Does Pennsylvania possess suitable habitat to support gray wolves for the purpose of regulating white-tailed deer to improve forest productivity?

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Submitted in fulfillment of the senior thesis requirements of the Department of Environmental Science at Allegheny College and approved by the senior thesis committee.

Chris Shaffer	5/7/15		5/7/15
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Abstract

Prior to European settlement, white-tailed deer and gray wolves were two of the most prevalent wildlife species found in Pennsylvania during the 1800s. However, deer populations were diminished by the end of the 1800s because they were a vital resource and wolves, like other predators, were purposely extirpated through lethal control methods by the 1930s because they were deemed a major threat. Since then, deer populations have increased rapidly due to wildlife regulations established by the Pennsylvania Game Commission and today they are overabundant. Contrarily, wolf populations were never granted the opportunity to rebound. Consequently, the lack of natural predators, such as the gray wolf, has allowed deer populations to reach all-time highs and cause detrimental impacts to both forest ecosystems and humans. Currently, due to recent reintroduction programs, some wolf populations thrive in the conterminous United States within areas considered to be part of their historical range and their presence is extremely beneficial. In this study, geographic information systems (GIS) were utilized to determine if Pennsylvania possesses potential suitable habitat for wolf reintroduction. This study utilized key information from research compiled on existing wolf populations in the contiguous United States, in conjunction with successfully-proven management and reintroduction plans to identify habitat within the Commonwealth. Key variables used in this habitat suitability analysis included land cover, distance to protected lands, road density, human population density, deer harvest, distance to water sources and elevation. The results generated in this analysis show that gray wolves could potentially inhabit some ranges in Pennsylvania if reintroduced.

Introduction

White-tailed deer (*Odocoileus virginianus*) are Pennsylvania's official state mammal and plays an extremely influential role in forest ecosystems. White-tailed deer are hoofed animals, classified as ungulates, which belong to the Family Cervidae. During the nineteenth and twentieth centuries, the history of deer-human interaction in Pennsylvania began with overexploitation of deer through non-existent hunting regulations, succeeded with overprotection and population increase, and ended with significant habitat destruction caused by overbrowsing (White-tailed Deer Plan, 2013). Before European settlement occurred in the 1800s, white-tailed deer roamed the state of Pennsylvania and Native Americans were the only humans that inhabited the same area. With minimal resources to ensure survival, they depended on deer as a source of food, clothing, shelter and goods for trading. During this time period, deer were in the proper balance with their forest habitat, ranging from nearly 8 to 10 deer per mi2, and their populations were regulated by large predators, such as gray wolves (*Canis lupus*) and cougars (*Puma concolor*), and Native Americans (PA DCNR - White-tailed Deer, 2001). However, when Europeans arrived, they also depended on deer for survival. Consequently, white-tailed deer populations drastically reduced by the end of the nineteenth centruy due to large-scale hunting to supply the country's growing population with resources and a lack of enforcement of wildlife regulations (Julian and Smith, 2001).

In response to the annihilation of the once populous white-tailed deer population, the Pennsylvania Game Commission (PGC) was founded in 1895 to protect and restore the state's wildlife and wildlife resources (Julian and Smith, 2001). In an effort to reestablish the deer population, the PGC carried out various tasks. The commission established "game lands" to help revitalize wildlife populations, transported deer from other states to restock Pennsylvania, and

enacted a law that prohibited the killing of does (female or "antlerless" deer) (Julian and Smith, 2001). During the 1800s when European settlement began, most of the state's forests had been cleared to produce lumber and grow crops. However, a large proportion of that cleared forested land regenerated by the early twentieth century and new stands of young trees and shrubs began to flourish. This new habitat was critical for the rejuvenated white-tailed deer population because it provided ideal cover and an ample amount of food. Deer were nearly extinct in Pennsylvania by 1900, but populations recovered significantly as protective laws were enforced and areas that had been logged for timber regenerated (Diefenbach et al., 1997). The strategic management actions taken by the PGC to revive the population, combined with the new available forest habitat found in Pennsylvania in the early 1900s, generated optimal conditions for deer (Julian and Smith, 2001). As a result, white-tailed deer populations began to skyrocket in the early 1900s.

From a management standpoint, the PGC was pleased during this time because their initial objectives and goals were met. White-tailed deer once again inhabited Penn's Woods and their population was on the rise. Nonetheless, the PGC soon learned that their actions caused devastation to the forest ecosystems. A few decades after the initial restocking of deer, the total population became too excessive and began causing severe habitat damage across large portions of forests located in the northern range of Pennsylvania (PA DCNR - White-tailed Deer Plan, 2013). This is because deer are "browsers". As a browser, a deer's diet primarily consists of the leaves, twigs, and shoots of young trees, shrubs, and wildflowers that develop in the forest understory (Julian and Smith, 2001). This is problematic when large populations of deer are present in an area because by selectively overbrowsing on young plant and tree species, a forest's

growth is extremely hindered, forest stands are altered and habitat is diminished due to the reduction or elimination of young tree seedlings, shrubs and herbaceous plants (Tilghman, 1989).

Ecologically speaking, a healthy forest has high biological diversity. A forest ecosystem with high biological diversity is comprised of various tree, shrub, flower and wildlife species that are thriving. Various plants and trees are vital to forest ecosystems because they create layers, from the forest floor to the canopy, and each distinct layer is essential for biological diversity because they provide special conditions and niches for different wildlife and plant species (Julian and Smith, 2001). With the white-tail population boom, Pennsylvania's forests have been adversely impacted. Presently, many forests in the Commonwealth appear aesthetically pleasing because they are comprised of large trees and a dense, green forest floor of ferns, but few young trees exist and biodiversity is threatened (Julian and Smith, 2001). However, by the end of the twentieth century and turn of the twenty-first century, as a result of overbrowsing, the forest understory across vast areas of Pennsylvania had been diminished to a group of species that deer typically refrain from consuming. These less-desirable flora species, such as beech, striped maple, hay-scented fern, and mountain laurel, ultimately limit biodiversity because they are not sufficient sources of habitat, cover or food for deer and other wildlife species (PA DCNR - White-tailed Deer Plan, 2013). Although not a true keystone species, it has been well documented that white-tailed deer play a disproportionately large role in how a forest ecosystem functions by browsing. According to Mcshea and Rappole (1992), the influence of white-tailed deer in forest ecosystems expands the concept of "keystone" predator to "keystone species." Selective browsing ultimately causes inadequate forest regeneration, which in turn leads to the loss of biodiversity because the necessary understory to support other wildlife species is

diminished. Additionally, with a considerably reduced understory, deer and other wildlife species cannot successfully thrive because habitat, food and cover sources are essentially non-existent.

Today, the state of Pennsylvania still struggles with an overabundant population of white-tailed deer. Their population is estimated to be between 1.3-1.5 million animals, with an average of 30 deer per mi2 (Pennsylvania Deer News, 2014). This is nearly three times the amount of deer that roamed the land of Pennsylvania prior to European settlement in the1800s. Currently, the PGC's best strategy to regulate the state's deer population is through hunting. Although hunting is the current most effective means of controlling deer populations, restricted access to land by hunters presents a challenge. In urbanized areas, housing development expansion greatly prohibits access to hunt because the forest habitats surrounding these developments are generally in close proximity to residents (Diefenbach et al., 1997). Likewise, posted land in rural areas impedes a hunter's ability to hunt because of trespassing laws on private land.

