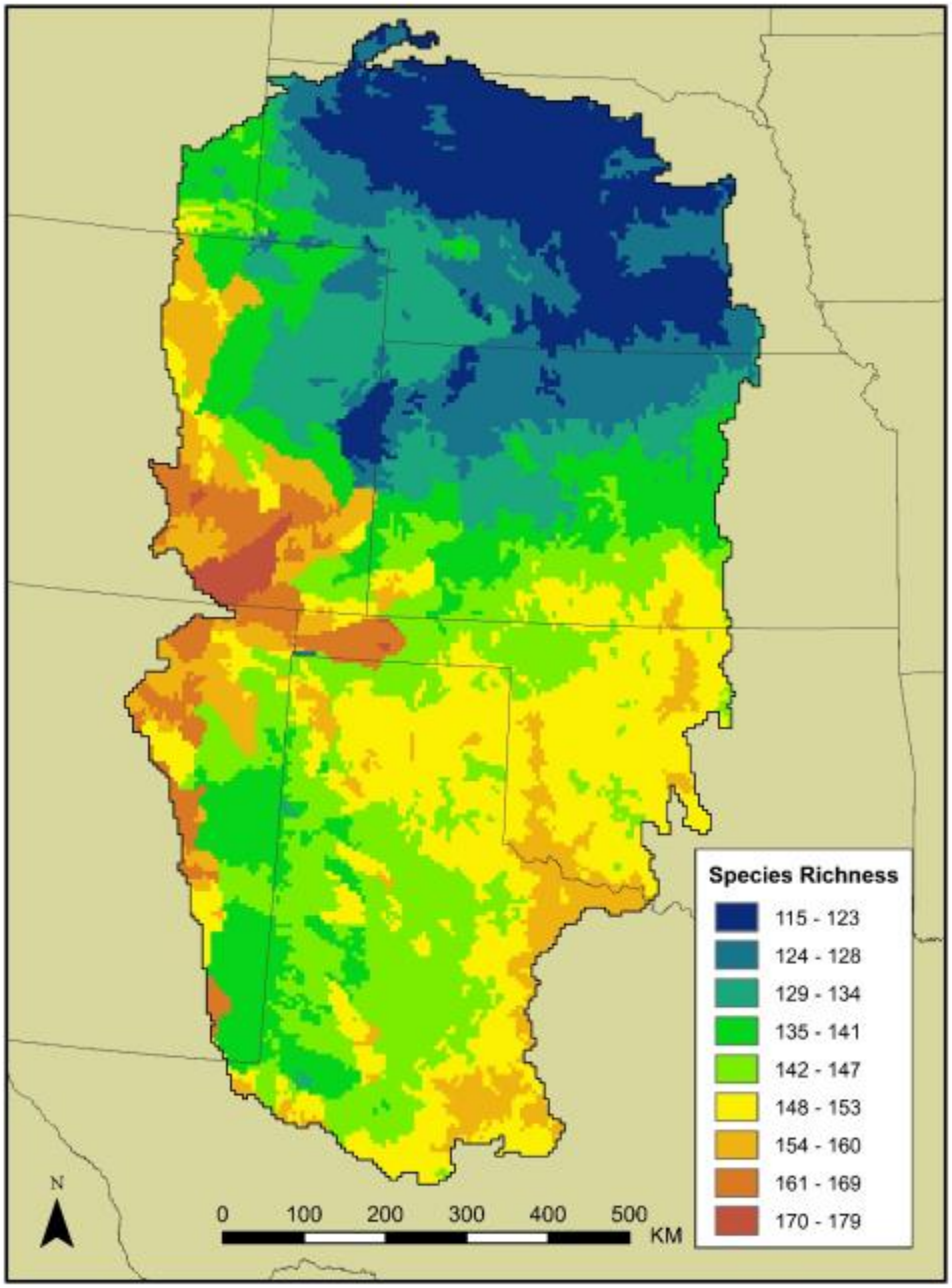


Figure 2.10 – Hotspots of state currently listed and pending for listing at-risk vertebrate species for the eight states in the study area of Bird Conservation Regions 18 and 19 (Texas, Oklahoma, New Mexico, Kansas, Colorado, Nebraska, Wyoming, and South Dakota) as of December, 2016. Warmer to cooler colors indicate a decreasing gradient of at-risk species richness.

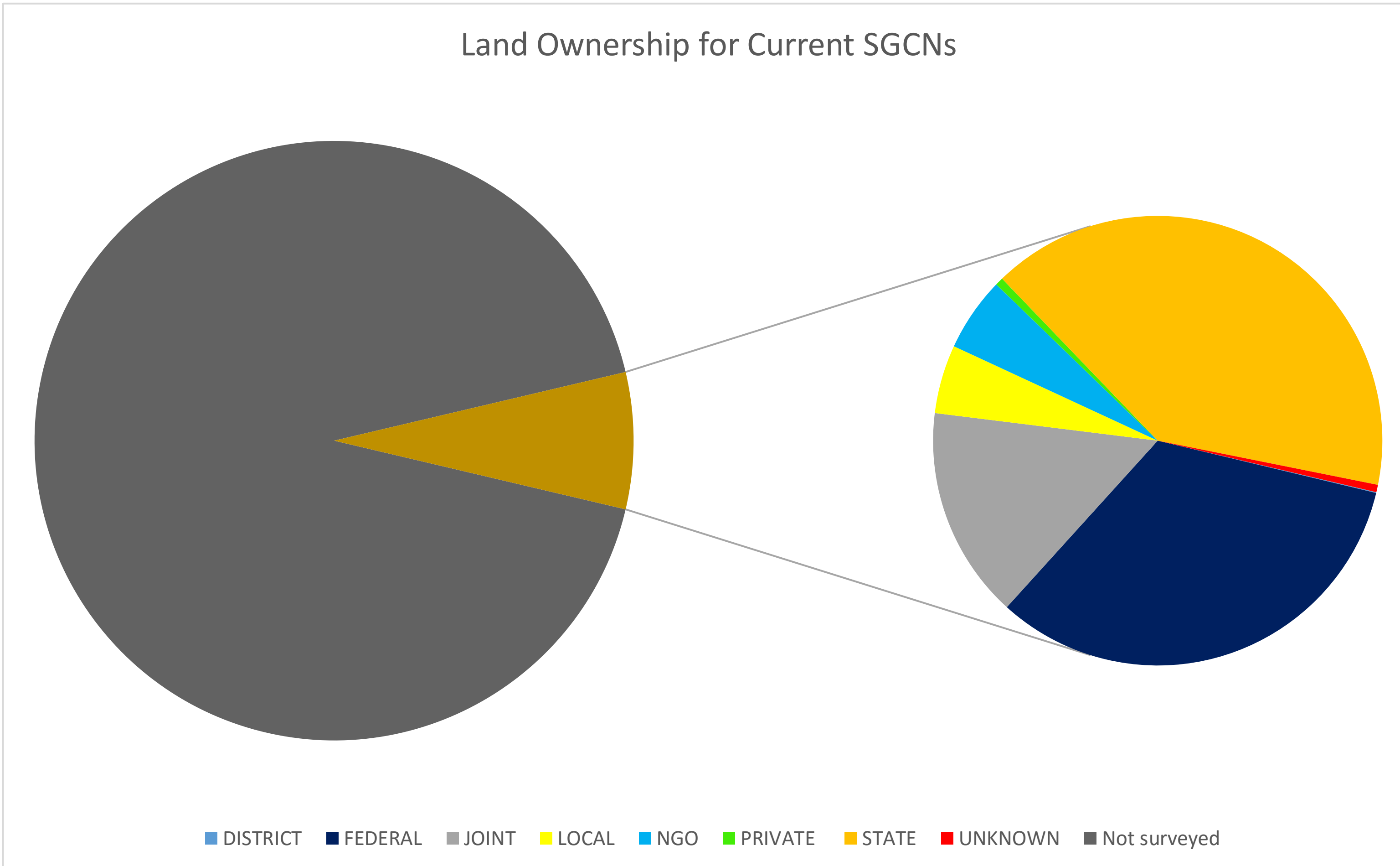


Figure 2.11– Proportion of land ownership for currently listed vertebrate Species of Greatest Conservation Need for the eight states in the study area of Bird Conservation Regions 18 and 19 (Texas, Oklahoma, New Mexico, Kansas, Colorado, Nebraska, Wyoming, and South Dakota) as of December, 2016. The pie chart on the right represents land surveyed and not surveyed by the PADUS 1.4 layer; the majority of which has not been surveyed. The nested pie chart, or the pie chart on the left, indicates land ownership of the surveyed portion of the PADUS 1.4 layer.

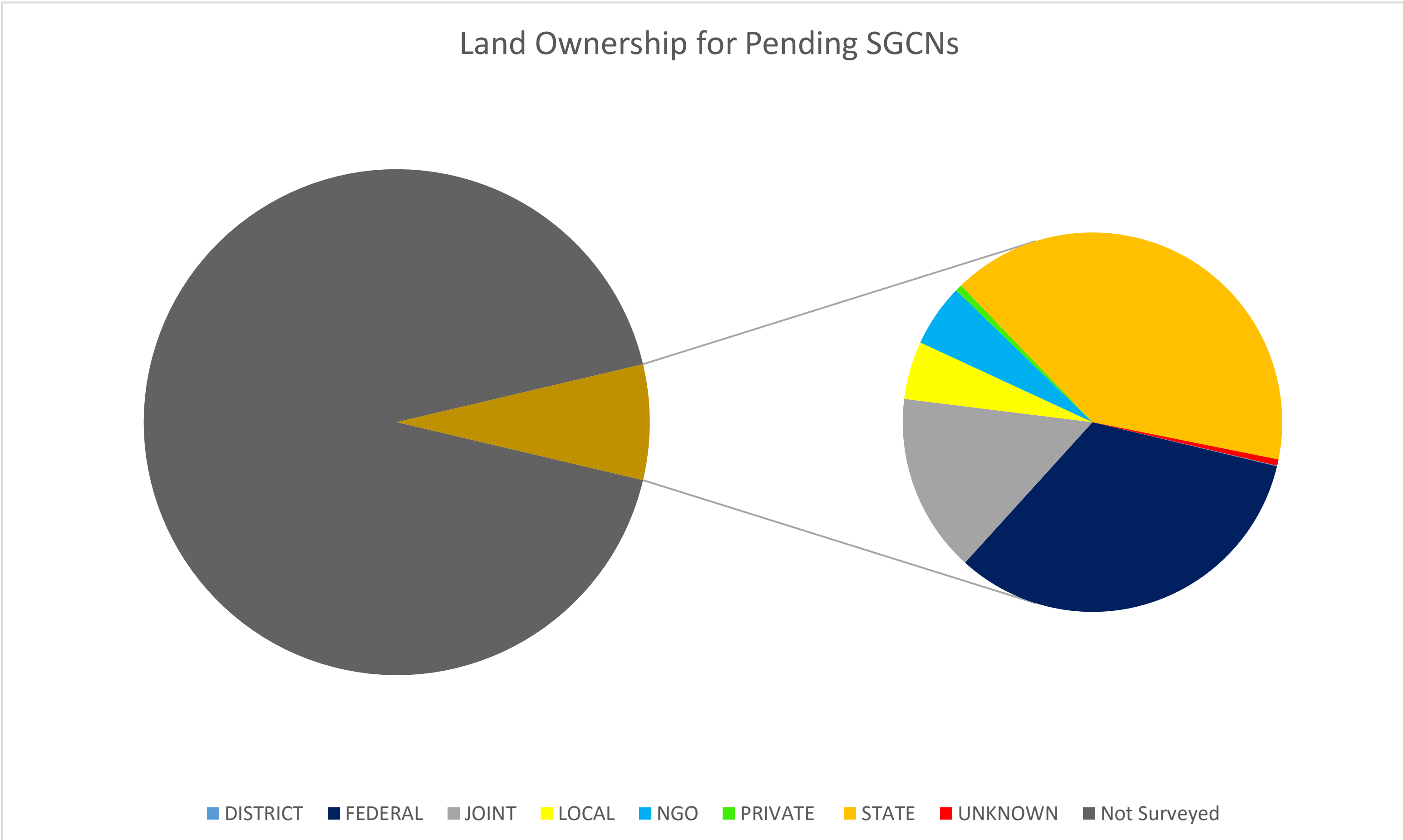


Figure 2.12– Proportion of land ownership for pending vertebrate Species of Greatest Conservation Need for the eight states in the study area of Bird Conservation Regions 18 and 19 (Texas, Oklahoma, New Mexico, Kansas, Colorado, Nebraska, Wyoming, and South Dakota) as of December, 2016. The pie chart on the right represents land surveyed and not surveyed by the PADUS 1.4 layer; the majority of which has not been surveyed. The nested pie chart, or the pie chart on the left, indicates land ownership of the surveyed portion of the PADUS 1.4 layer.

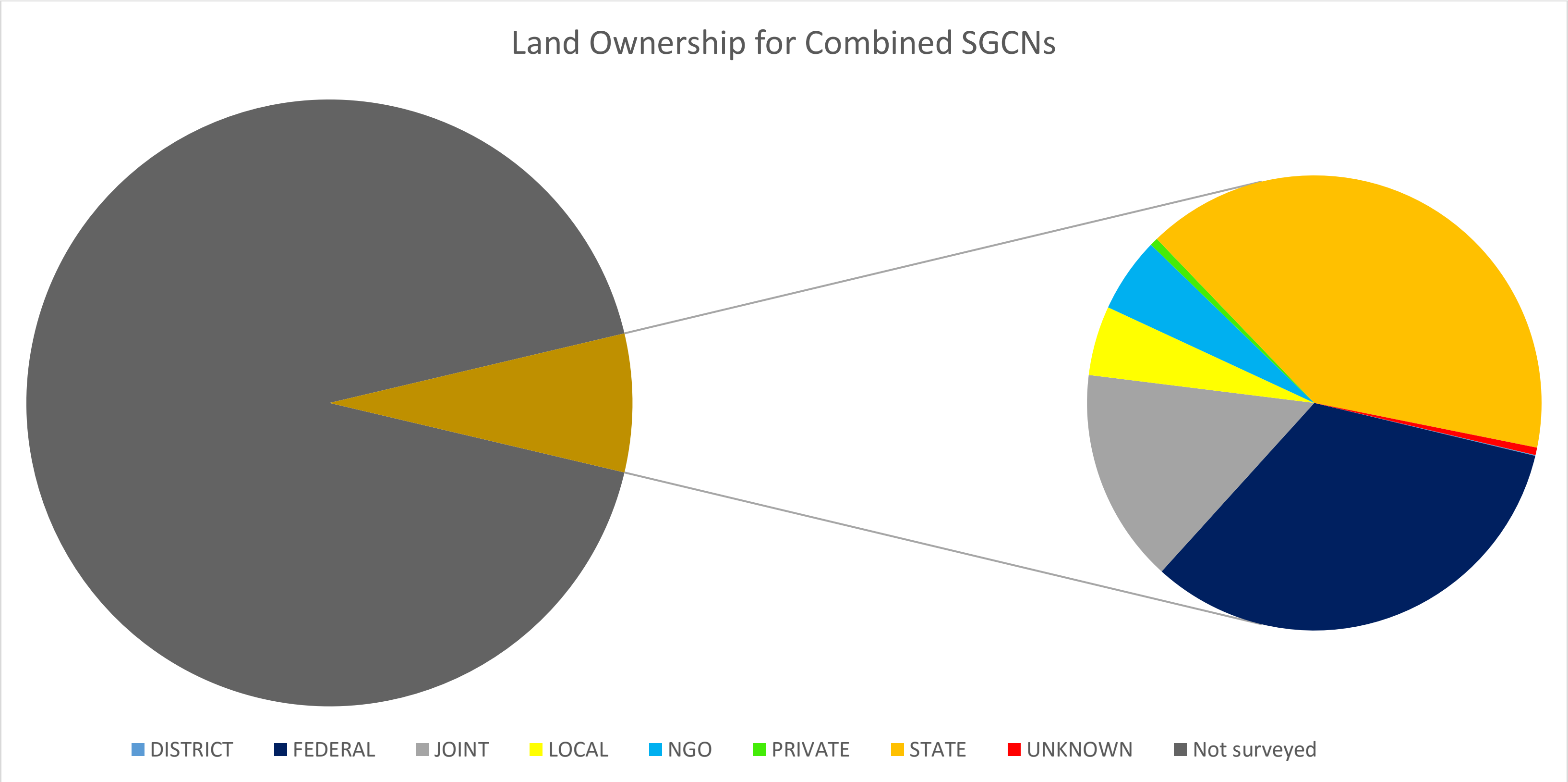


Figure 2.13 – Proportion of land ownership for currently listed and pending vertebrate Species of Greatest Conservation Need for the eight states in the study area of Bird Conservation Regions 18 and 19 (Texas, Oklahoma, New Mexico, Kansas, Colorado, Nebraska, Wyoming, and South Dakota) as of December, 2016. The pie chart on the right represents land surveyed and not surveyed by the PADUS 1.4 layer; the majority of which has not been surveyed. The nested pie chart, or the pie chart on the left, indicates land ownership of the surveyed portion of the PADUS 1.4 layer.