Despite the fact that hunting is restricted in these areas more often than not, the PGC created the Deer Management Assistance Program (DMAP) in 2003 (PA DCNR - White-tailed Deer Plan, 2013). DMAP was designed to aid landowners whose lands are impacted by overbrowsing or overpopulated by deer (PA DCNR – DMAP, 2015). Essentially, this program grants landowners and hunters the opportunity to apply for additional antlerless deer hunting permits to help manage deer numbers on their property or other site-specific DMAP areas. These specific efforts to balance deer populations have certainly helped enhance forest habitat conditions in many areas of Pennsylvania, but a vast portion of the state's forest ecosystems are still noticeably impacted from decades of overbrowsing. These areas, which experienced extreme overbrowsing pressure, have been left with severely depleted understories that continue to

imperil the overall health of forest ecosystems and numerous wildlife species, and the sustainability of the forests (PA DCNR - White-tailed Deer Plan, 2013).

Although hunting is presently the major strategy utilized to stabilize the deer population, and has had some success, implementing an additional strategy may help to restore the natural balance of the forest ecosystems. In theory, reintroducing a large predator such as the gray wolf (*Canis lupus*) into its historical, native habitat in Pennsylvania could prove to be an efficient tactic to help decrease the excessive white-tailed deer population to a level that is desirable and mitigate overbrowsing. As a keystone species, wolves play a disproportionately large role within their ecosystems, having both direct and indirect effects. In terms of direct effects, wolves help to restore the natural balance of forest ecosystems by preying upon white-tailed deer populations. On the other hand, wolves have the capability of affecting the ecosystems they inhabit indirectly. According to Laundré et al. (2001), when wolves are present, they alter the behavior of prey species such as white-tailed deer. A prime example of this was seen in Yellowstone National Park when wolves were first reintroduced in 1995. Before wolves entered the scene, elk spent long periods of time over-browsing in riparian zones and were able to do so with no repercussions because of the lack of predators. Nevertheless, after gray wolves were released, it was evident that elk were constantly on the move and instinctively seeking cover in order to evade the wolves. In a study that assessed the impacts that Yellowstone wolves had on the ecosystem fifteen years after their release in 1995, the results showed that aspen groves and other plant and tree species began to regenerate due to considerably less browsing by elk and biological diversity drastically increased because numerous wildlife species could now inhabit the regenerated areas (Ripple and Beschta, 2012). It has also been documented that wolves indirectly allow other populations of wildlife species to increase. Biological diversity also

increased because wolves indirectly provide food for various scavenger species and allow fawn and other small mammal populations to increase as a result of predation on coyotes (Berger et al., 2008; Wilmers et al., 2003). As a keystone species, this is a concrete example of how the presence of wolves positively affects forest ecosystems by promoting regeneration and enhancing overall biodiversity.

While hunting can be an effective component of managing white-tailed populations, there is a great reluctance among hunters to kill antlerless deer. For decades, many hunters resisted killing does. Essentially, targeting antlerless deer went against popular tradition because hunters believed it would ultimately reduce next year's buck population and decrease the overall population. Moreover, as seen in Brown et al. (2000), the trajectory of total number of hunters is declining due to social pressures and animal rights campaigning. Furthermore, another influential factor that is contributing to the decline of hunters is the potential risk of disease. According to Vaske and Lyon (2011), some hunters are concerned about the possibility of contracting a disease from the deer they hunt, such as Lyme disease from deer ticks (*Ixodes scapularis*), making fear an additional deterrent. According to Côté (2004), the reintroduction of a major predator is the only feasible approach to affectively get white-tailed deer populations back under control and to a desirable level.

The overall goal of this study was to perform a habitat suitability analysis, using geographic information systems (GIS), for the reintroduction of the gray wolf (*Canis lupus*) into Pennsylvania for the purpose of regulating white-tailed deer populations to improve forest productivity. The overabundant population of white-tailed deer has negatively altered the natural balance of forest ecosystems (Rooney, 2001). Over-browsing by excessive deer populations ultimately hinders forest regeneration because deer selectively consume the seedlings and

saplings of preferred, early successional trees and desirable understory plants (PA DCNR – Bureau of Forestry, 2015). This has detrimental forest ecosystem impacts because selectively over-browsing desirable flora species promotes the growth of undesirable, competing flora species, such as American beech (*Fagus grandifolia*), striped maple (*Acer pensylvanicum*), hay-scented fern (*Dennstaedtia punctilobula*) and New York fern (*Thelypteris noveboracensis*) (PA DCNR – Bureau of Forestry, 2015). These species out-compete desirable species because they possess the ability to tolerate a shady understory and are not typically browsed by deer due to their unpalatable characteristics and lack of nutrients (PA DCNR – Bureau of Forestry, 2015). In addition, invasive plants have the ability to establish and eventually cause adverse effects to the ecosystem because they grow rapidly and suppress the native plant communities (PA DCNR – Bureau of Forestry, 2015). Furthermore, over-browsing essentially decreases overall biodiversity because competing and invasive plant species prohibit the growth of various desirable, native plant species that countless wildlife species heavily rely on for adequate sources of habitat, food and cover. When forest regeneration is hindered due to over-browsing and the subsequent spread of competing and invasive flora species, forest productivity ultimately decreases because numerous valuable, native species are reduced or non-existent. To help address this complex issue involving an overabundance of deer, over-browsing and forest productivity in Pennsylvania, GIS was utilized to identify potential areas of suitable habitat for wolf reintroduction.

Study Area

The geographic location of this study occurs within the state boundaries of Pennsylvania. The "Keystone State" has an area of 116,075 km^2 and an estimated human population of 12,773,801 (United States Census Bureau, 2013). According to Paquet and Carbyn (2003), gray wolves once inhabited the entire state of Pennsylvania before European settlement in the nineteenth century.



Figure 1. Current gray wolf range and historical gray wolf range (Before European settlement occurred in the beginning of the nineteenth century. (Paquet and Carbyn, 2003).

As seen in Figure 1, the gray wolf historically inhabited most of the range in North America, except portions along the coast of California and the southeastern region. Little is known on why gray wolves didn't inhabit these specific areas. However, as a result of European settlement, the wolf was extirpated from most of the contiguous 48 US states by 1930 (USDOJ,

2013, and was subsequently listed as endangered under the Endangered Species Act (ESA) of 1973 (Licht et al., 2010). According to Merritt (1987), the last time a gray wolf existed in the wild in Pennsylvania was in 1892 in Clearfiled County; the disappearance of this species directly relates to humans eradication through means of hunting, trapping, and poisoning. In this analysis, the state boundary was used as a limiting factor for the calculations of the study.

Methods

GIS was utilized to identify potential suitable habitat for gray wolf reintroduction. GIS is a computer-based system that aids in the collection, maintenance, storage, analysis, output, and distribution of spatial data and information (Bolstad, 2002). Essentially, GIS help identify and address environmental problems by providing vital information on where problems occur and who are affected by them (Bolstad, 2002). GIS can be used to identify the source, location, and extent of adverse environmental impacts, and help formulate practical plans for monitoring, managing, and mitigating environmental damage (Bolstad, 2002). A habitat suitability analysis was conducted to identify potential areas of suitable habitat for gray wolves in Pennsylvania based on their habitat and range requirements.

In this study, a raster-based habitat suitability analysis was conducted, using ArcGIS Desktop 10.2.2 software. Raster data models, which are essentially the representation of the world into a regular grid of cells (pixels), are useful for storing data that varies continuously, as in elevation, an aerial photograph or satellite image. To begin the process, spatial data was collected. Secondary sources needed to be accessed in order to collect spatial data because it was not feasible to personally collect all of the necessary data for this study. The study area was too large and resources needed to collect the wide array of variables were inaccessible. Spatial data

(input variables) were acquired from online spatial data repositories, such as the USGS National Map Viewer and Pennsylvania Spatial Data Access. Once the data was acquired, input variables were projected so that they all shared a common coordinate system. If the different layers had different coordinate systems, map overlay wouldn't work correctly because different spatial references don't align properly, ultimately causing map overlay problems. For this particular study region, the Lambert Conformal Conic - NAD 1983 (meters) coordinate system was most appropriate because this spatial reference was a perfect match for all of the spatial data that was utilized.