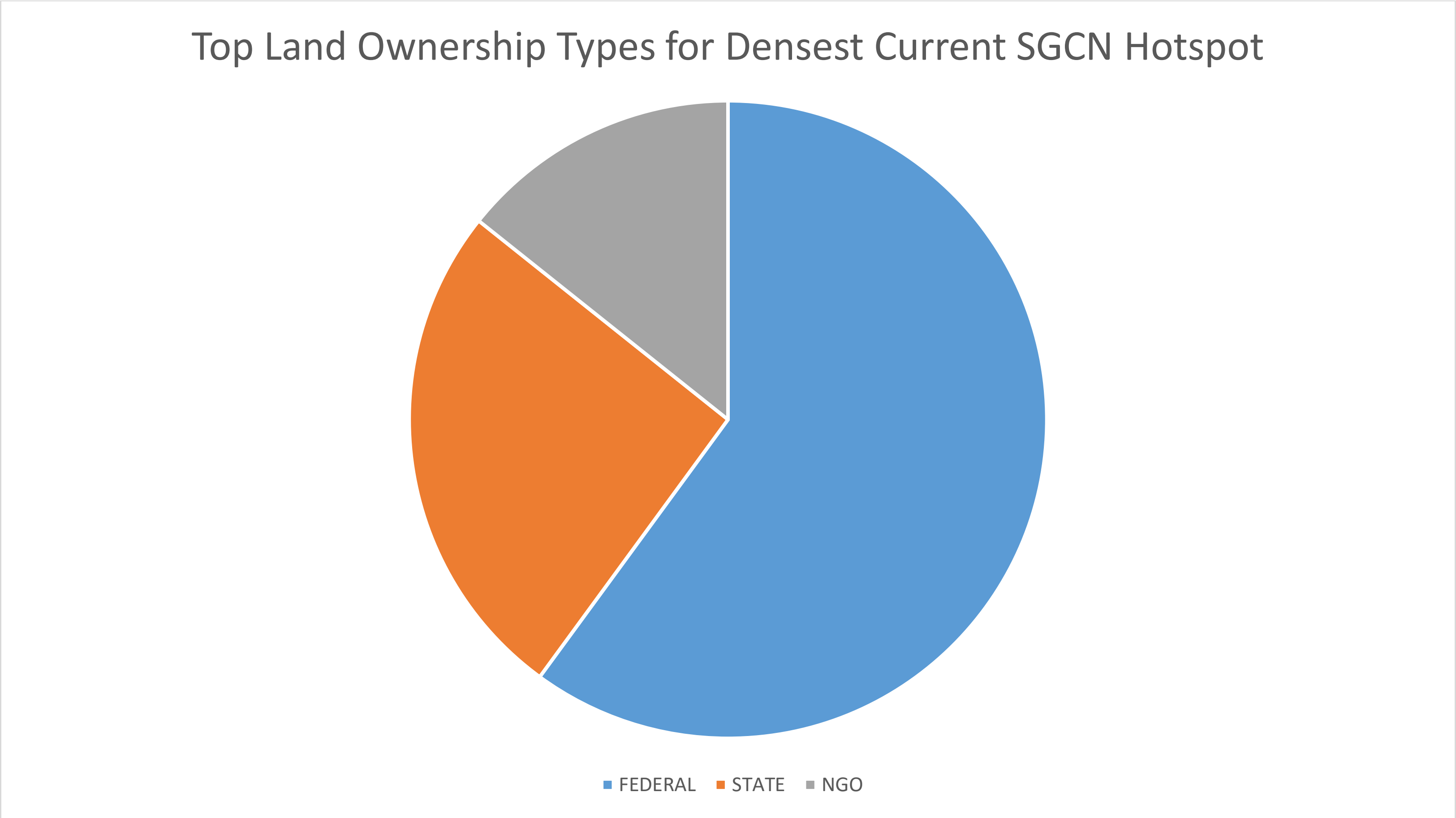


Figure 2.14 – Top three landownership types for densest hotspot category (161-169) for currently listed vertebrate Species of Greatest Conservation Need for the eight states in the study area of Bird Conservation Regions 18 and 19 (Texas, Oklahoma, New Mexico, Kansas, Colorado, Nebraska, Wyoming, and South Dakota) as of December, 2016.

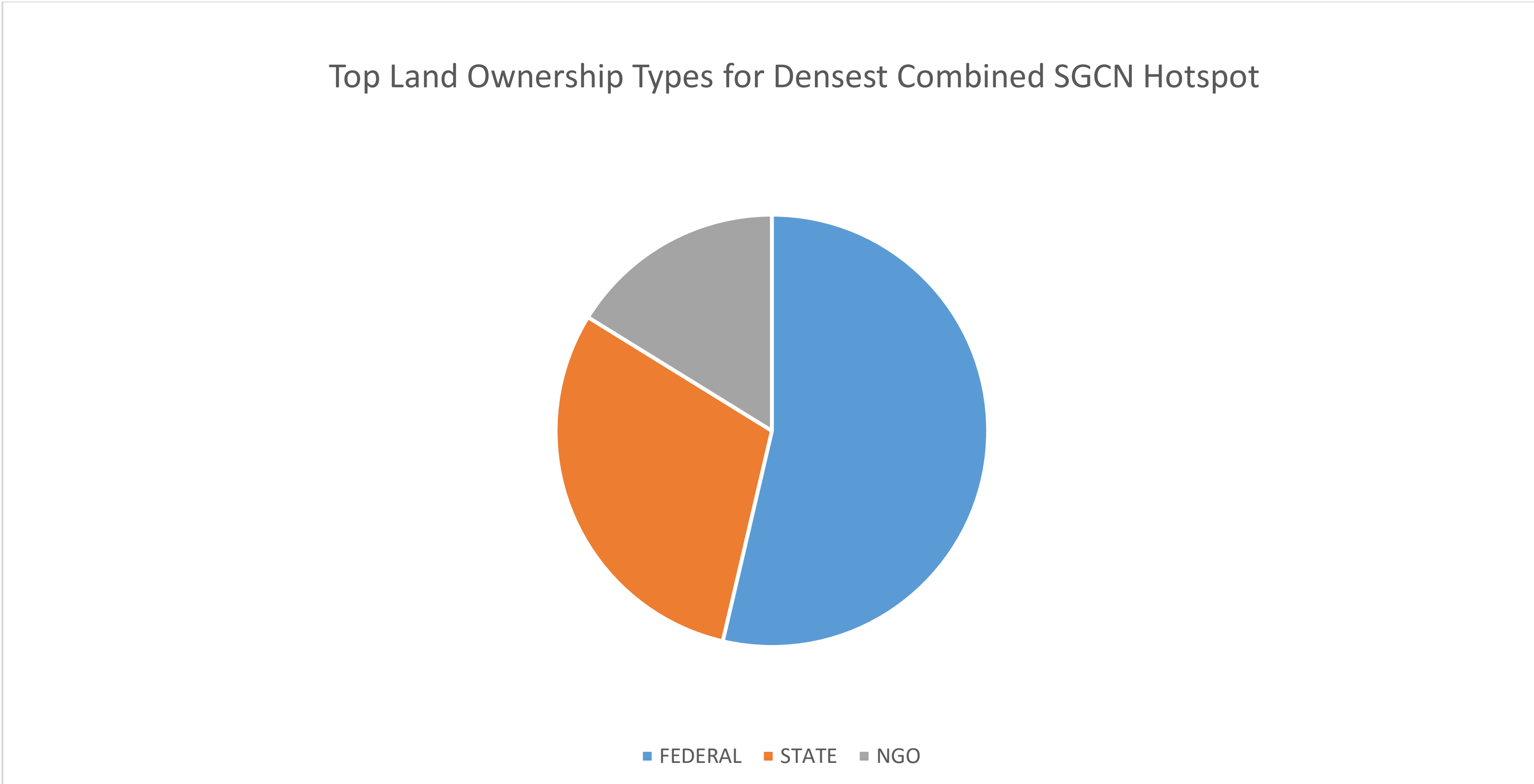


Figure 2.15 – Top three landownership types for densest hotspot category (170-179) for current and pending vertebrate Species of Greatest Conservation Need for the eight states in the study area of Bird Conservation Regions 18 and 19 (Texas, Oklahoma, New Mexico, Kansas, Colorado, Nebraska, Wyoming, and South Dakota) as of December, 2016.

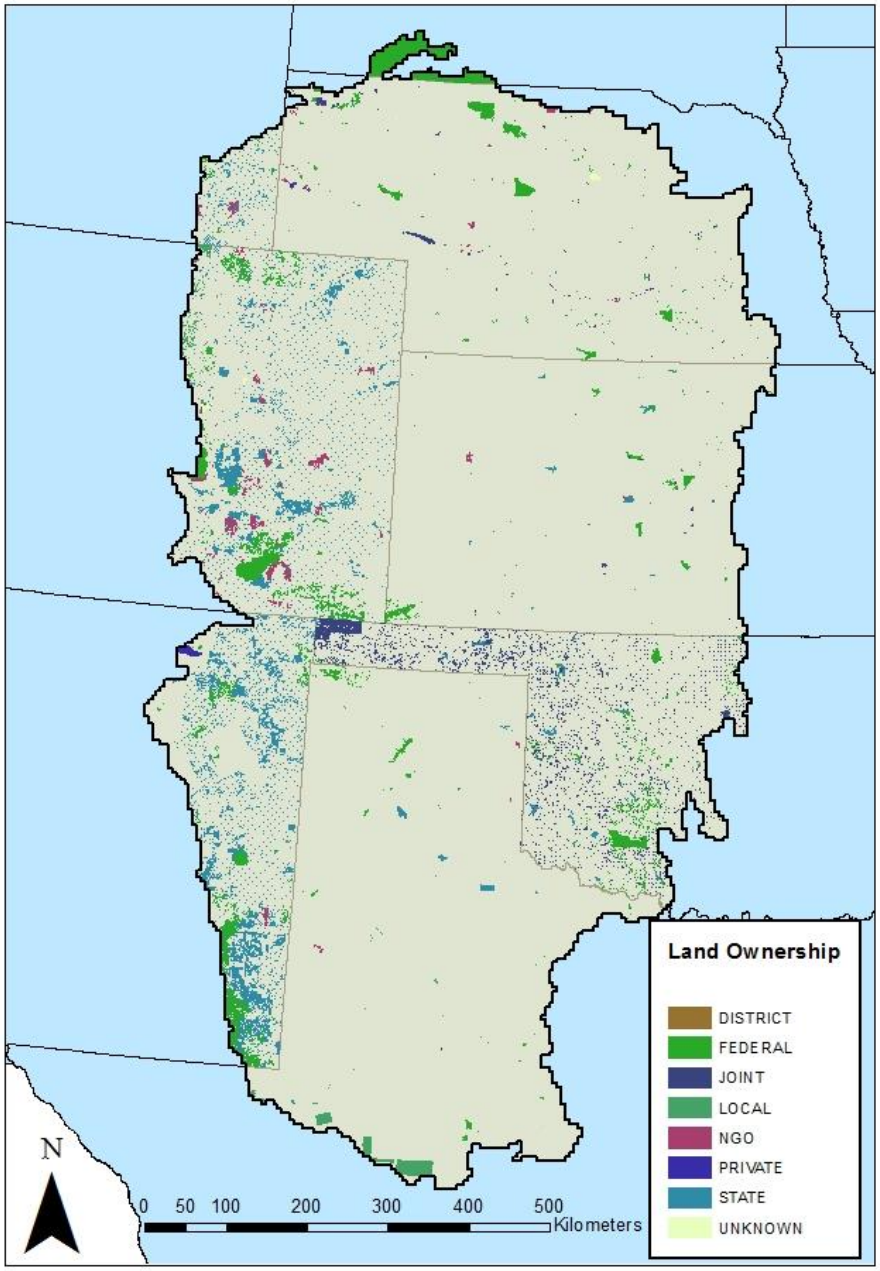


Figure 2.16 – Land ownership (PADUS 1.4) map for the eight states in the study area of Bird Conservation Regions 18 and 19 (Texas, Oklahoma, New Mexico, Kansas, Colorado, Nebraska, Wyoming, and South Dakota).

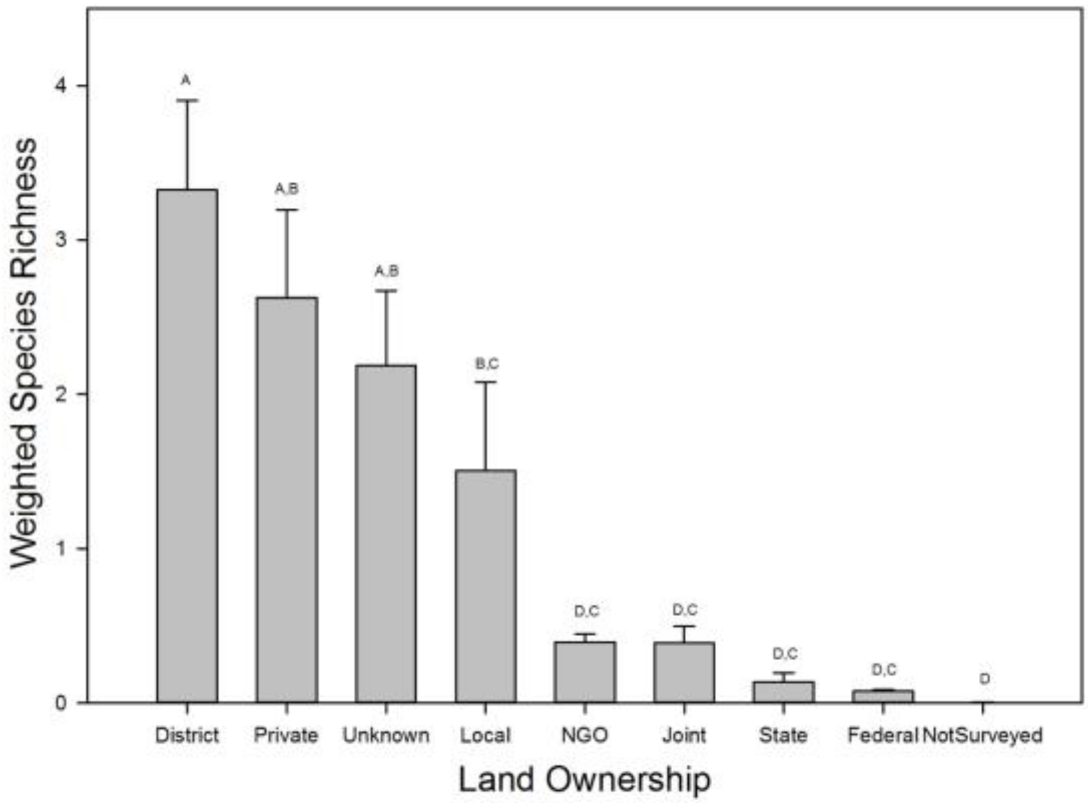


Figure 2.17 – Bar graph with standard error and Tukey test results for log transformed current vertebrate Species of Greatest Conservation Need species richness across hotspot category for each land ownership type for the eight states in the study area of Bird Conservation Regions 18 and 19 (Texas, Oklahoma, New Mexico, Kansas, Colorado, Nebraska, Wyoming, and South Dakota) as of December, 2016. Letters above bars indiciate Tukey test results of which land ownership categories overlap in terms of statistical significance of hosting a given hotspot category.