Table 1. Data Dictionary of Spatial Data (secondary sources). List of different input criteria and a description of why each is important.

Input Criteria	**Originator**	**Date**	**Data Model**	**Justification**
Antler-less Deer Harvest	Pennsylvania Game Commission	2012	Vector	Deer would be the primary prey base for wolves
Elevation	U.S. Geological Survey	2006	Raster	Wolves have shown to prefer lower elevations
Human Population Density	U.S. Census Bureau	2010	Vector	Wolf-human interaction can be dangerous
Land Cover	U.S. Geological Survey	2011	Raster	Wolves prefer to live in forest habitats
Distance to Protected Lands	The Conservation Fund	2004	Vector	Wolves are generally safe in this areas
Distance to Roads	Pennsylvania Department of Transportation	2015	Vector	Roads are dangerous barriers that can lead to death
Distance to Water Sources	U.S. Geological Survey	2004	Vector	Wolf dens are located near water sources to support pups

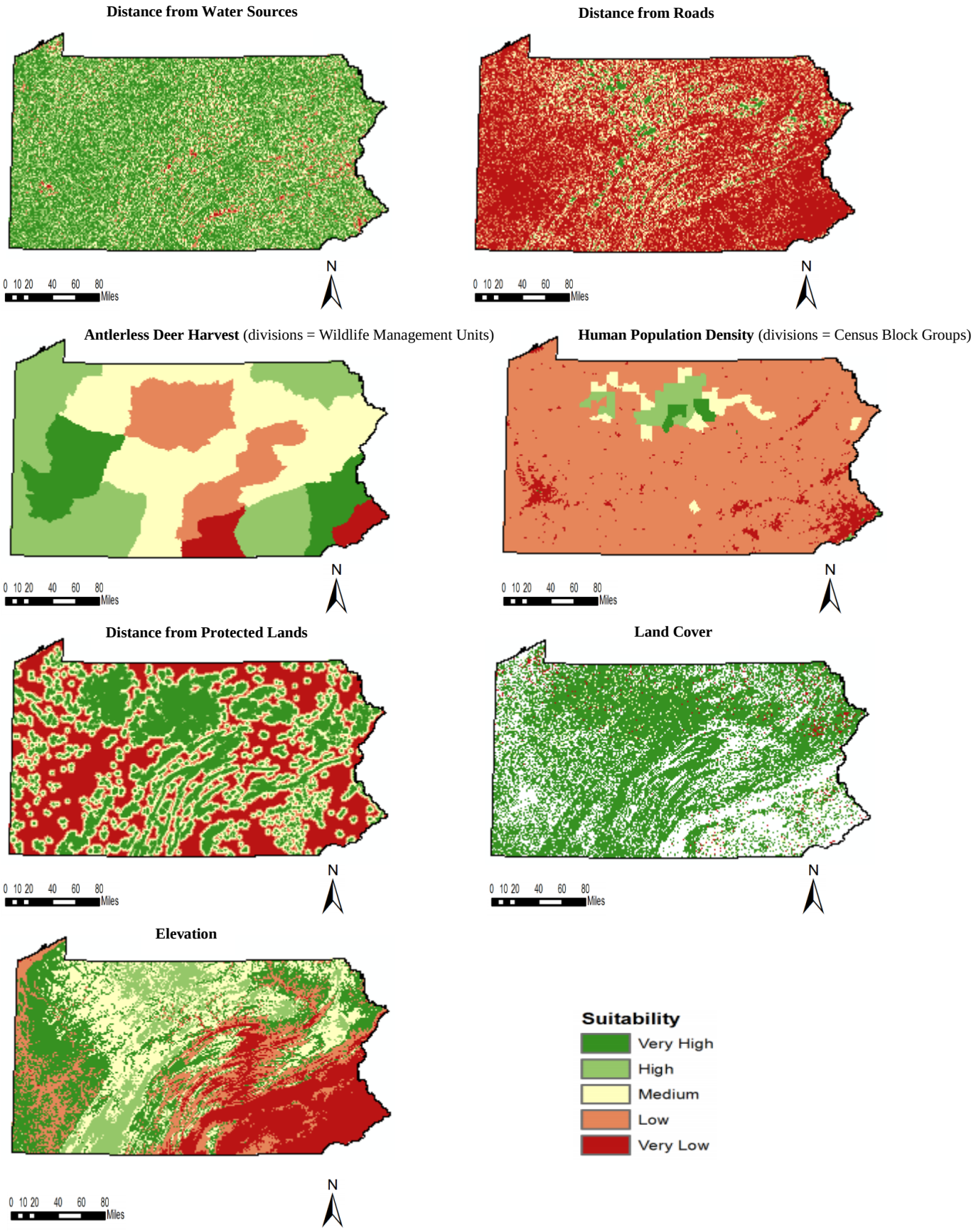

Figure 2. Maps of input criteria after they have been reclassified to share a common scale. The white portions in the land cover map indicate NoData (Null value). Map scale= 1:7,000,000

Drawing upon research pertaining to existing wolf populations that currently thrive in some areas of the contiguous United States, a set of criteria was generated based on each of the input variables. The first step involved ranking each input criteria on a common scale. Variables needed to be ranked on a common scale because it is not possible to combine them in their present form without reclassifying them. The common scale consisted of a 1-5 rank, with 1 being the worst and 5 the best.

Land Cover Type

Gray wolves are considered habitat generalists because they have the ability to thrive in essentially any habitat. For instance, wolves can live in tundra plains, deserts, prairies, or forests. However, according to Harrison and Chapin (1998), areas consisting of contiguous land dominated with heavy forest cover tend to be the most successful habitats. Based off of this rationale, a rank of 5 was assigned to mixed, evergreen, and deciduous forests. Due to the types of land cover that exist within Pennsylvania, a rank of 4 was non-existent. A rank of 3 was assigned to shrub, scrub, woody wetlands, and emergent herbaceous wetlands. These land cover types were ranked as a 3 because they could potentially be inhabited, but they were not preferable or desirable when compared to forested areas. Similar to a rank of 4, a rank of 2 was

also non-existent because the land cover types that are present in Pennsylvania considerably vary and multiple types tend to be categorized in the same class. A rank of 1 was assigned to barren land, hay, pasture and cultivated crops. These types of land cover were deemed as the worst because they are generally associated with agricultural and livestock development by humans. Land cover type was the only input variable that contained a rank of 0. Open water and developed land were assigned a 0, meaning totally restricted, because wolves can absolutely not inhabit these areas.

Distance from Protected Lands

Public protected lands are critical to the survival of wolves because wolves typically can't be killed in these areas. Notable types of protected lands that are ideal for wolves to inhabit are national parks, such as Yellowstone, national forests, and state forests. Based off of this rationale, a distance of 0-0.5 miles from these areas was assigned a rank of 5. This distance range was assigned a 5 because 0 miles from protected lands means that wolves are on protected lands and 0.5 miles from protected lands is extremely close. A rank of 4 was assigned to distances ranging from 0.51 miles-1 mile. This distance range was assigned a 4 because although it wasn't the most desirable distance, it was close enough in proximity to protected lands where wolves could effortlessly make their way back. A rank of 3 was assigned to distances ranging from 1.1 mile- 2 miles. This range was assigned a 3 because it is a short distance for wolves to travel, but the presence of humans living in this proximity from protected lands could be an issue. A rank of 2 was assigned to distances ranging from 2.1-3 miles. This range was assigned a 2 because although it is a considerably short distance for wolves to travel, the presence of humans is likely to increase. A rank of 1 was assigned to distances ranging from 3 miles or more. Once again,

although wolves can easily cover this distance in a single day, this range was assigned a 1 because the presence of humans greatly increases.