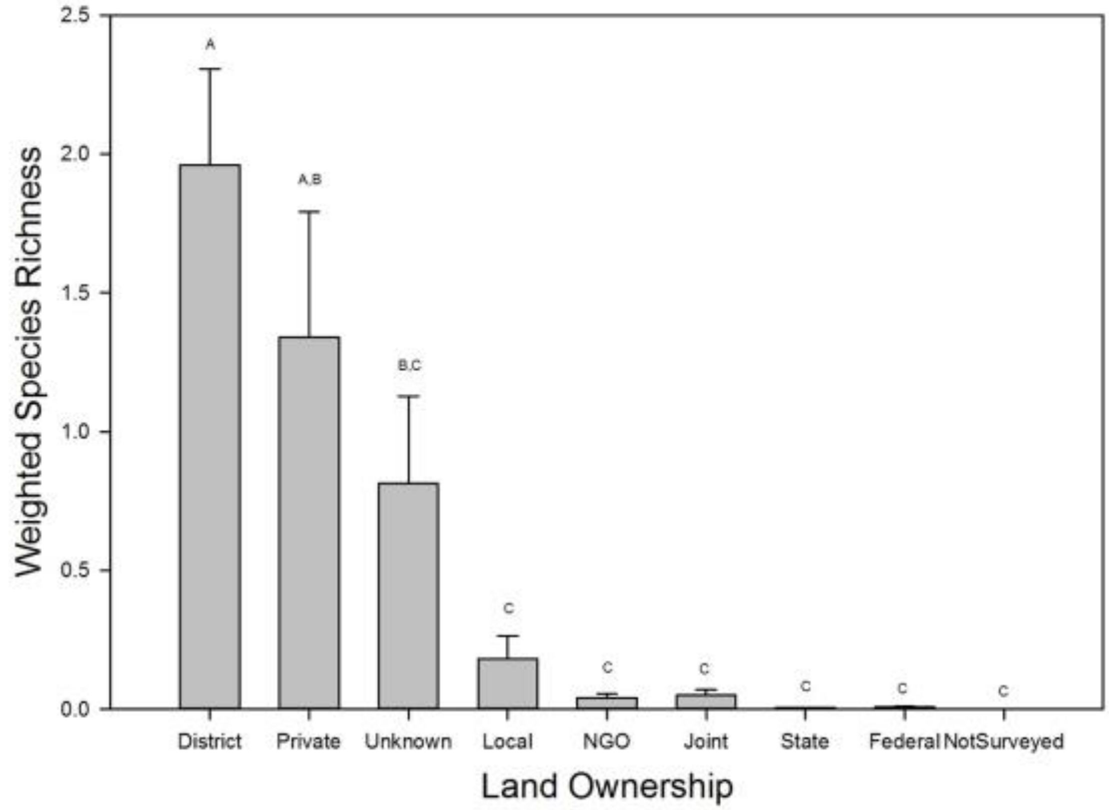


Figure 2.18 – Bar graph with standard error and Tukey test results for log-transformed pending vertebrate Species of Greatest Conservation Need species richness across hotspot category for each land ownership type for the eight states in the study area of Bird Conservation Regions 18 and 19 (Texas, Oklahoma, New Mexico, Kansas, Colorado, Nebraska, Wyoming, and South Dakota) as of December, 2016. Letters above bars indiciate Tukey test results of which land ownership categories overlap in terms of statistical significance of hosting a given hotspot category.

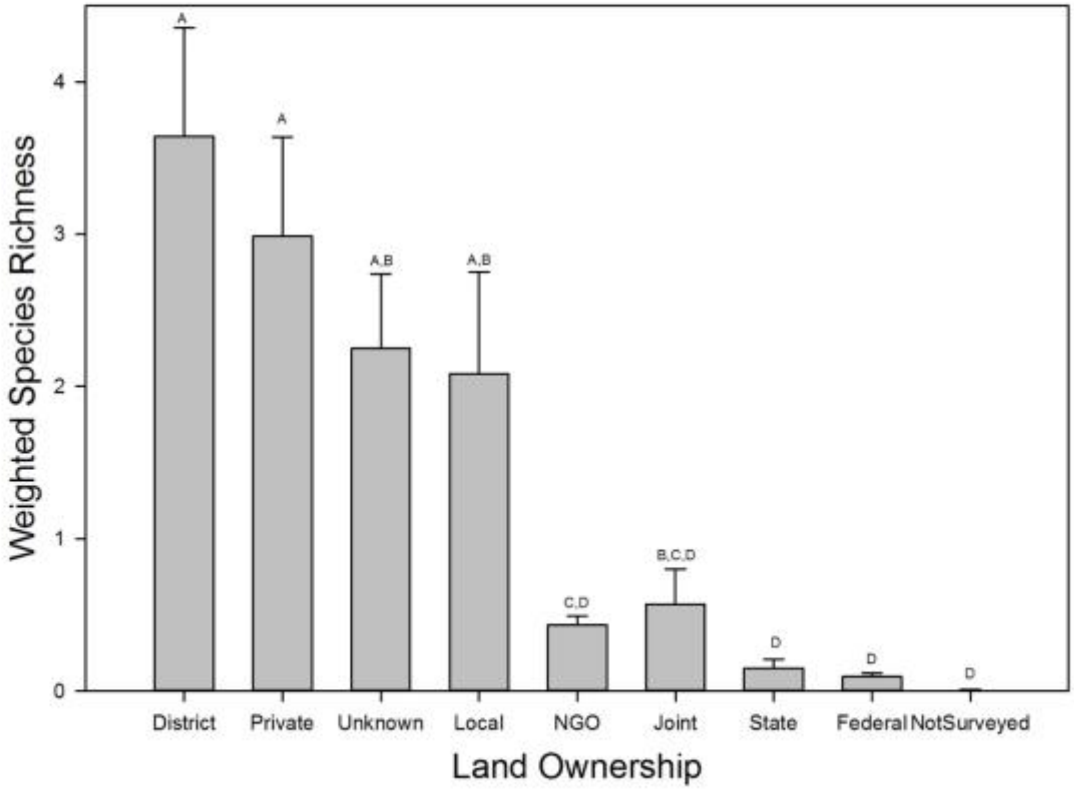


Figure 2.19 – Bar graph with standard error and Tukey test results for log transformed combined vertebrate Species of Greatest Conservation Need species richness across hotspot category for each land ownership type for the eight states in the study area of Bird Conservation Regions 18 and 19 (Texas, Oklahoma, New Mexico, Kansas, Colorado, Nebraska, Wyoming, and South Dakota) as of December, 2016. Letters above bars indiciate Tukey test results of which land ownership categories overlap in terms of statistical significance of hosting a given hotspot category

Appendix 2.1 – Consolidated list of scientific names and common names for currently listed SGCN species for which range files exist for the study area (Bird Conservation Regions 18 and 19 covering the states of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming).

Scientific/Common Name

Amphibian

Acris crepitans Northern Cricket Frog
Ambystoma tigrinum (Eastern) Tiger Salamander
Lithobates pipiens Northern Leopard Frog

Bird

Accipiter gentilis Northern Goshawk
Accipiter striatus Sharp-shinned Hawk
Aechmophorus clarkii Clark's Grebe
Aechmophorus occidentalis Western Grebe
Aegalius acadicus Northern Saw-whet Owl
Aegolius funereus Boreal Owl
Aeronautes saxatalis White-throated Swift
Aimophila ruficeps Rufous-crowned Sparrow
Ammodramus henslowii Henslow's Sparrow
Ammodramus leconteii Le Conte’s Sparrow
Ammodramus nelsoni Nelson's Sharp-tailed Sparrow
Ammodramus savannarum Grasshopper Sparrow
Amphispiza belli Sage Sparrow
Anas acuta Northern Pintail
Anas americana American Wigeon
Anas cyanpotera Cinnamon Teal
Anthus spragueii Sprague's Pipit
Antrostomus carolinensis Chuck-will's-widow
Aquila chrysaetos Golden Eagle
Archilochus colubris Ruby-throated Hummingbird
Asio flammeus Short-eared Owl
Athene cunicularia Burrowing Owl
Aythya affinis Lesser Scaup
Aythya americana Redhead
Aythya valisineria Canvasback
Baeolophus bicolor Tufted Titmouse
Baeolophus ridgwayi Juniper Titmouse
Bartramia longicauda Upland Sandpiper

Bassariscus astutus Ringtail
Botaurus lentiginosus American Bittern
Buteo lineatus Red-shouldered Hawk
Buteo regalis Ferruginous Hawk
Buteo swainsoni Swainson's Hawk
Calamospiza melanocorys Lark Bunting
Calcarius ornatus Chestnut-collared Longspur
Calcarius pictus Smith's Longspur
Calidris bairdii Baird's Sandpiper
Calidris fuscicollis White-rumped Sandpiper
Calidris himantopus Stilt Sandpiper
Calidris mauri Western Sandpiper
Calidris melanotos Pectoral Sandpiper
Calidris minutilla Least Sandpiper
Calidris pusilla Semipalmated Sandpiper
Callipepla squamata Scaled Quail
Catoptrophorus semipalmatus Willet
Centrocercus urophasianus Greater Sage-Grouse
Certhia americana Brown Creeper
Charadrius alexandrines nivosus Western Snowy Plover
Charadrius melodus Piping Plover
Charadrius montanus Mountain Plover
Charadrius nivosus Snowy Plover
Chlidonias niger Black Tern
Chondestes grammacus Lark Sparrow
Chordeiles minor Common Nighthawk
Cinclus mexicanus American dipper
Circus cyaneus Northern Harrier
Cistothorus platensis Sedge Wren
Coccyzus americanus Yellow-billed Cuckoo
Coccyzus erythropthalmus Black-billed Cuckoo
Colinus virginianus Northern Bobwhite
Columbina passerina Common Ground-Dove
Contopus cooperi Olive-Sided Flycatcher
Contopus virens Eastern Wood-Pewee
Corvus cryptoleucus Chihuahuan Raven
Cygnus buccinator Trumpeter Swan
Cypseloides niger Black Swift
Dolichonyx oryzivorus Bobolink
Dryocopus pileatus Pileated Woodpecker

Egretta caerulea Little Blue Heron
Egretta thula Snowy Egret
Empidonax occidentalis Cordilleran Flycatcher
Empidonax traillii Willow Flycatcher
Euphagus carolinus Rusty Blackbird
Euphagus cyanocephalus Brewer’s Blackbird
Falco columbarius Merlin
Falco femoralis Aplomado Falcon
Falco mexicanus Prairie Falcon
Falco peregrinus Peregrine Falcon
Gallinago delicata Wilson’s Snipe
Gavia immer Common Loon
Glaucidium gnoma Northern Pygmy-Owl
Grus americana Whooping Crane
Grus canadensis Sandhill Crane
Gymnorhinus cyanocephalus Pinyon Jay
Haliaeetus leucocephalus Bald Eagle
Histrionicus histrionicus Harlequin Duck
Hylocichla mustelina Wood Thrush
Icterus bullockii Bullock's Oriole
Icterus cucullatus Hooded Oriole
Icterus galbula Baltimore Oriole
Icterus spurius Orchard Oriole
Ictinia mississippiensis Mississippi Kite
Ixobrychus exilis Least Bittern
Junco hyemalis Dark-eyed Junco
Lagopus leucura White-Tailed Ptarmigan
Lanius ludovicianus Loggerhead Shrike
Laterallus jamaicensis Black Rail
Leucosticte atrata Black Rosy-Finch
Limnodromus scolopaceus Long-billed Dowitcher
Limosa haemastica Hudsonian Godwit
Melanerpes aurifrons Golden-fronted Woodpecker
Melanerpes erythrocephalus Red-headed Woodpecker
Melanerpes lewis Lewis’s Woodpecker
Meleagris gallopavo Wild Turkey
Melospiza georgiana Swamp Sparrow
Micrathene whitneyi Elf Owl
Mniotilta varia Black-and-white Warbler
Myadestes townsendi Townsend's Solitaire

Myiarchus cinerascens Ash-throated Flycatcher
Nucifraga columbiana Clark's Nutcracker
Numenius americanus Long-billed Curlew
Nycticorax nycticorax Black-crowned Night-Heron
Oreoscoptes montanus Sage Thrasher
Pandion haliaetus Osprey
Parkesia motacilla Louisiana Waterthrush
Passerculus sandwichensis Savannah Sparrow
Passerina ciris Painted Bunting
Passerina versicolor Varied Bunting
Patagioenas fasciata Band-Tailed Pigeon
Pelecanus erythrorhynchos American White Pelican
Peucaea cassinii Cassin's Sparrow
Phalacrocorax brasilianus Neotropic Cormorant
Phalaenoptilus nuttallii Common Poorwill
Phalaropus tricolor Wilson's Phalarope
Pica hudsonia Black-billed Magpie
Picoides dorsalis American Three-toed Woodpecker
Picoides scalaris Ladder-backed Woodpecker
Pipilo maculatus Spotted Towhee
Pipistrellus subflavus Eastern Pipistrelle
Piranga rubra Summer Tanager
Plegadis chihi White-faced Ibis
Pluvialis dominica American Golden-Plover
Podiceps nigricollis Eared Grebe
Poecile carolinensis Carolina Chickadee
Protonotaria citrea Prothonotary Warbler
Psaltriparus minimus Bushtit
Rallus elegans King Rail
Rallus limicola Virginia Rail
Recurvirostra americana American Avocet
Rhynchophanes mccownii McCown's Longspur
Riparia riparia Bank Swallow
Scolopax minor American Woodcock
Setophaga discolor Prairie Warbler
Setophaga graciae Grace's Warbler
Setophaga nigrescens Black-Throated Gray Warbler
Setophaga petechia Yellow Warbler
Sitta pygmaea Pygmy Nuthatch
Sphyrapicus thyroideus Williamson's Sapsucker

Spinus pinus Pine Siskin
Spiza americana Dickcissel
Spizella arborea American Tree Sparrow
Spizella breweri Brewer’s Sparrow
Spizella pusilla Field Sparrow
Sterna forsteri Forster's Tern
Sternula antillarum Least Tern
Strix occidentalis lucida Mexican Spotted Owl
Sturnella magna Eastern Meadowlark
Tachycineta thalassina Violet-green Swallow
Thryothorus ludovicianus Carolina Wren
Toxostoma curvirostre Curve-billed Thrasher
Tringa flavipes Lesser Yellowlegs
Tringa melanoleuca Greater Yellowlegs
Tringa solitaria Solitary Sandpiper
Tryngites subruficollis Buff-breasted Sandpiper
Tympanuchus pallidicinctus Lesser Prairie-Chicken
Tyrannus forficatus Scissor-tailed Flycatcher
Tyrannus tyrannus Eastern Kingbird
Tyrannus verticalis Western Kingbird
Tyrannus vociferans Cassin's Kingbird
Tyto alba Barn Owl
Vermivora cyanoptera Blue-winged Warbler
Vireo atricapilla Black-capped Vireo
Vireo bellii Bell's Vireo
Vireo flavifrons Yellow-throated Vireo
Vireo griseus White-eyed Vireo
Vireo plumbeus Plumbeous Vireo
Vireo vicinior Gray Vireo
Zenaida macroura Mourning Dove
Zonotrichia querula Harris's Sparrow

Mammal

Antrozous pallidus Pallid Bat
Castor canadensis American Beaver
Corynorhinus townsendii Townsend's big-eared Bat
Cynomys gunnisoni Gunnison’s Prairie Dog
Cynomys ludovicianus Black-tailed Prairie Dog
Eptesicus fuscus Big Brown Bat
Euderma maculatum Spotted Bat

Geomys bursarius Plains Pocket Gopher
Gulo gulo Wolverine
Lasiurus blossevillii Western Red Bat
Lasiurus borealis Eastern Red Bat
Lepus americanus Snowshoe Hare
Lepus californicus Black-tailed Jackrabbit
Lepus callotis White-sided Jackrabbit
Lepus townsendii White-tailed Jackrabbit
Martes americana American Marten
Mustela frenata Long-tailed Weasel
Mustela nigripes Black-footed Ferret
Myotis ciliolabrum Western Small-footed Myotis
Myotis evotis Long-eared Myotis
Myotis lucifugus Little Brown Myotis
Myotis occultus Arizona Myotis Bat
Myotis thysanodes Fringed Myotis
Myotis velifer Cave Myotis
Myotis volans Long-legged Myotis
Nycticeius humeralis Evening Bat
Nyctinomops femorosaccus Pocketed Free-Tailed Bat
Nyctinomops macrotis Big free-tailed Bat
Ochotona princeps American Pika
Ovis canadensis Bighorn Sheep
Peromyscus truei Piñon Deermouse
Sorex merriami Merriam's Shrew
Sorex nanus Dwarf Shrew
Spilogale gracilis Western Spotted Skunk
Spilogale putorius Eastern Spotted Skunk
Tadarida brasiliensis Brazilian Free-tailed Bat
Taxidea taxus American badger
Vulpes velox Swift Fox
Xerospermophilus spilosoma Spotted Ground Squirrel
Zapus hudsonius Meadow Jumping Mouse

Reptile
Agkistrodon contortrix Copperhead
Apalone mutica mutica Midland Smooth Softshell Turtle
Apalone mutica Smooth Soft-shelled Turtle
Apalone spinifera Spiny Softshell Turtle
Carphophis vermis Western Worm Snake

Cnemidophorus tesselatus Common Checkered Whiptail
Coleonyx brevis Texas Banded Gecko
Crotalus atrox Western Diamondback Rattlesnake
Crotalus horridus Timber Rattlesnake
Crotalus viridis Prairie Rattlesnake
Emydoidea blandingii Blanding’s Turtle
Eumeces multivirgatus Many-lined Skink
Graptemys ouachitensis Ouachita Map Turtle
Graptemys pseudogeographica False Map Turtle
Graptemys versa Texas Map Turtle
Heterodon platirhinos Eastern Hog-nosed Snake
Holbrookia maculata Common Lesser Earless Lizard
Hypsiglena jani Chihuahuan Nightsnake
Lampropeltis triangulum Milk Snake
Leptotyphlops dissectus New Mexico Threadsnake
Macrochelys temminckii Alligator Snapping Turtle
Nerodia harteri Brazos Water Snake
Nerodia paucimaculata Concho Water Snake
Opheodrys vernalis Smooth Greensnake
Ophisaurus attenuatus Slender Glass Lizard
Phrynosoma cornutum Texas Horned Lizard
Phrynosoma hernandesi Greater Short-horned Lizard
Phrynosoma modestum Round-tailed Horned Lizard
Plestiodon anthracinus Coal Skink
Plestiodon laticeps Broadhead Skink
Regina grahamii Graham's Crayfish Snake
Rhinocheilus lecontei Long-nosed Snake
Sistrurus catenatus Massasauga
Sternotherus carinatus Razor-backed Musk Turtle
Storeria occipitomaculata Red-bellied Snake
Tantilla nigriceps Plains Black-headed Snake
Terrapene ornata Ornate Box Turtle
Thamnophis elegans Terrestrial Garter Snake
Thamnophis marcianus Checkered Garter Snake
Thamnophis proximus Western Ribbon Snake
Thamnophis radix Plains Gartersnake
Tropidoclonion lineatum Lined Snake
Virginia striatula Rough Earthsnake
Virginia valeriae Smooth Earthsnake

Appendix 2.2 – Consolidated list of scientific names and common names for pending Species of Greatest Conservation Need for which range files exist for the study area (Bird Conservation Regions 18 and 19 covering the states of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming).