Distance from Roads

The presence of roads can be extremely detrimental to the survival of wolves because motor vehicle collisions can occur and roads can grant humans easy access to wolf habitat. In a study that assessed the relationship between wolves and human constructions, Kaartinen et al. (2005) found that wolves generally avoided areas <= 250 m from roads. In a study that assessed the relationship between wolves and distance from roads in the Yellowstone to Yukon region, Craighead (2002) reported that travel routes by wolves were less likely to be located within 500 m of year-round paved roads. In a study that looked at the relationship between wolf den and rendezvous sites, and distance to roads, the results indicated that the mean distance to roads from den sites and rendezvous sites was 1,562 m and 1,296 m respectively (Unger et al., 2009). In addition, in a study assessing human impact on wolf activity, Theeurkauf et al. (2007) found that wolves on average stayed 500 – 1,500 m from roads.

When considering the results from these studies, a distance from roads range of 1,501+ m was assigned a rank of 5. A rank of 5 was assigned for this specific range because critical den sites are commonly established more than 1,500 m from roads. A rank of 4 in this study was assigned a range of 1,001-1,500 m from roads. A 4 was selected for this specific range because critical rendezvous sites are commonly established more than 1,000 m from roads. A rank of 3 was assigned for a range of 501-1,000 m from roads. A 3 was chosen for this specific range because literature suggests that wolves are often found to be within the lowest tier of this range. A rank of 2 was assigned a range of 251-500 m from roads. A rank of 2 was assigned for this

specific range because it has been documented that wolves are less likely to be within 500 m of paved roads. A rank of 1 was assigned a range of 0-250 m from roads. A rank of 1 was designated for this specific range because literature has shown that wolves generally avoid this close of a distance from roads. A rank of 5 and 4 were deemed to be good indicators of the relationship between wolves and distance to roads because wolves spend the majority of the year at den and rendezvous sites.

Distance from Water Sources

In order to successfully thrive, wolves absolutely need a source of water. According to the Wisconsin Department of Natural Resources (2006), pack leaders instinctively select den sites that are within close proximity to water sources. According to the Wisconsin Department of Natural Resources (2006), water sources are often located within approximately 100-200 meters of den sites because that is the maximum distance that wolf pups can physically travel. Nevertheless, it should be noted that this specific distance does not apply to more mature or adult wolves because they are highly mobile and are capable of traveling up to approximately forty-eight km per day (United States Fish and Wildlife Service, 2007).

In this study, a rank of 5 was assigned to a distance range of 0-50 meters within a water source because it is a considerably short distance for pups to travel in regard to their full potential. A rank of 4 was assigned to a distance range of 51-100 meters because it is about half the distance that young pups are capable of traveling. A rank of 3 was assigned a distance range of 101-200 meters because the upper tier of this range is considered to be the maximum distance that pups can travel for water. A rank of 2 was assigned a distance range of 201-500 meters because although wolf pups may not be able to travel as far as 500 meters, it has been

documented that dens have been constructed up to 500 meters from a water source, but not any further (Paquet and Carbyn, 2003). A rank of 1 was assigned to distances that exceeded 500 meters away from water sources because pup survival is in serious jeopardy at these distances.

Prey Density Requirements

Like water, in order to successfully thrive, it is essential that wolves have access to prey for food. "On average, each wolf can consume approximately 15-18 deer annually as seen in Mech, 1997 and Fuller, 1995" (Michigan Gray Wolf Recovery Team, 1997). This number was derived from wolves that rely on deer as their major prey base, so the value of 15-18 deer is a solid approximation for the rate of deer consumption in potential wolf packs in Pennsylvania. "White-tailed deer are the most prevalent ungulate and are said to be the keystone species in the state of Pennsylvania so it is reasonable to assume that they would be the most prevalent part of the wolves' diet" (Pennsylvania Game Commission, 2008). In this study, the deer harvest variable was comprised of antlerless deer kills per wildlife management unit (WMU). Antlerless deer kills per WMU were utilized to get at the prey base in Pennsylvania because it has been well documented that predators, like wolves, kill most deer during their first summer from the time they are born to approximately 12 weeks of age (Pennsylvania Game Commission, 2010).

Based on this rationale, a rank of 5 was assigned to 12,900 + antlerless deer kills per WMU because this range was considered to be optimal. A rank of 4 was assigned to a range of 7,700-12,899 antlerless deer kills because this specific range was deemed as a sufficient prey base. A rank of 3 was assigned to a range of 6,100-7,699 kills because this specific range was determined to be average. A rank of 2 was assigned to a range of 3,800-6,099 kills because this specific range was determined to be below average. A rank of 1 was assigned to a range of

3,600-3,799 kills because this specific range was determined to be insufficient to support a thriving wolf population.

Human Population Density

In the northern region of the United States, it has been documented that potential core wolf habitat is characterized as areas with less than four humans per km2 (Harrison and Chapin, 1998). Likewise, this figure was identical to the results of a study that aimed to determine the feasibility of wolf reintroduction to the Adirondack Park in New York (Paquet et al., 1999). Dispersal habitat is classified as areas which animals use to travel from one area of high suitability to another region of high suitability. According to Wydeven, Fuller, Weber, and MacDonald (1998), potential dispersal habitat, based on studies of wolves in the western Great Lakes region, was classified as areas with ten humans or less per km2.

In this study, a rank of 5 was assigned to human population densities of 0-3 per km2. This specific range was determined to be ranked a 5 because results from numerous studies regarding core wolf habitat and human population densities support this. A rank of 4 was assigned to human population densities of 4-7 per km2 because according to supporting literature, this specific range is literally in between the highest amount of what is defined as core and dispersal habitat. A rank of 3 was assigned an 8-10 human population density per km2. This range was ranked a 3 on the suitability scale because the upper tier of this specific range constitutes the highest amount of human density per km2 that has been classified as dispersal habitat. A rank of 2 was assigned an 11-1,000 human population density range per km2. This specific range was ranked a 2 because it is extremely unlikely for wolves to thrive in this

populated of an area. A rank of 1 was assigned a human population density range of 1,001 + because it is essentially impossible for wolves to survive in this type of environment.

Elevation

Wolves typically inhabit areas with low elevation (Paquet et al., 1999). This is particularly true in winter months. It has been documented that wolves usually refrain from utilizing slopes more than 45 degrees because their mobility is extremely hindered due to high snow depths (Paquet et al., 1999). Since elevation and slope go hand-in-hand, evidence from existing literature supports the fact that wolves tend to prefer areas of low elevation. In addition, it is important to note that Pennsylvania has an average elevation of 1,100 feet (Pennsylvania Geography, 2001).

In this study, a rank of 5 was assigned an elevation range of 0-699 feet because wolves prefer to inhabit relatively flat areas and these areas are prevalent in this specific range. A rank of 4 was assigned a range of 700-1,102 feet because the upper tier of this specific range is the average elevation in Pennsylvania and the slope is less than 45 degrees. A rank of 3 was assigned a range of 1,103-1,473 feet because slopes are roughly 45 degrees. A rank of 2 was assigned to a range of 1,474-1,900 feet because the upper tier of this specific range is slightly above the average elevation in Pennsylvania and slopes in this range exceed 45 degrees. A rank of 1 was assigned to a range of 1,901-3,212 feet because this specific range is essentially the opposite of flat terrain and slopes considerably surpass 45 degrees.

Table 2. Rankings and descriptions of input variables. Justifications for different rankings among the different criteria were based on existing scientific literature regarding gray wolves.

Rank	Land cover type	Distance from Protected Lands (miles)	Distance from Roads (meters)	Distance from water (meters)	A/L Deer Kills per WMU zones	Human population density (per km2)	Elevation (ft)
5 (Best)	Mixed, Evergreen, and Deciduous Forests	0 – 0.5	1,501 +	0 – 50	12,900 +	0 – 3	0 - 699
4	X	0.51 – 1	1,001 – 1,500	51 - 100	7,700 - 12,899	4 – 7	700 – 1,102
3	Shrub, Scrub, Woody wetlands, Emergent herbaceous wetlands	1.1 – 2	501 – 1,000	101 - 200	6,100 – 7,699	8 – 10	1,103 – 1,473
2	X	2.1 - 3	251 – 500	201 - 500	3,800 - 6099	11 – 1,000	1,474 – 1,900
1 (Worst)	Woody welands, Emergent herbaceous wetlands	3 +	0 - 250	501 +	3,600 – 3,799	1,001 +	1,901 – 3,212
<Null>	Open water, Developed land, Barren land, Hay/pasture, Cultivated crops						

The next step in this study involved assigning each input variable a weight based on perceived influence. In this study, land cover type and distance to protected lands were weighted the most based on relative importance and both were equal in value at 20%. Land cover type was considered to be the most important variable because dense, contiguous forest lands are classified as optimal wolf habitat. Likewise, distance to protected lands was also considered to be the most important variable because the largest contiguous patches of forest lands are located in these areas, and human population and road densities are significantly low in these areas when

compared to the rest of the state. The variable that received the second highest weighted value was road density. Weighted at 17%, the road density variable was critical because wolves can't successfully thrive in areas with high road densities due to human access. The variable that received the third highest weighted value was human population density. Weighted at 14%, human population density was vital when determining potential suitable habitat for wolf reintroduction because past centuries have demonstrated that wolves and humans haven't exactly co-existed peacefully. Humans ultimately eradicated gray wolves because they believed that wolves were ferocious killing machines that put their lives at risk, caused substantial economic losses due to predation on livestock and competed with them for white-tailed deer and the resources that they had to offer. The antlerless deer kills per WMU variable received the fourth highest weight, with a value of 11%. Although Pennsylvania currently has an overabundant white-tailed deer population, this variable was perceived to be more valuable than both elevation and distance to water sources because water sources can be found virtually everywhere in Pennsylvania and elevation doesn't limit a potential suitable area if the aforementioned variables are present. As previously mentioned, distance to water sources and elevation were weighted the least based on relative importance and both received a value of 9%.

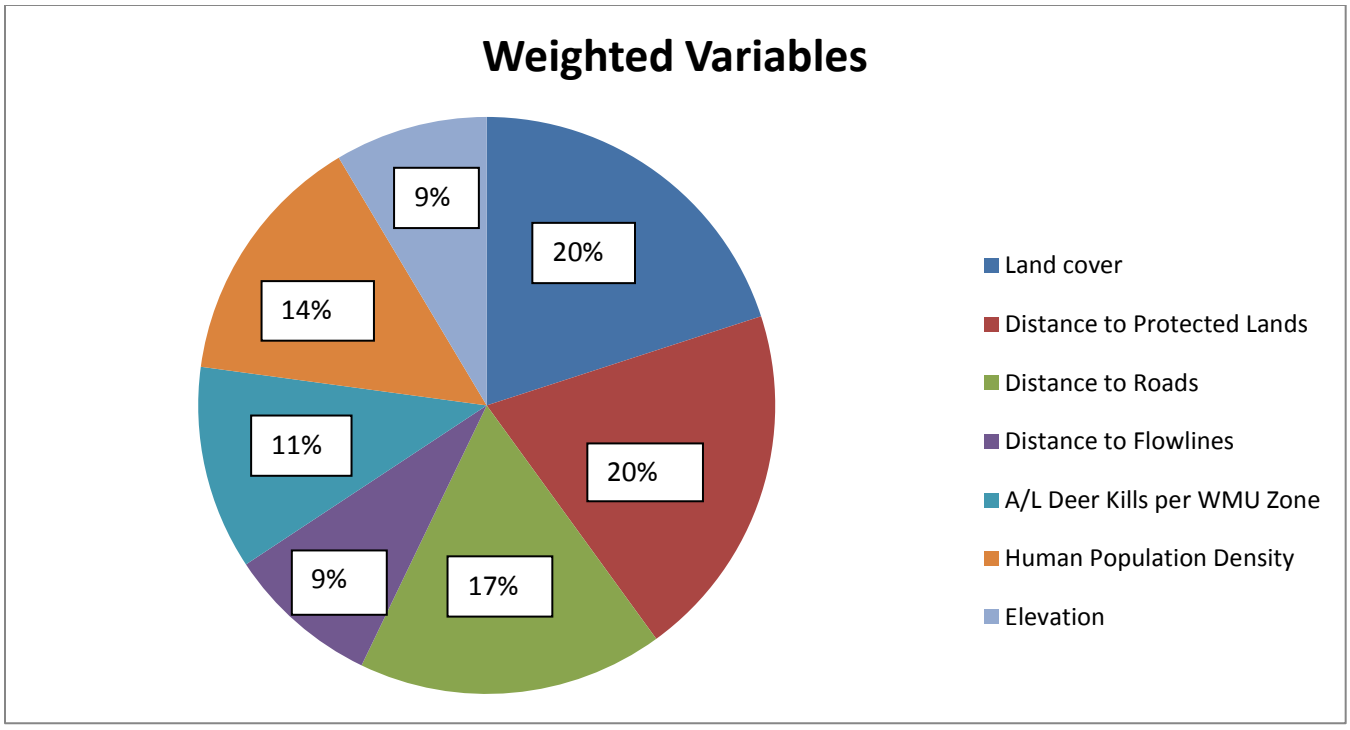

Figure 3. Weights of Input Variables based on Perceived Importance

Once all of the input variables were ranked on a common scale and applied a weighted value based on perceived influence, the final step in the process involved compiling all of the input variables into one map through map overlay.

Results

Based on the habitat requirements identified in the aforementioned research of existing and reintroduced wolf packs highlighted in this study, the calculations in Pennsylvania determined that suitable land exists for gray wolf reintroduction. According to the calculations generated through GIS, three of the largest areas deemed suitable are the Allegheny National Forest, Susquehannock State Forest, and Sproul State Forest. These three prioritized areas were selected because they represented the largest areas in the state that were dominated by a high and

very high suitability rank (Figure 4). In addition, these sites were deemed to be ideal for reintroduction because they are owned by federal and state agencies; the majority of areas that wolves have been reintroduced to in the contiguous United States are owned and managed by federal and state agencies.