Scientific/Common Name

Bird

Archilochus alexandri Black-chinned Hummingbird
Ardea herodias Great Blue Heron
Bubulcus ibis Cattle Egret
Catherpes mexicanus Canyon Wren
Falco sparverius American Kestrel
Geothlypis tolmiei MacGillivray's Warbler (formerly *Oporornis tolmiei*)
Geothlypis trichas Common Yellowthroat
Icterus parisorum Scott's Oriole
Leucophaeus pipixcan Franklin's Gull
Loxia curvirostra Red Crossbill
Oreothlypis virginiae Virginia's Warbler (formerly *Vermivora virginiae*)
Passerina caerulea Blue Grosbeak
Polioptila caerulea Blue-Gray Gnatcatcher
Progne subis Purple Martin
Psiloscops flammeolus Flammulated Owl (formerly *Otus flammeolus)*
Selasporus rufus Rufous Hummingbird
Thryomanes bewickii Bewick's Wren
Vireo olivaceus Red-eyed Vireo

Mammal

Cynomys leucurus White-tailed Prairie Dog
Myotis yumanensis Yuma Myotis

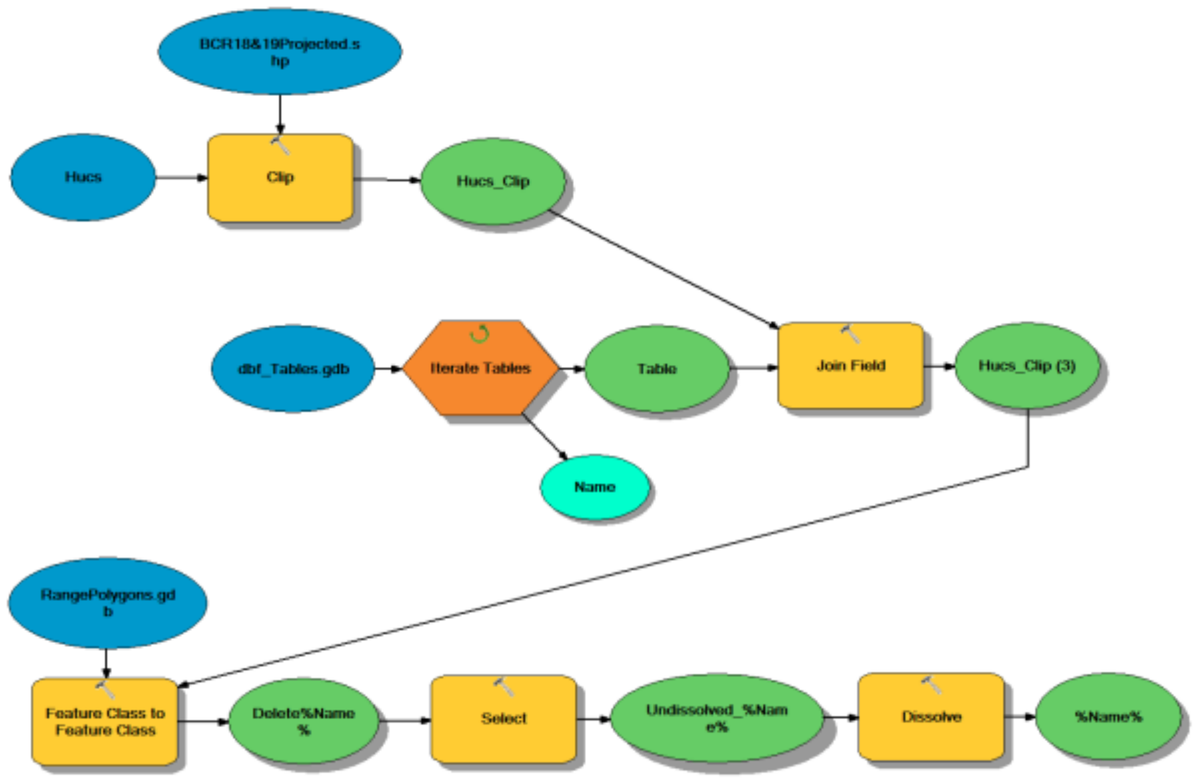
Reptile

Holbrookia lacerata Spot-tailed Earless Lizard
Pseudemys gorzugi Rio Grande Cooter
Sceloporus tristichus Plateau Fence Lizard

Appendix 2.3 – All model syntaxes are tools created by Dr. Krista Mougey and should be cited as follows:

Mougey, K. 2017. Model syntax for iterative landscape analyses. pp 72 in D. Gary (author). Examining the southern Great Plains for hotspots of at-risk biodiversity and assessing the efficacy of a decision support tool. Master's Thesis, Texas Tech University, Lubbock Texas.

Syntax 1 – Step 1: This ArcMap syntax and corresponding Python code transforms all range files (current and pending) from .dbf to raster format (Mougey 2017).



```
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Name = "Zon_que_HASPx_Range"
Hucs = "C:\\"Your Pathway"\\HUCs_lower48.gdb\\Hucs"
BCR18_19Projected_shp = "C:\\"Your Pathway"\\BCR18&19Projected.shp"
Hucs_Clip = "C:\\"Your Pathway"\\HUCs_lower48.gdb\\Hucs_Clip1"
Hucs_Clip__3_ = Hucs_Clip
Table = "C:\\"Your Pathway"\\dbf_Tables.gdb\\Zon_que_HASPx_Range"
Delete_Name_ = Hucs_Clip__3_
RangePolygons_gdb = "C:\\"Your Pathway"\\RangePolygons.gdb"
Undissolved__Name_ = "C:\\"Your Pathway"\\RangePolygons.gdb\\Undissolved_%Name%"
v_Name_ = "C:\\"Your Pathway"\\RangePolygons.gdb\\%Name%"

# Process: Iterate Tables
arcpy.IterateTables_mb(dbf_Tables_gdb, "", "", "RECURSIVE")

# Process: Clip
arcpy.Clip_analysis(Hucs, BCR18_19Projected_shp, Hucs_Clip, "")

# Process: Join Field
arcpy.JoinField_management(Hucs_Clip, "HUC12RNG", Table, "HUC12RNG",
"HUC12RNG;GapOrigin;GapPres;GapRepro;GapSeas;CompSrc;NS_cd;NWGap_cd;SEGap_cd;SWGap_cd")

# Process: Feature Class to Feature Class
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15 Text 0 0 ,First,#,C:\\"Your
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Pathway"\\HUCs_lower48.gdb\\Hucs_Clip1,NWGap_cd,-1,-1;SEGap_cd \"SEGap_cd\" true true
false 4 Text 0 0 ,First,#,C:\\"Your
Pathway"\\HUCs_lower48.gdb\\Hucs_Clip1,SEGap_cd,-1,-1;SWGap_cd \"SWGap_cd\" true true
false 4 Text 0 0 ,First,#,C:\\"Your
Pathway"\\HUCs_lower48.gdb\\Hucs_Clip1,SWGap_cd,-1,-1", "")

# Process: Select
arcpy.Select_analysis(Delete_Name_, Undissolved__Name_, "\"GapOrigin\" = 1")

# Process: Dissolve
arcpy.Dissolve_management(Undissolved__Name_, v_Name_, "", "", "MULTI_PART",
"DISSOLVE_LINES")
```
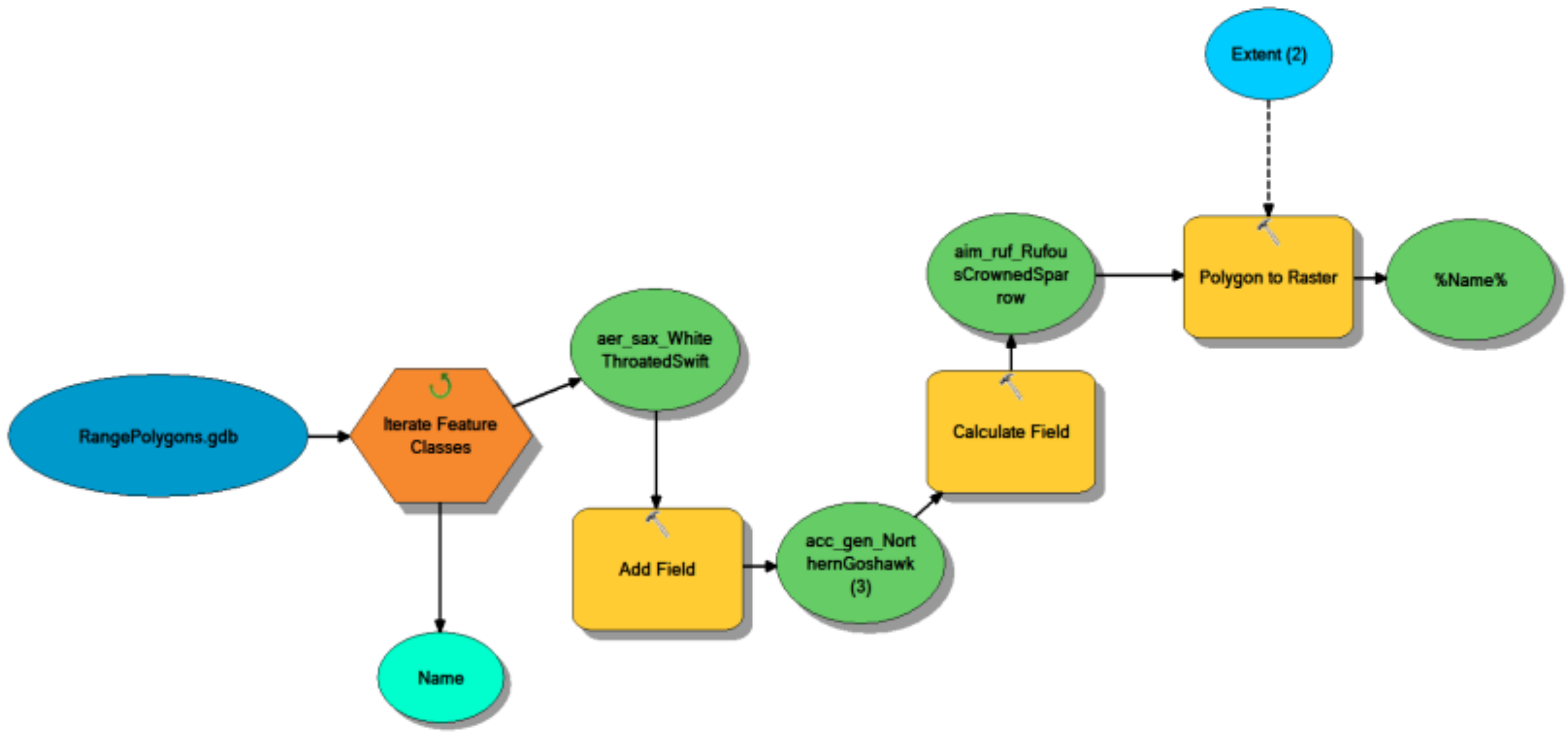
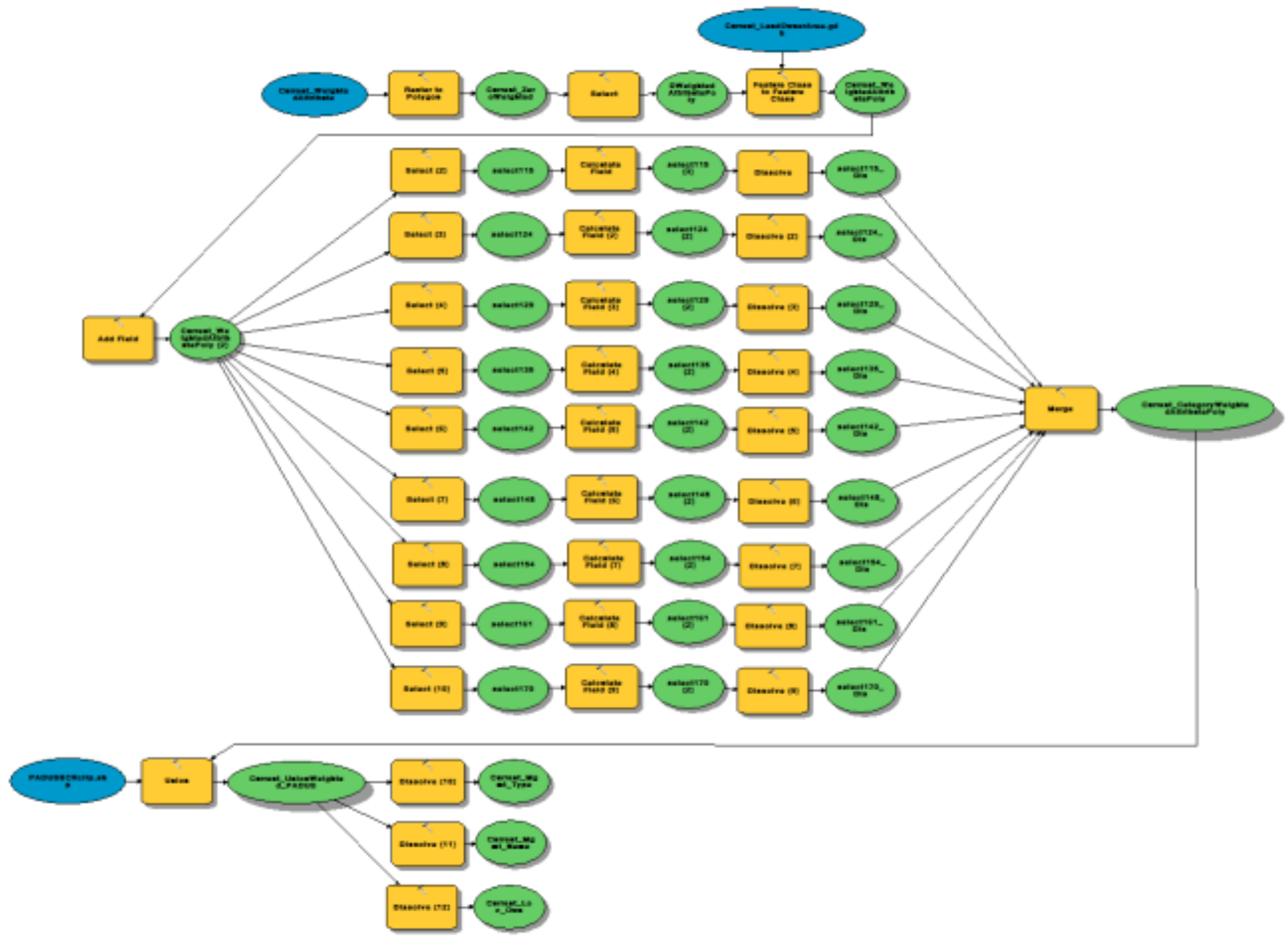

Step 2 –This ArcMap syntax clips all rasterized range files (current and pending) to the study area (Mougey 2017).



```
# Local variables:
RangePolygons_gdb = "C:\\"Your Pathway"\\RangePolygons.gdb"
Name = "Acc_gen_NOGOx_Range"
aer_sax_WhiteThroatedSwift = "C:\\"Your Pathway"\\RangePolygons.gdb\\Acc_gen_NOGOx_Range"
acc_gen_NorthernGoshawk__3_ = aer_sax_WhiteThroatedSwift
aim_ruf_RufousCrownedSparrow = acc_gen_NorthernGoshawk__3_
Extent__2_ = "-2873815.528708 -292108.490353 2443707.426693 3742029.177922"
v_Name_ = "C:\\"Your Pathway"\\FinalRasters.gdb\\%Name%"

# Process: Iterate Feature Classes
arcpy.IterateFeatureClasses_mb(RangePolygons_gdb, "", "", "NOT_RECURSIVE")

# Process: Add Field
arcpy.AddField_management(aer_sax_WhiteThroatedSwift, "RAST", "SHORT", "", "", "", "",
"NULLABLE", "NON_REQUIRED", "")

# Process: Calculate Field
arcpy.CalculateField_management(acc_gen_NorthernGoshawk__3_, "RAST", "1", "VB", "")

# Process: Polygon to Raster
tempEnvironment0 = arcpy.env.extent
arcpy.env.extent = Extent (2)
arcpy.PolygonToRaster_conversion(aim_ruf_RufousCrownedSparrow, "RAST", v_Name_,
"CELL_CENTER", "NONE", "5000")
arcpy.env.extent = tempEnvironment0
```

Appendix 2.4 – This ArcMap model syntax and corresponding Python code was run for current, pending, and combined Species of Greatest Conservation Need to overlay PADUS 1.4 layer onto and extract land ownership values by attribute "MangType" or management type. This was used on three geodatabases (each hotspot layer) for current, pending, and combined SGCNs (Mougey 2017).