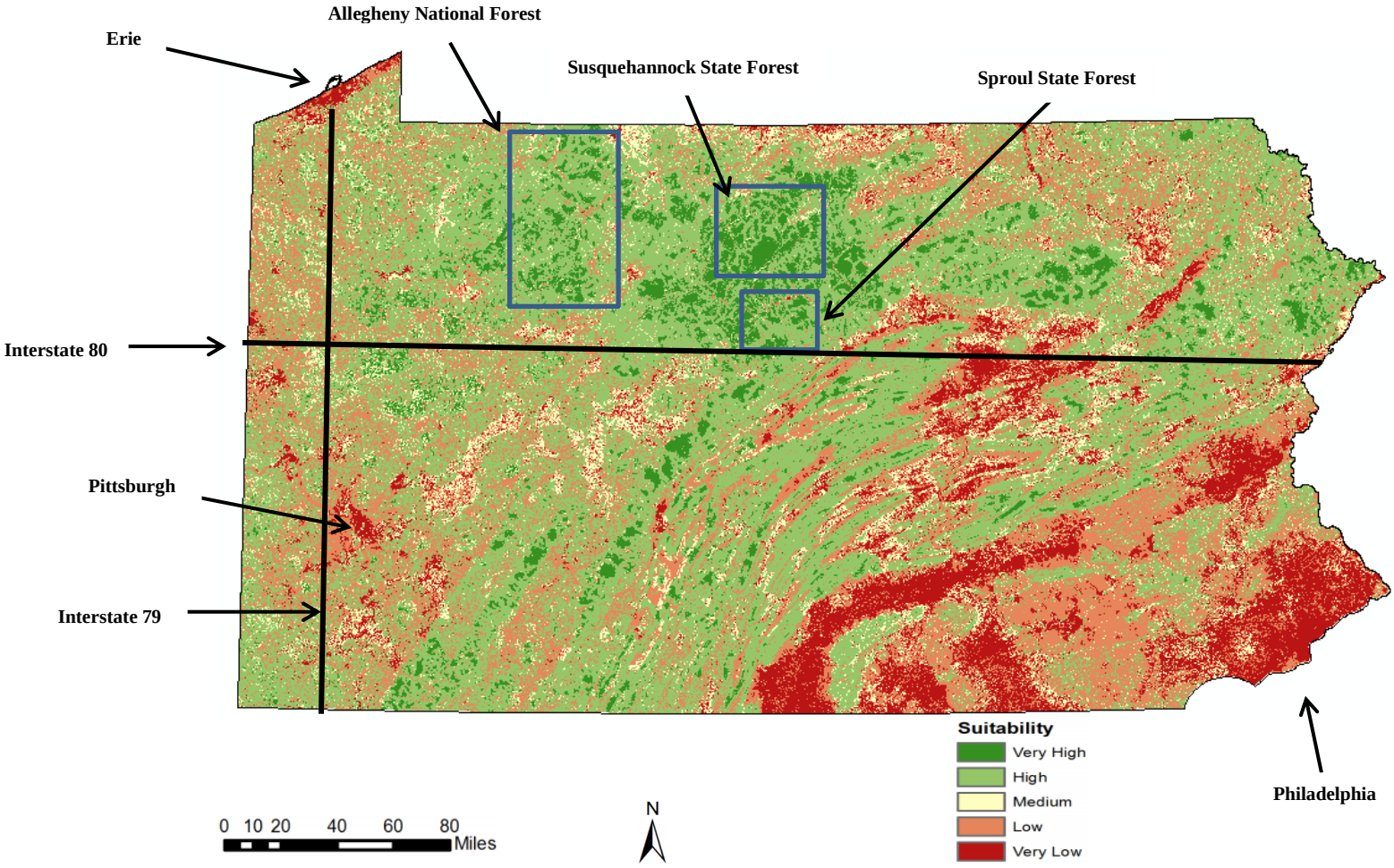

Figure 4. Final Habitat Suitability Map (Unequal Weights) - Map scale= 1:2,000,000

Table 3. Classification of land by percent (%) in Pennsylvania for wolf reintroduction

Very High	(Rank = 5)	6%
High	(Rank = 4)	18%
Medium	(Rank = 3)	5%
Low	(Rank = 2)	30%
Very Low	(Rank = 1)	41%

One potential site for reintroduction is the Allegheny National Forest. This potential site has a total area of 1,777.58 km^2. Of this total area, a high suitability score (Rank = 4) and very high suitability score (Rank = 5) make up 67.56% and 27.64% respectively.

Table 4. Classification of land for Allegheny National Forest (km^2)

Total area	1,777.58 km^2
Rank 4 & 5	1,692.25 km^2
Rank 5 (Very High)	491.32 km^2

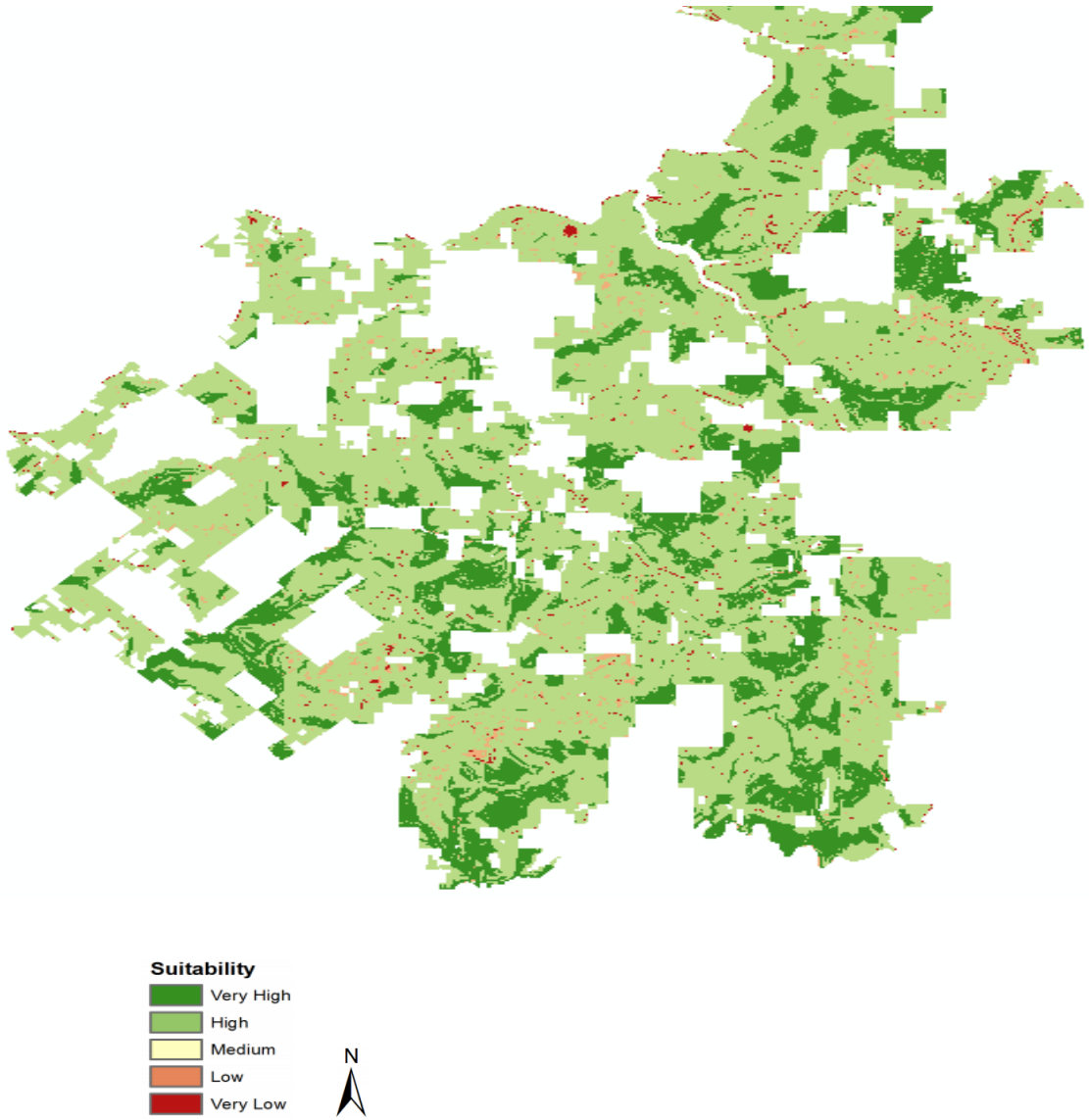

Figure 7. Allegheny National Forest - Map scale= 1:500,000

The Susquehannock State Forest is another prioritized site. This potential site has a total area of 903.27 km^2. Of this total area, a high suitability score (4) and very high suitability score (5) make up 53.60% and 45.42% respectively.

Table 5. Classification of land for Susquehannock State Forest (km^2)

Total area	903.27 km^2
Rank 4 & 5	894.42 km^2
Rank 5 (Very High)	410.27 km^2

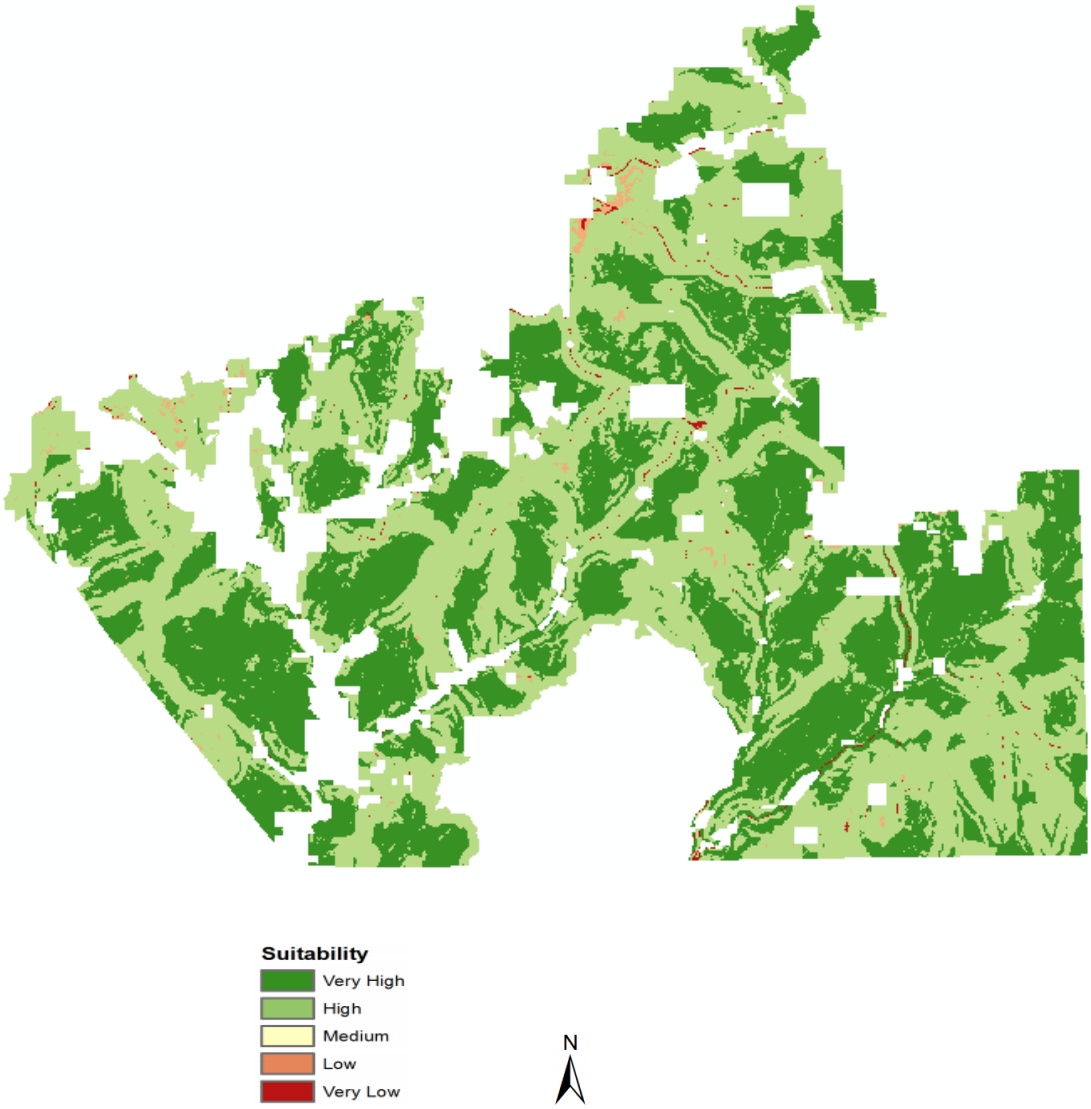

Figure 8. Susquehannock State Forest - Map scale= 1:300,000

A third prioritized site is the Sproul State Forest. This potential site has a total area of 481.51 km^2. Of this total area, a high suitability score (4) and very high suitability score (5) make up 51.71% and 47.49% respectively.

Table 6. Classification of land for Sproul State Forest (km^2)

Total area	481.51 km^2
Rank 4 & 5	477.69 km^2
Rank 5 (Very High)	228.70 km^2

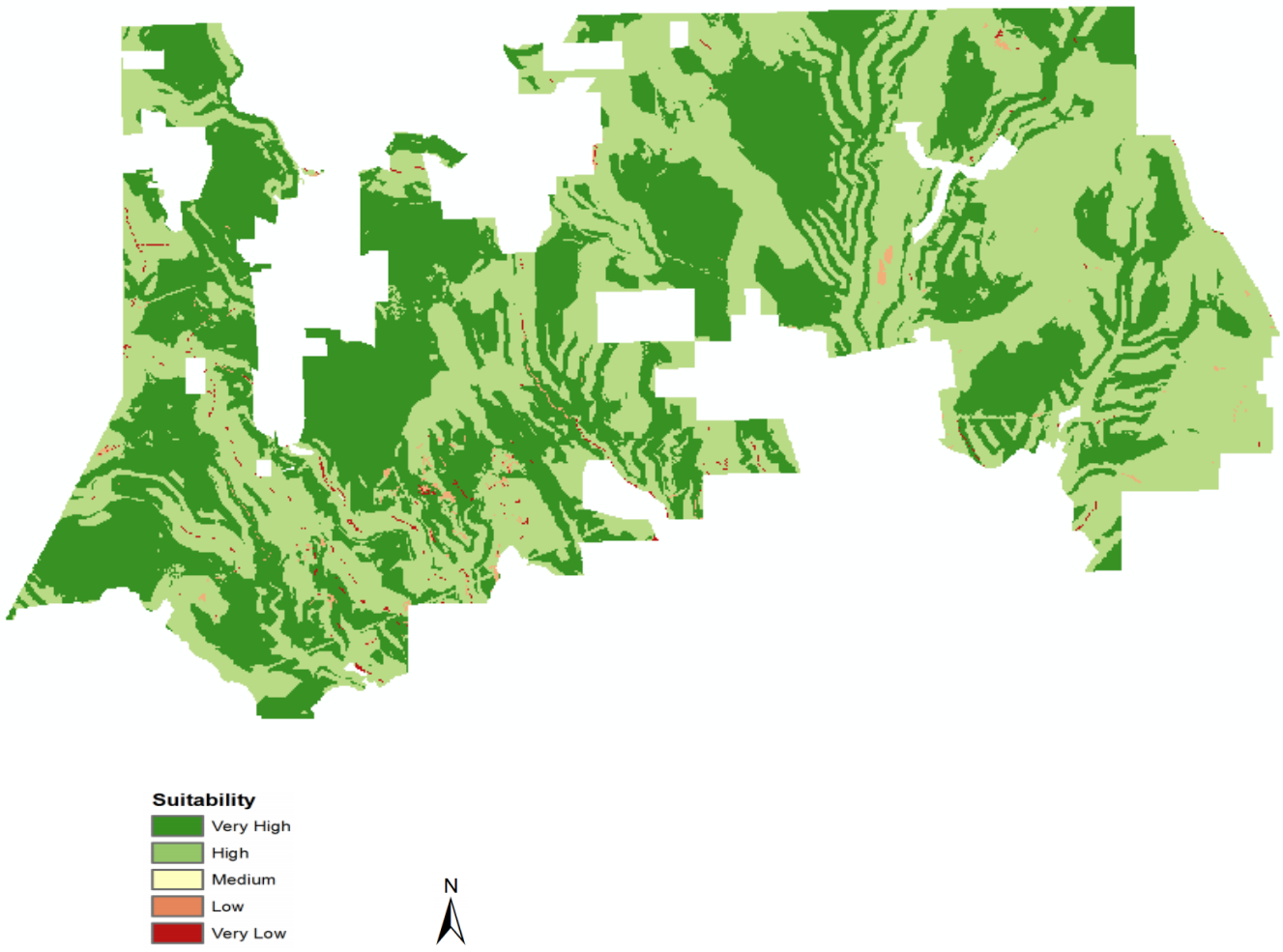

Figure 9. Sproul State Forest - Map scale= 1:200,000

Discussion

A wolf pack is comprised of at least two wolves that travel together and are capable of breeding (Michigan Gray Wolf Recovery Team, 1997). Each wolf requires approximately twenty-five km^2 of suitable contiguous habitat to thrive based on the statistic of approximately 4.1 wolves per 100 km^2 that was documented in Minnesota (Erb, 2008). Based on this calculation, a wolf pack consisting of two wolves requires at least a range of approximately fifty km^2 of contiguous habitat.