Step 1 – This ArcMap model syntax and corresponding Python overlays PADUS 1.4 layer onto and extracts land ownership values by attribute "MangType" or management type.



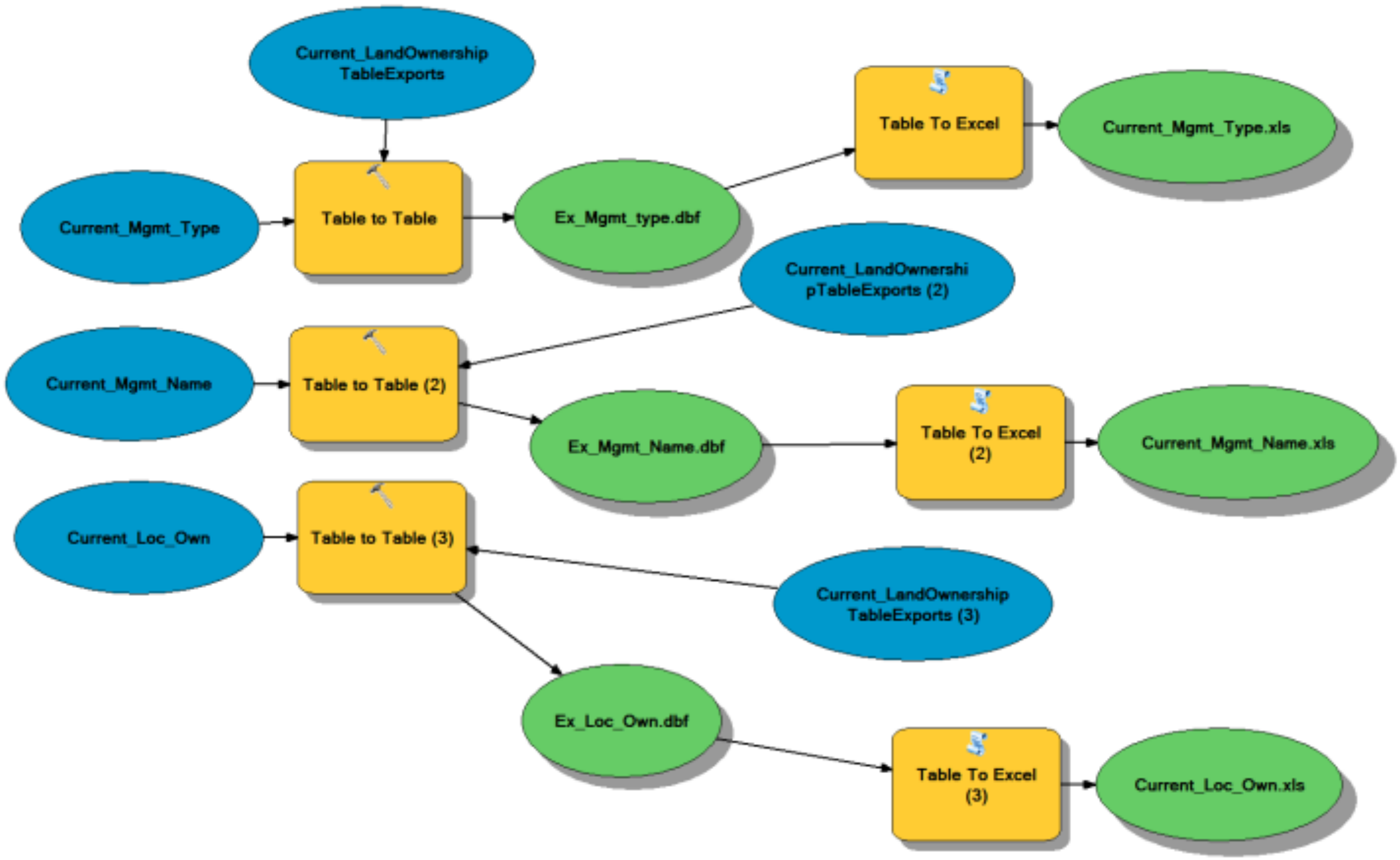
```
# Local variables:
PADUSBCRclip_shp = "C:\\"Your Pathway"\\LandOwnership\\PADUSBCRclip.shp"
Current_WeightedAttribute = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\Current_WeightedAttribute"
Current_ZeroWeighted = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\Current_ZeroWeighted"
DWeightedAttributePoly = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\DWeightedAttributePoly"
Current_WeightedAttributePoly = DWeightedAttributePoly
Current_LandOwnerArea_gdb = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb"
Current_WeightedAttributePoly__2_ = Current_WeightedAttributePoly
select115 = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select115"
select115__3_ = select115
select115_Dis = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select115_Dis"
select124 = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select124"
select124__2_ = select124
select124_Dis = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select124_Dis"
select129 = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select129"
select129__2_ = select129
select129_Dis = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select129_Dis"
select135 = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select135"
select135__2_ = select135
select135_Dis = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select135_Dis"
select142 = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select142"
select142__2_ = select142
select142_Dis = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select142_Dis"
select148 = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select148"
select148__2_ = select148
select148_Dis = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select148_Dis"
select154 = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select154"
select154__2_ = select154
select154_Dis = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select154_Dis"
select161 = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select161"
select161__2_ = select161
select161_Dis = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select161_Dis"
select170 = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select170"
select170__2_ = select170
select170_Dis = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select170_Dis"
Current_CategoryWeightedAttributePoly = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\Current_CategoryWeightedAttributePoly"
Current_UnionWeighted_PADUS = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\Current_UnionWeighted_PADUS"
Current_Mgmt_Type = "C:\\"Your
```

```
Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\Current_Mgmt_Type"
Current_Mgmt_Name = "C:\\"Your
Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\Current_Mgmt_Name"
Current_Loc_Own = "C:\\"Your
Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\Current_Loc_Own"

# Process: Raster to Polygon
arcpy.RasterToPolygon_conversion(Current_WeightedAttribute, Current_ZeroWeighted,
"NO_SIMPLIFY", "Value")

# Process: Select
arcpy.Select_analysis(Current_ZeroWeighted, DWeightedAttributePoly, "gridcode > 0")

# Process: Feature Class to Feature Class
arcpy.FeatureClassToFeatureClass_conversion(DWeightedAttributePoly,
Current_LandOwnerArea_gdb, "Current_WeightedAttributePoly", "", "Shape_Length
\"Shape_Length\" true false true 0 Double 0 0 ,First,#,C:\\"Your
Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\DWeightedAttributePoly,
Shape_Length,-1,-1;Shape_Area \"Shape_Area\" true false true 0 Double 0 0
,First,#,C:\\"Your
Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\DWeightedAttributePoly,
Shape_Area,-1,-1;ID \"ID\" true true false 0 Long 0 0 ,First,#,C:\\"Your
Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\DWeightedAttributePoly,
ID,-1,-1;GRIDCODE \"GRIDCODE\" true true false 0 Long 0 0 ,First,#,C:\\"Your
Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\DWeightedAttributePoly,
GRIDCODE,-1,-1", "")

# Process: Add Field
arcpy.AddField_management(Current_WeightedAttributePoly, "HotspotCat", "TEXT", "", "",
"10", "", "NULLABLE", "NON_REQUIRED", "")

# Process: Select (2)
tempEnvironment0 = arcpy.env.scratchWorkspace
arcpy.env.scratchWorkspace = "C:\\"Your
Pathway"\\LandOwnership\\All_SGCN\\All_LandOwnerArea.gdb"
tempEnvironment1 = arcpy.env.workspace
arcpy.env.workspace = "C:\\"Your
Pathway"\\LandOwnership\\All_SGCN\\All_LandOwnerArea.gdb"
arcpy.Select_analysis(Current_WeightedAttributePoly__2_, select115, "GRIDCODE < 124")
arcpy.env.scratchWorkspace = tempEnvironment0
arcpy.env.workspace = tempEnvironment1

# Process: Calculate Field
arcpy.CalculateField_management(select115, "HotspotCat", "\"115-123\"", "VB", "")

# Process: Dissolve
arcpy.Dissolve_management(select115__3_, select115_Dis, "HotspotCat", "", "MULTI_PART",
"DISSOLVE_LINES")

# Process: Select (3)
arcpy.Select_analysis(Current_WeightedAttributePoly__2_, select124, "GRIDCODE >= 124
AND GRIDCODE <= 128")

# Process: Calculate Field (2)
arcpy.CalculateField_management(select124, "HotspotCat", "\"124-128\"", "VB", "")

# Process: Dissolve (2)
arcpy.Dissolve_management(select124__2_, select124_Dis, "HotspotCat", "", "MULTI_PART",
"DISSOLVE_LINES")

# Process: Select (4)
arcpy.Select_analysis(Current_WeightedAttributePoly__2_, select129, "GRIDCODE >= 129
AND GRIDCODE <= 134")

# Process: Calculate Field (3)
arcpy.CalculateField_management(select129, "HotspotCat", "\"129-134\"", "VB", "")
```

```
# Process: Dissolve (3)
arcpy.Dissolve_management(select129__2_, select129_Dis, "HotspotCat", "", "MULTI_PART",
"DISSOLVE_LINES")

# Process: Select (5)
arcpy.Select_analysis(Current_WeightedAttributePoly__2_, select135, "GRIDCODE >= 135
AND GRIDCODE <= 141")

# Process: Calculate Field (4)
arcpy.CalculateField_management(select135, "HotspotCat", "\"135-141\"", "VB", "")

# Process: Dissolve (4)
arcpy.Dissolve_management(select135__2_, select135_Dis, "HotspotCat", "", "MULTI_PART",
"DISSOLVE_LINES")

# Process: Select (6)
arcpy.Select_analysis(Current_WeightedAttributePoly__2_, select142, "GRIDCODE >= 142
AND GRIDCODE <= 147")

# Process: Calculate Field (5)
arcpy.CalculateField_management(select142, "HotspotCat", "\"142-147\"", "VB", "")

# Process: Dissolve (5)
arcpy.Dissolve_management(select142__2_, select142_Dis, "HotspotCat", "", "MULTI_PART",
"DISSOLVE_LINES")

# Process: Select (7)
arcpy.Select_analysis(Current_WeightedAttributePoly__2_, select148, "GRIDCODE >= 148
AND GRIDCODE <= 153")

# Process: Calculate Field (6)
arcpy.CalculateField_management(select148, "HotspotCat", "\"148-153\"", "VB", "")

# Process: Dissolve (6)
arcpy.Dissolve_management(select148__2_, select148_Dis, "HotspotCat", "", "MULTI_PART",
"DISSOLVE_LINES")

# Process: Select (8)
arcpy.Select_analysis(Current_WeightedAttributePoly__2_, select154, "GRIDCODE >= 154
AND GRIDCODE <= 160")

# Process: Calculate Field (7)
arcpy.CalculateField_management(select154, "HotspotCat", "\"154-160\"", "VB", "")

# Process: Dissolve (7)
arcpy.Dissolve_management(select154__2_, select154_Dis, "HotspotCat", "", "MULTI_PART",
"DISSOLVE_LINES")

# Process: Select (9)
arcpy.Select_analysis(Current_WeightedAttributePoly__2_, select161, "GRIDCODE >= 161
AND GRIDCODE <= 169")

# Process: Calculate Field (8)
arcpy.CalculateField_management(select161, "HotspotCat", "\"161-169\"", "VB", "")

# Process: Dissolve (8)
arcpy.Dissolve_management(select161__2_, select161_Dis, "HotspotCat", "", "MULTI_PART",
"DISSOLVE_LINES")

# Process: Select (10)
arcpy.Select_analysis(Current_WeightedAttributePoly__2_, select170, "GRIDCODE >= 170
AND GRIDCODE <= 179")

# Process: Calculate Field (9)
arcpy.CalculateField_management(select170, "HotspotCat", "\"170-179\"", "VB", "")

# Process: Dissolve (9)
```

```
arcpy.Dissolve_management(select170__2_, select170_Dis, "HotspotCat", "", "MULTI_PART",
"DISSOLVE_LINES")

# Process: Merge
arcpy.Merge_management("C:\\"Your
Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select115_Dis;C:\\"Your

Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select124_Dis;C:\\"Your

Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select129_Dis;C:\\"Your

Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select135_Dis;C:\\"Your

Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select142_Dis;C:\\"Your

Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select148_Dis;C:\\"Your

Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select154_Dis;C:\\"Your

Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select161_Dis;C:\\"Your
 Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select170_Dis",
Current_CategoryWeightedAttributePoly, "HotspotCat \"HotspotCat\" true true false 10
Text 0 0 ,First,#,C:\\"Your
Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select115_Dis,HotspotCa
t,-1,-1,C:\\"Your
Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select124_Dis,HotspotCa
t,-1,-1,C:\\"Your
Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select129_Dis,HotspotCa
t,-1,-1,C:\\"Your
Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select135_Dis,HotspotCa
t,-1,-1,C:\\"Your
Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select142_Dis,HotspotCa
t,-1,-1,C:\\"Your
Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select148_Dis,HotspotCa
t,-1,-1,C:\\"Your
Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select154_Dis,HotspotCa
t,-1,-1,C:\\"Your
Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select161_Dis,HotspotCa
t,-1,-1,C:\\"Your
Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\select170_Dis,HotspotCa
t,-1,-1")

# Process: Union
arcpy.Union_analysis("C:\\"Your Pathway"\\LandOwnership\\PADUSBCRclip.shp #;C:\\"Your
Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\Current_CategoryWeighte
dAttributePoly #", Current_UnionWeighted_PADUS, "ALL", "", "GAPS")

# Process: Dissolve (10)
arcpy.Dissolve_management(Current_UnionWeighted_PADUS, Current_Mgmt_Type,
"Mang_Type;HotspotCat", "", "MULTI_PART", "DISSOLVE_LINES")

# Process: Dissolve (11)
arcpy.Dissolve_management(Current_UnionWeighted_PADUS, Current_Mgmt_Name,
"HotspotCat;Mang_Name", "", "MULTI_PART", "DISSOLVE_LINES")

# Process: Dissolve (12)
arcpy.Dissolve_management(Current_UnionWeighted_PADUS, Current_Loc_Own,
"HotspotCat;Loc_Own", "", "MULTI_PART", "DISSOLVE_LINES")
```

Step 2 – This ArcMap model syntax and corresponding Python code exports Land Ownership values to Microsoft Excel tables.



```

# Local variables:
Current_Mgmt_Type = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\Current_Mgmt_Type"
Ex_Mgmt_type_dbf = Current_Mgmt_Type
Current_LandOwnershipTableExports = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnershipTableExports"
Current_Mgmt_Type_xls = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnershipTableExports\\Current_Mgmt_Type.xls"
Current_Mgmt_Name = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\Current_Mgmt_Name"
Ex_Mgmt_Name_dbf = Current_Mgmt_Name
Current_LandOwnershipTableExports__2_ = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnershipTableExports"
Current_Mgmt_Name_xls = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnershipTableExports\\Current_Mgmt_Name.xls"
Current_Loc_Own = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\Current_Loc_Own"
Ex_Loc_Own_dbf = Current_Loc_Own
Current_LandOwnershipTableExports__3_ = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnershipTableExports"
Current_Loc_Own_xls = "C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnershipTableExports\\Current_Loc_Own.xls"

# Process: Table to Table
arcpy.TableToTable_conversion(Current_Mgmt_Type, Current_LandOwnershipTableExports, "Ex_Mgmt_type.dbf", "", "Mang_Type \"Mang_Type\" true true false 50 Text 0 0 ,First,#,C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\Current_Mgmt_Type,Mang_Type,-1,-1;HotspotCat \"HotspotCat\" true true false 10 Text 0 0 ,First,#,C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\Current_Mgmt_Type,HotspotCat,-1,-1;Shape_Leng \"Shape_Leng\" false true true 8 Double 0 0 ,First,#,C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\Current_Mgmt_Type,Shape_Length,-1,-1;Shape_Area \"Shape_Area\" false true true 8 Double 0 0 ,First,#,C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\Current_Mgmt_Type,Shape_Area,-1,-1", "")

# Process: Table To Excel
arcpy.TableToExcel_conversion(Ex_Mgmt_type_dbf, Current_Mgmt_Type_xls, "NAME", "CODE")

# Process: Table to Table (2)
arcpy.TableToTable_conversion(Current_Mgmt_Name, Current_LandOwnershipTableExports__2_, "Ex_Mgmt_Name.dbf", "", "Mang_Name \"Mang_Name\" true true false 70 Text 0 0 ,First,#,C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\Current_Mgmt_Name,Mang_Name,-1,-1;HotspotCat \"HotspotCat\" true true false 10 Text 0 0 ,First,#,C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\Current_Mgmt_Name,HotspotCat,-1,-1;Shape_Leng \"Shape_Leng\" false true true 8 Double 0 0 ,First,#,C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\Current_Mgmt_Name,Shape_Length,-1,-1;Shape_Area \"Shape_Area\" false true true 8 Double 0 0 ,First,#,C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\Current_Mgmt_Name,Shape_Area,-1,-1", "")

# Process: Table To Excel (2)
arcpy.TableToExcel_conversion(Ex_Mgmt_Name_dbf, Current_Mgmt_Name_xls, "NAME", "CODE")

# Process: Table to Table (3)
arcpy.TableToTable_conversion(Current_Loc_Own, Current_LandOwnershipTableExports__3_, "Ex_Loc_Own.dbf", "", "Loc_Own \"Loc_Own\" true true false 250 Text 0 0 ,First,#,C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\Current_Loc_Own,Loc_Own,-1,-1;HotspotCat \"HotspotCat\" true true false 10 Text 0 0 ,First,#,C:\\"Your Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\Current_Loc_Own,HotspotCat,-1,-1;Shape_Leng \"Shape_Leng\" false true true 8 Double 0 0 ,First,#,C:\\"Your
```

```
Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\Current_Loc_Own,Shape_L
ength,-1,-1;Shape_Area \"Shape_Area\" false true true 8 Double 0 0 ,First,#,C:\\"Your
Pathway"\\LandOwnership\\Current_SGCN\\Current_LandOwnerArea.gdb\\Current_Loc_Own,Shape_A
rea,-1,-1", "")

# Process: Table To Excel (3)
arcpy.TableToExcel_conversion(Ex_Loc_Own_dbf, Current_Loc_Own_xls, "NAME", "CODE")


```

CHAPTER III

Evaluation of single species management as an umbrella for multi-species conservation: a case study of the Lesser Prairie-Chicken Range-wide Plan

Abstract

Conservation efforts around the globe often target a single species, but this approach is inadequate for dealing with the large number of species that are at risk. Using already-funded management to protect additional species can help stretch limited resources and protect more biodiversity. In the southern Great Plains, a conservation plan exists for the Lesser Prairie-Chicken (LPC), designed to protect critical habitat for this species. The LPC may act as an umbrella species if its range-wide plan protects non-target species with similar habitat requirements. In this study, I evaluated overlap of at-risk species' home ranges and the area covered by the range-wide plan for the Lesser Prairie-Chicken, and then compared habitat requirements between the non-target at-risk species and the LPC. There are 204 currently listed SGCNs and 20 pending species for SGCN listing that overlap with the LPC range. For these species, I then evaluated how well the LPC performs as an umbrella species by identifying non-target overlapping species that share habitat requirements with the LPC. There were 40 species I identified as grassland obligates, or that specifically share habitat requirements with the LPC, suggesting it functions as an umbrella for these non-target species. This information is useful for land managers to bolster the importance and applicability of this conservation tool.

Introduction

Biodiversity loss is currently 100 to 1,000 times that indicated by pre-human fossil records (IUCN 2009, Pimm et al. 1995) and is not slowing (Butchart et al. 2010).

Several factors contribute to biodiversity loss, but habitat destruction and fragmentation are well-accepted to be the main drivers (Convention on Biological Diversity 2010, Pereira et al. 2012). Habitat fragmentation or land cover conversion to urban development, agriculture, or industrial development such as energy production can eliminate or alter habitat for many species (Foley et al. 2005). As the human population grows, alteration of ecosystems to provide food, energy, and other commodities for the human population is inevitable but is not without consequences.

Biodiversity loss can lead to ecosystem instability (McCann 2000, Krebs 2009), which is the ability of an ecosystem to maintain resilience to or recover quickly after disturbances (Lewontin 1969). Production of ecosystem services such as fuel, food, recreation, fiber, and building materials can be diminished by biodiversity loss or alteration (Hooper et al. 2005). Biodiversity conservation helps to maintain ecosystem stability, and high species richness is particularly critical in intensively used landscapes to maintain ecosystem function (Naeem et al. 1994, McGrady-Steed et al. 1997, Loreau et al. 2001). In other words, protection of ecosystem function and biodiversity help support the production of agricultural goods and energy services and provide for the human population. Unfortunately, biodiversity and ecosystem services are not always considered when land is developed for human use.

Along with providing ecosystem services, biological diversity preservation is considered a goal of conservation biology as an ultimate good (Primack 2008). Aldo Leopold and Gifford Pinchot, two of the early figures in conservation, believed that the goal of land management was to use natural resources for the greater good and maintain overall ecosystem health (Callicott 2000). We can see how preservation of the natural southern Great Plains ecosystem is helpful for the greater good, as the plains are a massive carbon sink (Zhang et al. 2011). Alteration of native flora and fauna of the southern Great Plains has resulted in erosion and poor nutrient cycling, thus compromising the system's productivity and ability to support humans (Samson and Knopf 1994).

Land-cover conversion has resulted in the Great Plains losing 20-99% of its original landscape cover (Samson and Knopf 1994) and has caused the Great Plains to be among the most endangered biomes of North America (Ricklетts et al. 1999). The southern Great Plains is currently home to more than 1,000 species at risk (see Chapter II) due to human development from agriculture and energy development. The southern Great Plains are important sources of cotton, grain, and cattle grazing for the U.S. (Rosenow et al. 1983, Samson and Knopf 1994, Unger 1994), and oil, gas, and wind developments are also prominent in this region (Paxton 2001). The southern Great Plains have experienced significant land cover changes and will likely experience more as the demand for energy and agricultural goods increases with the human population, causing habitat loss for wildlife.

This habitat loss and conversion has contributed to declines of many species in the Great Plains. For example, grassland birds have experienced the most severe population declines of any group of birds on the continent (Knopf 1994), with nearly 60% of grassland-breeding birds in North America showing significant declines in recent decades. This is the most consistently negative trend of any group of birds (Vickery and Herkert 2001, Brennan and Kuvlesky 2005, Sauer et al. 2014) and is largely attributed to the conversion of Great Plains prairie to cropland (With et al. 2008). Although birds have perhaps the best-documented trends, declines and extirpations of various other organisms throughout the Great Plains, such as prairie dogs, are also known (Samson and Knopf 1994, Benedict et al. 1996, Corn and Peterson 1996). Because birds have well-established, long-term monitoring protocols (unlike most other vertebrates), conservation efforts designed for them may be co-opted for use with other taxa to provide an umbrella of protection.

An umbrella species may be used as a tool in conservation planning when management for one species is used to protect a suite of other species with similar habitat requirements (Caro and O'Doherty 1999). Fleishman (2000) expands on this definition and recognizes an effective umbrella species as displaying three characteristics: co-occurrence with other species, not extremely rare nor ubiquitous, and being sensitive to human disturbance. In fragmented landscapes where many species require conservation, use of umbrella species may be especially important (Lambeck 1997, Fleishman et al. 2000) to protect the greatest number of species in a limited area. Since the southern Great Plains are home to many at-risk species and have a fragmented landscape, using existing protection plans of well-known at-risk species (such as grassland birds) to protect multiple species could be effective from a conservation and financial resource standpoint.

The Lesser Prairie-Chicken (LPC, *Tympanuchus pallidicinctus*), is a grassland bird endemic to the southern Great Plains short- and mixed-grass ecoregions. Lesser Prairie-Chickens have experienced considerable decline from historic populations (Crawford 1980, Fuhlendorf et al. 2002, Garten et al. 2016), and agricultural development inducing habitat fragmentation is considered to be the primary cause of their decline (Hagen et al. 2004). In response to its decline, natural resource managers from the five states that encompass the LPC range (Texas, New Mexico, Oklahoma, Kansas, and Colorado) created a range-wide plan to protect habitat and conserve the species. As a part of the range-wide plan, the LPC Working Group and the Western Association of Fish and Wildlife Agencies (WAFWA) created the Southern Great Plains Crucial Habitat Assessment Tool (CHAT) to help industry site infrastructure responsibly (www.wafwa.org/initiatives/grasslands/lesser_prairie_chicken/). Many other species co-occur in the same area as the LPC (see Chapter II), so it is feasible that the LPC could act as an umbrella species to protect other at-risk species. This has not been evaluated, however, and so was the focus of my work.

The Lesser Prairie-Chicken, fitting Fleishman's (2000) three protocols for an effective umbrella species, and having a conservation plan already in place, presents a unique opportunity to protect multiple species using one plan. Continued habitat fragmentation throughout the southern Great Plains by agriculture and energy development is likely (Ruppel and Hovorka 1995, Matson et al. 1997), so the need to protect biodiversity is more important than ever. My project aims to address whether the conservation areas delineated by the CHAT tool, designed to protect the Lesser Prairie-Chicken, overlap with non-target species ranges. Additionally, my project identifies whether the LPC acts as an umbrella species to protect non-target overlapping species by identifying habitat requirements shared with the Lesser Prairie-Chicken. Some of the main habitat requirements of the LPC are sand shinnery oak or sand sagebrush shrubs, mixed grasses, and tall grasses; additionally, quality rather than quantity is considered key in determining chicken habitat (Haukos and Zavaleta 2016).

Methods

My study area includes Bird Conservation Regions (BCR) 18 and 19, as defined by the Commission for Environmental Cooperation (http://nabci-us.org/resources/bird-conservation-regions/), which covers most of the area impacted by LPC conservation measures indicated in the CHAT tool (Figure 3.1). This area corresponds to the short- and mixed-grass prairie ecoregions of the Great Plains. Within BCRs 18 and 19, the CHAT covers four ecoregions--sand shinnery oak, mixed-grass prairie, short-grass prairie, and sand sagebrush—in Texas, New Mexico, Oklahoma, Nebraska, Colorado, Kansas, Wyoming, and South Dakota.

I compiled lists of state-designated at-risk species (Species of Greatest Conservation Need [SGCN]) for these eight states from Texas Parks and Wildlife Department, New Mexico Game and Fish, Oklahoma Department of Wildlife Conservation, Nebraska Game and Parks Commission, Colorado Parks and Wildlife, Kansas Department of Wildlife and Parks, Wyoming Game and Fish Department, and South Dakota Game, Fish, and Parks. There were a total of 1763 currently listed at-risk species and 120 pending species for listing. I included only vertebrate species for the analysis (710 currently listed SGCNs and 53 pending SGCNs) because range information was limited for invertebrates. Digital range files from USGS Gap Analysis program (https://gapanalysis.usgs.gov) exist for 346 of these species. Of these, 265 range files (excluding the LPC) overlapped with the study area and were transformed from .dbf (database) files into raster format (Appendix 2.3, Chapter II) and used for analysis. I overlaid these range files in ArcMap 10.3.1 to create a hotspot density surface layer for currently listed SGCNs. I repeated this for the 23 of 53 pending SGCN species in the study area that had USGS Gap data and that overlapped with the study area. The resulting raster files were then converted into a fishnet (Model Syntax 3.1), which is a compilation of small polygons that mimic a raster, so that individual species and species richness could be identified. I used NAD 1983 to project all layers involved, as it is the projection used by USGS GAP Analysis program. The "0" category was eliminated, as it represented cells outside the study area. I thus created three hotspot surfaces (current, pending, and current and pending SGCN) with the raster to polygon tool.

I then overlaid the CHAT habitat layer on each of the three hotspot surfaces and spatially joined them to identify which species occurred in the full CHAT layer. Within the full crucial habitat layer, there were five designated sub-habitats in descending order of importance for the LPC: focal area, connectivity zone, lek Maxent models, estimated occupied range, and the estimated occupied range plus a ten-mile buffer. These areas are ranked as 1, 2, 3, 4, and 5, respectively, from highest to lowest management priority, with the focal and connectivity zones being most important as they are state-identified areas of intact LPC habitat (Southern Great Plains Crucial Habitat Assessment Tool 2013). Using the entire CHAT extent, focal areas, connectivity zones, and then focal and connectivity zones combined, I spatially joined each with the three hotspot layers to identify overlapping species. Attribute tables for each spatial join were created and exported into Microsoft Excel version 2013, where species occurrence was delineated with a "1" and no occurrence with "0."

I considered LPC an umbrella species for other assessed at-risk species overlapping with it in range and sharing habitat requirements, as per definition of an umbrella species (Lambeck 1997, Caro and O'Doherty 1999). For species ranges that overlap with the CHAT focal and connectivity layers, or the highest priority habitat, I conducted a literature review on whether the species shared habitat requirements with the LPC, such as sand shinnery oak shrubs, sand sagebrush shrubs, mixed grasses, and tall grasses (Haukos and Zavaleta 2016). I began by narrowing down which species were grassland and/or shrub land obligates, which I defined as living in grasslands or shrub lands or depending on them for a critical part of their life cycle (i.e., breeding). I used basic habitat and range info from the Cornell Lab of Ornithology (allaboutbirds.org), the National Audubon society (audubon.org), and the IUCN red list (IUCNredlist.org) to determine which species were grassland or shrub land obligates or using the same ecoregions as the Lesser Prairie-Chicken. I noted these species in a spreadsheet (Microsoft Excel 2013) and investigated further literature when necessary to determine specific shared habitat requirements with the LPC.

Results

For currently listed SGCNs, 204 of 266 ranges (77%) overlapped with the crucial habitat layer of the CHAT tool (Appendix 3.1). For the focal and connectivity layer (ranked 1 and 2 priority) and just the focal layer (ranked 1 priority), current SGCN species richness were equivalent in number and species identity. The majority of species with ranges that overlap the CHAT are avian: there are 146 birds, 29 mammals, 26 reptiles, and 3 amphibians.

For pending SGCNs, 20 of 23 (87%) ranges overlapped with the crucial habitat layer of the CHAT tool (Appendix 3.2). Pending species were the same for both the focal and connectivity layer (ranked 1 and 2 priority) and the focal layer only (ranked 1 priority). Of pending species ranges that overlapped with the CHAT, there are 18 birds and 2 reptiles. The current at-risk species in BCR 18 and 19 that are not covered by protections for the LPC are 35 birds, 9 mammals, and 18 reptiles (Appendix 3.4). The pending at-risk species in BCR 18 and 19 that are not covered by protections for the LPC include the flammulated owl, the spot-tailed earless lizard, and the white-tailed prairie dog (Appendix 3.4).

When current SGCNs and pending SGCNs are combined, then 84% of all species ranges overlap with the CHAT to some degree (Figure 3.2). Of all the overlapping ranges, 18% are grassland obligates and share some habitat characteristics with the LPC (Appendix 3.3), and all are currently listed SGCNs. All current and pending species that did not overlap with the CHAT are listed in Appendix 3.4. Across all SGCN layers, the majority of overlapping ranges are avian; this is not surprising as avian range files were the most available.

Discussion

Overall, the LPC range-wide plan and CHAT covers 84% of the current and pending vertebrate SGCNs for the study area, of which 18% of the current and pending are grassland and/or shrub land obligates. Both focal and connectivity areas, those with the greatest protections, provide protection for the exact same species. The range-wide plan does best for protecting species that need similar habitat to the LPC, such as sand shinnery oak, short- and mixed-grass prairie, and a combination of open grassland interspersed with shrub cover, as these are the regions it was designed to protect for the LPC. Species that are generalists or that require forest are not conserved by the plan. Overall, 224 species ranges overlap with the CHAT and 40 of these species are grassland and/or shrub land obligates for which the LPC acts as an umbrella species. The range-wide plan and CHAT were developed specifically to protect the Lesser Prairie-Chicken, but these results suggest they can offer a multi-species approach to conservation.

Multi-species approaches to conservation are becoming more popular given the rise of landscape-level conservation practices (Hobbs 1994) and the fact that financial resources for conservation are limited (McDonald-Madden et al. 2008). Use of umbrella species is one example of a multi-species approach to conservation. In the case of the Bay checker-spot butterfly (*Euphydryas editha bayensis*), Launer and Murphy (1994) found that its conservation plan could protect up to 98% of serpentine-soil plant species, many of which are at-risk. Another study showed that forest bird diversity was relatively higher within 300 meters of capercaillie (*Tetrao urogallus*) leks, and at a 1000-meter scale overall species richness was higher (Pakkala et al. 2003). The range-wide plan and CHAT originally designed to protect the Lesser Prairie-Chicken, like these other conservation programs, are successful as umbrella species in providing multi-species conservation.

The applicability of a species as an umbrella can be bolstered when shared habitat characteristics are considered between species (Lambeck 1997). Forty current SGCNs depend on shared habitat characteristics with the Lesser Prairie-Chicken for all or a critical portion of their life cycle, making the LPC a good candidate to be an umbrella for these species. The LPC depends on a mix of short- and mixed-grasses as well as shrub cover for its habitat (Jones 1963, Elmore et al. 2009, Haukos and Zavaleta 2016), all of which occur under the range-wide plan. Cassin's sparrow (*Peucaea cassinii*), meadowlarks (*Sturnella species*), chestnut-collared longspur (*Calcarius ornatus*), and lark bunting (*Calamospiza melanocorys*) are known to use the sand shinnery oak ecoregion for breeding and during migration (Smythe and Haukos 2010), as does the LPC (Taylor and Guthery 1980, Bell et al. 2010). Other species such as the Texas horned lizard (*Phrynosoma cornutum*) depend on open, sparse vegetation and shrubs for foraging (Whiting et al. 1993). Although fragmentation has limited its historic range, the swift fox (*Vulpes velox*) has habitat only in grasslands that occur throughout the short- and mixed-grass ecoregions (Kamler et al. 2003), as does the LPC. Various taxa overlap with the share the grassland and shrub land habitat requirements with the LPC. important in croplands (Fahrig et al. 2011) such as the southern Great Plains.

The majority of species overlapping with the LPC range are avian. This was expected because birds have the best available information (range files) and are the most speciose of the taxa I examined. There were 40 species whose ranges overlap with the LPC and share some habitat characteristics. This is not to detract from the fact that the range-wide plan protects over 200 species by range overlap alone, it is simply to put emphasis on how the LPC fits the definition of an umbrella species. Just because a species overlaps with other species' ranges does not make it an effective umbrella; the LPC fits the three protocol for an effective umbrella per Fleishman (2000) and also shares habitat requirements with some overlapping species, which supports the efficacy of the umbrella species approach (Caro and O'Doherty 1999). My evaluation is focused on vertebrates; therefore, my estimate of non-target conserved species is conservative. Moreover, since the range-wide plan and CHAT specifically cover sand shinnery oak, short- and mixed-grass prairie, and open grassland interspersed with shrub cover, this study is predisposed to finding overlapping habitat requirements among species using these specific vegetation types.

This project is the first to make a qualitative assessment of the LPC as an umbrella species at the first order of habitat selection and incorporating components of third order of habitat selection. The first order of habitat selection is the geographic range of a species, while third order is core range, which pertains to types of habitat or habitat components within the home range of the species (Johnson 1980). The LPC selects certain habitat types at a fine level (fourth order habitat selection) in regards to percent visual obstruction, types of food preferred during different seasons, etc. (Haukos and Zavaleta 2016), which this project does not address. This project does assess which species geographic ranges overlap (first order selection) as well as which species share habitat requirements with the LPC such as sand shinnery oak or mixed grass ecoregions (third order habitat selection). The results of this project do not assess fine scale needs of individual species overlapping with the range-wide plan and CHAT, but are useful for large-scale habitat conservation plans using a multi-species approach.

Although originally formulated to help specifically the LPC, these results indicate that the range-wide plan and CHAT provide multi-species conservation benefit. In 2016 alone, the CHAT helped mitigate 114 energy development projects and helped secure two permanent conservation sites for the LPC (Wolfe et al. 2016). These successes may translate into protecting habitat for non-target species covered by the range-wide plan and CHAT. With 224 at-risk species ranges overlapping and 40 of those species sharing habitat requirements with the LPC, this grassland bird can act as an umbrella species for non-target vertebrates, particularly other grassland birds. Addressing habitat fragmentation and prioritizing land for conservation is a main goal of the range-wide plan, which applies to many at-risk species in the area. The range-wide plan and CHAT's function and importance for multiple species could be bolstered based on the results of this study and maximize efficacy of conservation planning in this region.

For those species in my study not covered by the range-wide plan, I recommend a landscape-scale, multi-species conservation plan for those biodiversity hotspots (specifically identified in Chapter II). This plan would focus on type of habitat to preserve in said areas of dense species richness; in other words, focusing on the habitat requirements of many species instead of trying to preserve species themselves on an individual basis. I would also recommend identifying key threats to habitat and developing a way to mitigate those, like the CHAT tool does for the Lesser Prairie-Chicken.

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Figures, Appendices, Syntaxes

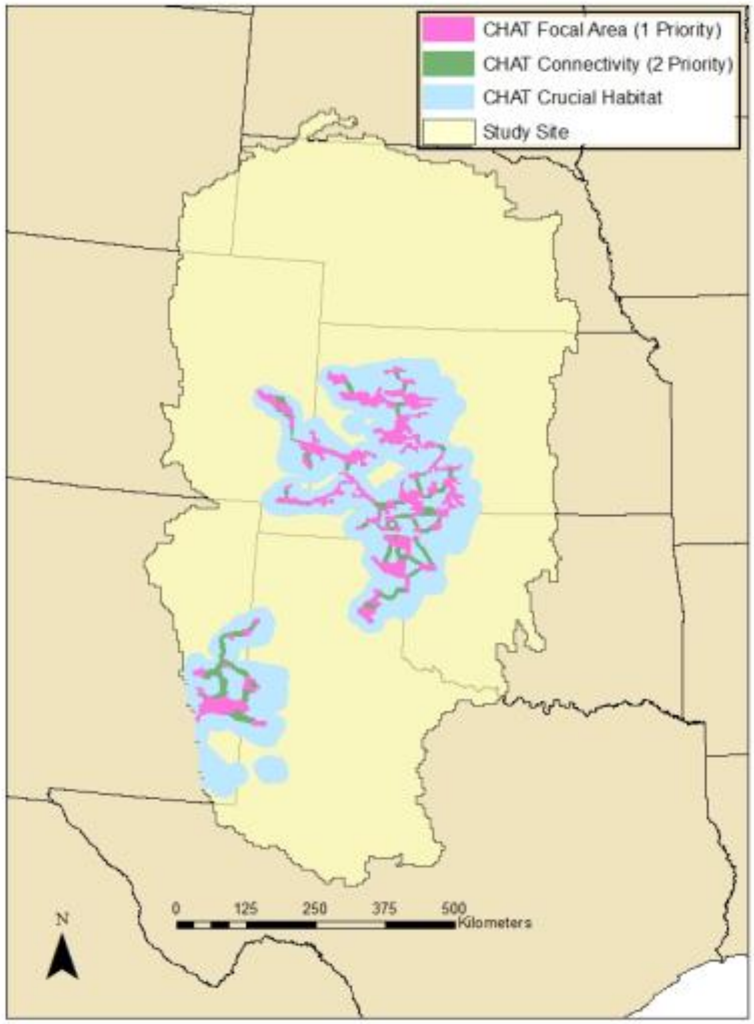


Figure 3.1 – The study area of Bird Conservation Regions 18 and 19 covers portions of Texas, New Mexico, Oklahoma, Colorado, Kansas, Wyoming, Nebraska, and South Dakota. The Southern Great Plains Crucial Habitat Assessment Tool (CHAT) for the Lesser Prairie-Chicken covers portions of Texas, New Mexico, Oklahoma, Colorado, and Kansas. CHAT regions are identified.

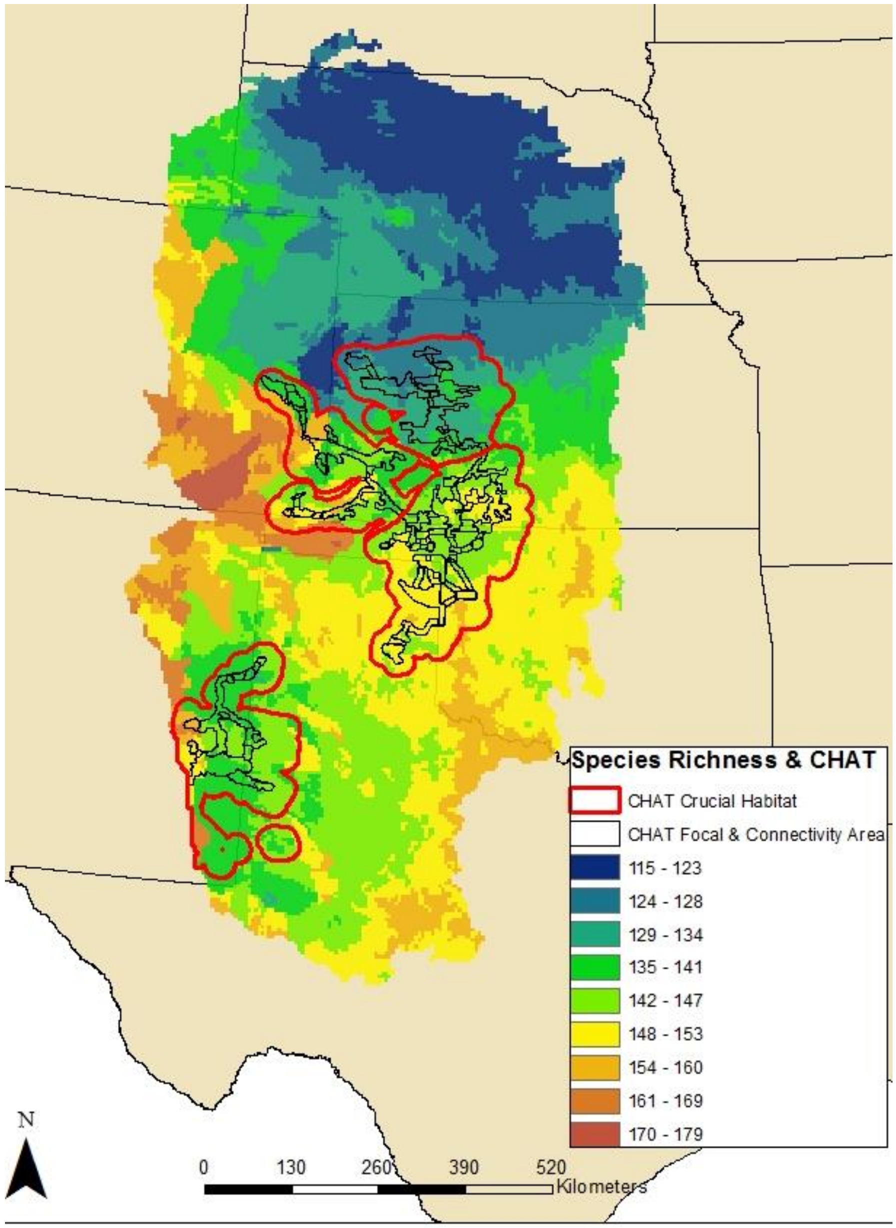


Figure 3.2 – Combined (current plus pending) vertebrate Species of Greatest Conservation Need hotspot layer for the eight states in the study area of Bird Conservation Regions 18 and 19 (Texas, Oklahoma, New Mexico, Kansas, Colorado, Nebraska, Wyoming, and South Dakota) as of December, 2016, plus Crucial Habitat Assessment Tool layers.

Appendix 3.1 – Current Species of Greatest Conservation Need that overlap with CHAT crucial habitat, focal, and connectivity zones for the Lesser Prairie-Chicken.

Scientific/Common Name

Amphibian
Ambystoma tigrinum (Eastern) Tiger Salamander
Lithobates pipiens Northern Leopard Frog

Bird
Accipiter gentilis Northern Goshawk
Accipiter striatus Sharp-shinned Hawk
Aechmophorus clarkii Clark's Grebe
Aechmophorus occidentalis Western Grebe
Aegalius acadicus Northern Saw-whet Owl
Aimophila cassinii Cassin’s Sparrow
Aimophila ruficeps Rufous-crowned Sparrow
Ammodramus leconteii Le Conte’s Sparrow
Ammodramus savannarum Grasshopper Sparrow
Amphispiza belli Sage Sparrow
Anas acuta Northern Pintail
Anas americana American Wigeon
Anas cyanpotera Cinnamon Teal
Anthus rubescens American Pipit
Anthus spragueii Sprague's Pipit
Aphelocoma californica Western Scrub-jay
Aquila chrysaetos Golden Eagle
Archilochus colubris Ruby-throated Hummingbird
Asio flammeus Short-eared Owl
Athene cunicularia Burrowing Owl
Aythya affinis Lesser Scaup
Aythya americana Redhead
Aythya valisineria Canvasback
Baeolophus bicolor Tufted Titmouse
Baeolophus ridgwayi Juniper Titmouse
Bartramia longicauda Upland Sandpiper
Bassariscus astutus Ringtail
Botaurus lentiginosus American Bittern
Buteo regalis Ferruginous Hawk
Buteo swainsoni Swainson's Hawk

Calamospiza melanocorys Lark Bunting
Calcarius mccownii McCown's Longspur
Calcarius ornatus Chestnut-collared Longspur
Calcarius pictus Smith's Longspur
Calidris bairdii Baird's Sandpiper
Calidris fuscicollis White-rumped Sandpiper
Calidris himantopus Stilt Sandpiper
Calidris mauri Western Sandpiper
Calidris melanotos Pectoral Sandpiper
Calidris minutilla Least Sandpiper
Calidris pusilla Semipalmated Sandpiper
Callipepla squamata Scaled Quail
Caprimulgus carolinensis Chuck-will's-widow
Carduelis pinus Pine Siskin
Certhia americana Brown Creeper
Charadrius alexandrines nivosis Western Snowy Plover
Charadrius nivosis Snowy Plover
Charadrius melodus Piping Plover
Charadrius montanus Mountain Plover
Chlidonias niger Black Tern
Chondestes grammacus Lark Sparrow
Chordeiles minor Common Nighthawk
Circus cyaneus Northern Harrier
Cistothorus platensis Sedge Wren
Coccyzus americanus Yellow-billed Cuckoo
Coccyzus erythropthalmus Black-billed Cuckoo
Colinus virginianus Northern Bobwhite
Corvus cryptoleucus Chihuahuan Raven
Dendroica graciae Grace's Warbler
Dendroica nigriscens Black Throated Gray Warbler
Dolichonyx oryzivorus Bobolink
Egretta caerulea Little Blue Heron
Egretta thula Snowy Egret
Empidonax traillii Willow Flycatcher
Euphagus carolinus Rusty Blackbird
Euphagus cyanocephalus Brewer's Blackbird
Falco columbarius Merlin
Falco femoralis Aplomado Falcon
Falco mexicanus Prairie Falcon
Falco peregrinus Peregrine Falcon

Gallinago delicata Wilson's Snipe
Gavia immer Common Loon
Glaucidium gnoma Northern Pygmy-Owl
Grus americana Whooping Crane
Grus canadensis Sandhill Crane (now *Antigone canadensis*)
Gymnorhinus cyanocephalus Pinyon Jay
Haliaeetus leucocephalus Bald Eagle
Hylocichla mustelina Wood Thrush
Icterus bullockii Bullock's Oriole
Icterus galbula Baltimore Oriole
Icterus spurius Orchard Oriole
Ictinia mississippiensis Mississippi Kite
Ixobrychus exilis Least Bittern
Junco hyemalis Dark-eyed Junco
Lanius ludovicianus Loggerhead Shrike
Laterallus jamaicensis Black Rail
Limnodromus scolopaceus Long-billed Dowitcher
Melanerpes aurifrons Golden-fronted Woodpecker
Melanerpes erythrocephalus Red-headed Woodpecker
Melanerpes lewis Lewis's Woodpecker
Meleagris gallopavo Wild Turkey
Melospiza georgiana Swamp Sparrow
Mniotilta varia Black-and-white Warbler
Myadestes townsendi Townsend's Solitaire
Myiarchus cinerascens Ash-throated Flycatcher
Nucifraga columbiana Clark's Nutcracker
Numenius americanus Long-billed Curlew
Nycticorax nycticorax Black-crowned Night-Heron
Oreoscoptes montanus Sage Thrasher
Pandion haliaetus Osprey
Passerculus sandwichensis Savannah Sparrow
Passerina ciris Painted Bunting
Pelecanus erythrorhynchos American White Pelican
Phalaenoptilus nuttallii Common Poorwill
Phalaropus tricolor Wilson's Phalarope
Pica hudsonia Black-billed Magpie
Picoides scalaris Ladder-backed Woodpecker
Pipilo maculatus Spotted Towhee
Pipistrellus subflavus Eastern Pipistrelle
Plegadis chihi White-faced Ibis

Pluvialis dominica American Golden-Plover
Podiceps nigricollis Eared Grebe
Poecile carolinensis Carolina Chickadee
Psaltriparus minimus Bushtit
Rallus limicola Virginia Rail
Recurvirostra americana American Avocet
Riparia riparia Bank Swallow
Sitta pygmaea Pygmy Nuthatch
Sphyrapicus thyroideus Williamson's Sapsucker
Spiza americana Dickcissel
Spizella arborea American Tree Sparrow
Spizella breweri Brewer's Sparrow
Spizella pusilla Field Sparrow
Sterna forsteri Forster's Tern
Sternula antillarum Least Tern
Strix occidentalis lucida Mexican Spotted Owl
Sturnella magna Eastern Meadowlark
Tachycineta thalassina Violet-green Swallow
Toxostoma curvirostre Curve-billed Thrasher
Tringa flavipes Lesser Yellowlegs
Tringa melanoleuca Greater Yellowlegs
Tringa solitaria Solitary Sandpiper
Tryngites subruficollis Buff-breasted Sandpiper
Tympanuchus pallidicinctus Lesser Prairie-Chicken
Tyrannus forficatus Scissor-tailed Flycatcher
Tyrannus tyrannus Eastern Kingbird
Tyrannus verticalis Western Kingbird
Tyrannus vociferans Cassin's Kingbird
Tyto alba Barn Owl
Vireo atricapilla Black-capped Vireo
Vireo bellii Bell's Vireo
Vireo plumbeus Plumbeous Vireo
Vireo vicinior Gray Vireo
Zenaida macroura Mourning Dove
Zonotrichia querula Harris's Sparrow

Mammal
Antrozous pallidus Pallid Bat
Castor canadensis American Beaver
Corynorhinus townsendii Townsend's big-eared Bat

Cynomys ludovicianus Black-tailed Prairie Dog
Eptesicus fuscus Big Brown Bat
Geomys bursarius Plains Pocket Gopher
Lasiurus borealis Eastern Red Bat
Lepus californicus Black-tailed Jackrabbit
Lepus townsendii White-tailed Jackrabbit
Mustela frenata Long-tailed Weasel
Mustela nigripes Black-footed Ferret
Myotis ciliolabrum Western Small-footed Myotis
Myotis evotis Long-eared Myotis
Myotis lucifugus Little Brown Myotis
Myotis occultus Arizona Myotis Bat
Myotis thysanodes Fringed Myotis
Myotis velifer Cave Myotis
Myotis volans Long-legged Myotis
Nycticeius humeralis Evening Bat
Nyctinomops macrotis Big free-tailed Bat
Ovis canadensis Bighorn Sheep
Peromyscus truei Piñon Deermouse
Sistrurus catenatus Massasauga
Sorex merriami Merriam's Shrew
Spermophilus spilosoma Spotted Ground Squirrel
Spilogale gracilis Western Spotted Skunk
Spilogale putorius Eastern Spotted Skunk
Tadarida brasiliensis Brazilian Free-tailed Bat
Taxidea taxus American badger
Vulpes velox Swift Fox
Zapus hudsonius Meadow Jumping Mouse

Reptile
Acris crepitans Northern Cricket Frog
Apalone mutica mutica Midland Smooth Softshell Turtle
Apalone mutica Smooth Soft-shelled Turtle
Apalone spinifera Spiny Softshell Turtle
Aspidoscelis tesselata Common Checkered Whiptail
Crotalus atrox Western diamondback rattlesnake
Crotalus viridis Prairie Rattlesnake
Heterodon platirhinos Eastern Hog-nosed Snake
Holbrookia maculata Common Lesser Earless Lizard
Hypsiglena jani Chihuahuan Nightsnake

Lampropeltis triangulum Milk Snake
Leptotyphlops dissectus New Mexico Threadsnake
Ophisaurus attenuatus Slender Glass Lizard
Phrynosoma cornutum Texas Horned Lizard
Phrynosoma hernandesi Greater Short-horned Lizard
Phrynosoma modestum Round-tailed Horned Lizard
Plestiodon multivirgat Many-lined Skink
Regina grahamii Graham's Crayfish Snake
Rhinocheilus lecontei Long-nosed Snake
Tantilla nigriceps Plains Black-headed Snake
Terrapene ornata Ornate Box Turtle
Thamnophis elegans Terrestrial Garter Snake
Thamnophis marcianus Checkered Garter Snake
Thamnophis proximus Western Ribbon Snake
Thamnophis radix Plains Gartersnake
Tropidoclonion lineatum Lined Snake

Appendix 3.2 – Pending Species of Greatest Conservation Need that overlap with CHAT crucial habitat, focal, and connectivity zones for the Lesser Prairie-Chicken.

Scientific/Common Name

Bird

Archilochus alexandri Black-chinned Hummingbird
Ardea herodias Great Blue Heron
Bubulcus ibis Cattle Egret
Catherpes mexicanus Canyon Wren
Falco sparverius American Kestrel
Geothlypis trichas Common Yellowthroat
Icterus parisorum Scott's Oriole
Leucophaeus pipixcan Franklin's Gull
Loxia curvirostra Red Crossbill
Oporornis tolmiei MacGillivray's Warbler
Passerina caerulea Blue Grosbeak
Polioptila caerulea Blue-Gray Gnatcatcher
Progne subis Purple Martin
Selasporus rufus Rufous Hummingbird
Thryomanes bewickii Bewick's Wren
Vermivora virginiae Virginia's Warbler
Vireo olivaceus Red-eyed Vireo

Mammal

Myotis yumanensis Yuma Myotis

Reptile

Pseudemys gorzugi Rio Grande Cooter
Sceloporus tristichus Plateau Fence Lizard

Appendix 3.3 – All Species of Greatest Conservation Need (which happen to be all currently listed) that overlap with CHAT crucial habitat, which also share habitat requirements.

Scientific/Common Name

Bird
Aimophila cassinii Cassin's Sparrow
Aimophila ruficeps Rufous-crowned Sparrow
Ammodramus leconteii Le Conte's Sparrow
Ammodramus savannarum Grasshopper Sparrow
Amphispiza belli Sage Sparrow
Anthus spragueii Sprague's Pipit
Bartramia longicauda Upland Sandpiper
Buteo regalis Ferruginous Hawk
Buteo swainsoni Swainson's Hawk
Calamospiza melanocorys Lark Bunting
Calcarius mccownii McCown's Longspur
Calcarius ornatus Chestnut-collared Longspur
Calcarius pictus Smith's Longspur
Calidris melanotos Pectoral Sandpiper
Callipepla squamata Scaled Quail
Charadrius montanus Mountain Plover
Falco mexicanus Prairie Falcon
Numenius americanus Long-billed Curlew
Oreoscoptes montanus Sage Thrasher
Phalaenoptilus nuttallii Common Poorwill
Spiza americana Dickcissel
Spizella pusilla Field Sparrow
Sturnella magna Eastern Meadowlark
Toxostoma curvirostre Curve-billed Thrasher
Tyrannus forficatus Scissor-tailed Flycatcher
Tyto alba Barn Owl
Zonotrichia querula Harris's Sparrow

Mammal
Cynomys ludovicianus Black-tailed Prairie Dog
Geomys bursarius Plains Pocket Gopher
Spermophilus spilosoma Spotted Ground Squirrel
Vulpes velox Swift Fox

Reptile

Crotalus viridis Prairie Rattlesnake
Holbrookia maculata Common Lesser Earless Lizard
Leptotyphlops dissectus New Mexico Threadsnake
Phrynosoma cornutum Texas Horned Lizard
Rhinocheilus lecontei Long-nosed Snake
Tantilla nigriceps Plains Black-headed Snake
Terrapene ornata Ornate Box Turtle
Thamnophis radix Plains Gartersnake
Tropidoclonion lineatum Lined Snake

Appendix 3.4 – All current and pending Species of Greatest Conservation Need that do not overlap with the CHAT.

Scientific/Common Name

Current SGCNS:

Bird

Aegolius funereus Boreal Owl
Aeronautes saxatalis White-throated Swift
Ammodramus henslowii Henslow's Sparrow
Ammodramus nelsoni Nelson's Sharp-tailed Sparrow
Buteo lineatus Red-shouldered Hawk
Centrocercus urophasianus Greater Sage-Grouse
Cinclus mexicanus American dipper
Columba fasciata Band-Tailed Pigeon
Columbina passerina Common Ground-Dove
Contopus cooperi Olive-Sided Flycatcher
Contopus virens Eastern Wood-Pewee
Cygnus buccinator Trumpeter Swan
Cypseloides niger Black Swift
Dendroica discolor Prairie Warbler
Dryocopus pileatus Pileated Woodpecker
Empidonax occidentalis Cordilleran Flycatcher
Histrionicus histrionicus Harlequin Duck
Icterus cucullatus Hooded Oriole
Lagopus leucura White-Tailed Ptarmigan
Leucosticte atrata Black Rosy-Finch
Limosa haemastica Hudsonian Godwit
Micrathene whitneyi Elf Owl
Passerina versicolor Varied Bunting
Phalacrocorax brasilianus Neotropic Cormorant
Picoides dorsalis American Three-toed Woodpecker
Piranga rubra Summer Tanager
Protonotaria citrea Prothonotary Warbler
Rallus elegans King Rail
Scolopax minor American Woodcock
Seiurus motacilla Louisiana Waterthrush
Thryothorus ludovicianus Carolina Wren

Tringa semipalmata Willet
Vermivora pinus Blue-winged Warbler
Vireo flavifrons Yellow-throated Vireo
Vireo griseus White-eyed Vireo

Mammal
Cynomys gunnisoni Gunnison's Prairie Dog
Euderma maculatum Spotted Bat
Gulo gulo Wolverine
Lasiurus blossevillii Western Red Bat
Lepus americanus Snowshoe Hare
Martes americana American Marten
Nyctinomops femorosaccus Pocketed Free-Tailed Bat
Ochotona princeps American Pika
Sorex nanus Dwarf Shrew

Reptile
Agkistrodon contortrix Copperhead
Carphophis vermis Western Worm Snake
Coleonyx brevis Texas Banded Gecko
Crotalus horridus Timber Rattlesnake
Emydoidea blandingii Blanding's Turtle
Graptemys ouachitensis Ouachita Map Turtle
Graptemys pseudogeographica False Map Turtle
Graptemys versa Texas Map Turtle
Macrochelys temminckii Alligator Snapping Turtle
Nerodia harteri Brazos Water Snake
Nerodia paucimaculata Concho Water Snake
Opheodrys vernalis Smooth Greensnake
Plestiodon anthracinus Coal Skink
Plestiodon laticeps Broadhead Skink
Sternotherus carinatus Razor-backed Musk Turtle
Storeria occipitomaculata Red-bellied Snake
Virginia striatula Rough Earthsnake

Pending SGCNS:

Bird
Otus flammeolus Flammulated Owl

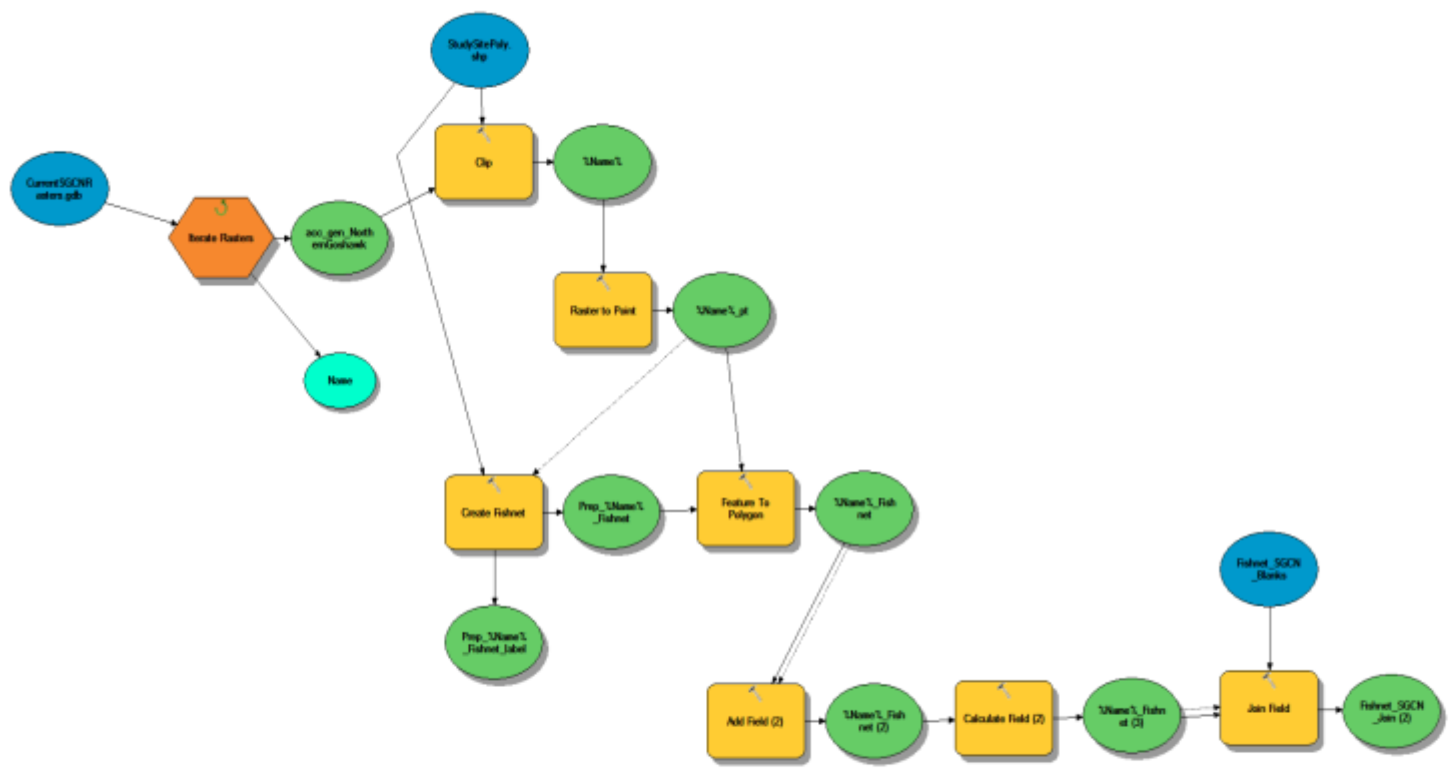
Mammal
Cynomys leucurus White-tailed Prairie Dog

Reptile
Holbrookia lacerata Spot-tailed Earless Lizard

Appendix 3.5 – All model syntaxes are tools created by Dr. Krista Mougey and should be cited accordingly:

Mougey, K. 2017. Model syntax for iterative landscape analyses. pp 114 in D. Gary (author). Examining the southern Great Plains for hotspots of at-risk biodiversity and assessing the efficacy of a decision support tool. Master's Thesis, Texas Tech University, Lubbock Texas.

This syntax transforms rasters into fishnet polygons and was run for current, pending, and combined Species of Greatest Conservation Need (starting geodatabase).



```
# Local variables:
CurrentSGCNRasters_gdb = "D:\\"Your Pathway"\\CurrentSGCNRasters.gdb"
StudySitePoly_shp = "D:\\"Your Pathway"\\StudySitePoly.shp"
Fishnet_SGCN_Blanks = "D:\\"Your
Pathway"\\Weighted_Summary_Files.gdb\\Fishnet_SGCN_Blanks"
v_Name_ = "D:\\"Your Pathway"\\CurrentSGCNFishClipRast.gdb\\%Name%"
v_Name__pt = "D:\\"Your Pathway"\\CurrentSGCNtoPtFish.gdb\\%Name%_pt"
Prep__Name__Fishnet = "D:\\"Your Pathway"\\FishnetCurrentSGCN.gdb\\Prep_%Name%_Fishnet"
v_Name__Fishnet = "D:\\"Your Pathway"\\FishnetCurrentSGCN.gdb\\%Name%_Fishnet"
v_Name__Fishnet__2_ = "D:\\"Your Pathway"\\FishnetCurrentSGCN.gdb\\%Name%_Fishnet"
acc_gen_NorthernGoshawk = "D:\\"Your
Pathway"\\CurrentSGCNRasters.gdb\\Current_WeightedAttribute"
v_Name__Fishnet__3_ = "D:\\"Your Pathway"\\FishnetCurrentSGCN.gdb\\%Name%_Fishnet"

# Process: Iterate Rasters
arcpy.IterateRasters_mb(CurrentSGCNRasters_gdb, "", "", "NOT_RECURSIVE")

# Process: Clip
arcpy.Clip_management(acc_gen_NorthernGoshawk, "-828815.528699999 867891.509600002
-43815.5287000028 2297891.5096", v_Name_, StudySitePoly_shp, "255", "NONE",
"MAINTAIN_EXTENT")

# Process: Raster to Point
arcpy.RasterToPoint_conversion(v_Name_, v_Name__pt, "Value")

# Process: Create Fishnet
arcpy.CreateFishnet_management(Prep__Name__Fishnet, "-828815.528699999
867891.509600002", "-828815.528699999 867901.509600002", "5000", "5000", "", "",
"-43815.5287000028 2297891.5096", "LABELS", StudySitePoly_shp, "POLYGON")

# Process: Feature To Polygon
arcpy.FeatureToPolygon_management("D:\\"Your
Pathway"\\FishnetCurrentSGCN.gdb\\Prep_%Name%_Fishnet", v_Name__Fishnet, "",
"ATTRIBUTES", v_Name__pt)

# Process: Add Field (2)
arcpy.AddField_management(v_Name__Fishnet, "%Name%", "SHORT", "", "", "", "",
"NULLABLE", "NON_REQUIRED", "")

# Process: Calculate Field (2)
arcpy.CalculateField_management(v_Name__Fishnet__2_, "%Name%", "!GRID_CODE!", "PYTHON",
"")

# Process: Join Field
arcpy.JoinField_management(Fishnet_SGCN_Blanks, "pointid", v_Name__Fishnet__3_,
"POINTID", "%Name%")
```