Based on this distribution of land among the different scale rankings, Pennsylvania has a grand total of 27,080.8128 km^2 when the high and very high suitability score are combined. Theoretically, this land could support approximately 1,083 gray wolves. When solely considering the land that's classified as very high suitability (7,312.6152 km^2), approximately 292 wolves could inhabit the area. However, these numbers are considerably skewed because a significant portion of the total km^2 that ranked as high and very high are in areas that are relatively close to high human population density and major highways. A much more realistic estimate of total number of wolves able to be reintroduced in Pennsylvania can be derived when focusing on prioritized public areas that possess contiguous land dominated by forest cover.

The first prioritized site identified using GIS was the Sproul State Forest. This area was deemed the best potential site for reintroduction because it is the most contiguous and it is essentially dominated by a rank of 4 and 5. Based on the parameter of one wolf per 25 km^2, approximately 9 wolves could be reintroduced into the Sproul State Forest. The second prioritized site was the Susquehannock State Forest. This area was deemed the second best potential site for wolf reintroduction because it is considerably contiguous and it is primarily

dominated by a rank of 4 and 5. Based on the parameter of one wolf per 25 km^2, approximately 16 wolves could be reintroduced into the Susquehannock State Forest. The third best prioritized site was the Allegheny National Forest. This area was deemed the third best because although it contains the most land compared and is primarily dominated by a rank of 4 and 5, the area is not very contiguous. Numerous private inholdings within the area are the main reason why contiguous land is minimal. Based on the parameter of one wolf per 25 km^2, approximately 19 wolves could be reintroduced into the Allegheny National Forest. In this study, the number of wolves that could potentially inhabit these areas is based off of how much land was comprised of the highest suitability rank of 5.

The results of this habitat suitability analysis show that Pennsylvania possesses suitable habitat that gray wolves could potentially inhabit if reintroduced. Areas near cities or high population and areas with high road densities all showed as the least favorable type of habitat while many areas owned by state and federal agencies with dense forests ranked among the highest. Based on the outcome of the results, the Allegheny National Forest, as well as the large conglomerate of State Parks East of the National Forest, most notably the Susquehannock and Sproul State Forests, show that suitable habitat for potential wolf reintroduction exists. In addition, the results indicate that land in between the Allegheny National Forest and Susquehannock State Forest could potentially be used as a habitat corridor connecting one area of high suitability to another area of high suitability.

On the other side of the spectrum, the results of this analysis tend to keep some things unnoticed when simply looking at the final map with its color-coded suitability scale. For instance, when solely analyzing the map through visual inspection, it is difficult to determine the true impacts of excessive overbrowsing by deer on forest regeneration and verify the true

conditions of the current forest ecosystems. However, according to the Pennsylvania Department of Conservation and Natural Resources (DCNR), recent federal data reveals that only fifty percent (50%) of forest plots studied in northern Pennsylvania has sufficient new growth to replace the existing forests (PA DCNR - White-tailed Deer Plan, 2013). If wolves are reintroduced into the Susquehannock and Sproul State Forests located in the northern portion of Pennsylvania, they can help to enhance forest productivity. For example, in a study that aimed to determine the impacts of wolf reintroduction to Yellowstone National Park's forest ecosystems fifteen years after wolves were released in 1995, Ripple and Beschta (2012) found that wolves improved forest productivity by allowing woody browse species to regenerate and canopy cover to increase. This was made possible because in a system with three trophic levels involving predators, prey and plants, predators can indirectly promote forest regeneration by influencing prey behavior and density (Strong and Frank, 2010). When wolves are present, overbrowsing by ungulate species is significantly reduced because wolves regulate their populations through predation and alter their behavior by inflicting fear and forcing them to run. Fear of predation by wolves is a critical component that helps to improve forest regeneration because deer and elk spend less time browsing and more time seeking cover.

Another key factor that is difficult to assess by simply looking at the final suitability map is whether or not wildlife corridors exist. In order for wolves to be able to thrive successfully, they must have access to wildlife corridors. Wildlife corridors are extremely vital because wolves utilize these smaller contiguous patches of suitable habitat to travel from one area of high suitability to another area of high suitability. Without corridors, the overall health of a wolf population can be in serious jeopardy. For instance, the risk of inbreeding increases because wolves can't successfully travel to find a mate. Inbreeding is detrimental to the overall health and

fitness of a wolf population because the lack of genetic variation causes genetic mutations and makes the population more susceptible to diseases. Furthermore, corridors are critical for survival because if wolves find themselves in an area that doesn't possess sufficient habitat, food and water resources, they can travel through these corridors to other areas that do possess these necessary resources.

The presence of wildlife corridors largely depends on the absence of barriers. Large-scale, natural and man-made barriers, such as rivers and major interstates, hinder the dispersing capability of gray wolves because they are typically difficult and dangerous to travel through. Barriers like major interstates are difficult to travel through because they are comprised of numerous lanes and dangerous because the risk of a wolf-vehicle collision is high. Likewise, big rivers are difficult to travel through due to relatively fast-flowing currents and dangerous because wolves can potentially be swept away or drown.

In terms of appliance and limitations of the results, there are certainly topics that need to be addressed. First and foremost, the representation, accuracy, and scale of some of the input data utilized in this study can be called into question. For instance, this study was a raster-based habitat suitability analysis that ultimately generated results within Pennsylvania in the form of pixels. This is a limitation because although suitable areas of habitat were identified, it is nonsensical to think that wolves will follow and respect pixel boundaries if reintroduced. This is just not feasible because they will ultimately go wherever they please.

Another prime example regarding a notable limitation of the representation of the results involves habitat corridors. When merely observing the final map, the northcentral region of the state appears to have a potential corridor connecting the Allegheny National Forest and the

Susquehannock State Forest. Nevertheless, although this may be true, it is worth noting that the West Branch Susquehanna River might actually prohibit wolves living in the Susquehannock State Forest from dispersing to the Sproul State Forest and vice versa if reintroduced.

Furthermore, there are limitations regarding the accuracy of the results. One example involves the antlerless deer harvest input variable. Although it is well documented that white-tailed deer populations are overabundant in Pennsylvania today, this particular deer data is biased and surely not the most accurate because it doesn't account for the total number of deer. On the other hand, possibly the biggest limitation regarding the accuracy of the results involves the total amount of land in an area considered to be very high suitability and how much of that land is actually contiguous. For instance, this is an obvious limitation because although a very high suitability rank of 5 in the Sproul State Forest comprises nearly 50% of the total area, that land is scattered in different patches and is not truly contiguous.

Despite this apparent limitation, it is essential to highlight that a much more realistic interpretation of total contiguous land within an area that can potentially be inhabited by wolves can be put into perspective when considering a suitability rank of 4 (High) and 5 (Very High). When a rank of 4 and 5 are both considered, the results clearly indicate that suitable, contiguous habitat for wolves is present in Pennsylvania. This is especially true when observing the areas within both prioritized state forests.

When comparing the results of this gray wolf habitat suitability analysis with other similar studies that have been conducted on gray wolves, it is evident that there are similarities and differences. One comparable study also aimed to determine if gray wolves could be reintroduced to Pennsylvania by utilizing GIS to conduct a habitat suitability analysis. In this

study, Beerman (2009) found that Pennsylvania possessed 1,224.625 km^2 of land that was suitable to reintroduce a total of forty-five wolves. Twelve separate ranges were identified. Ten of the ranges were located in the Central and Northcentral region of the state, and two of the ranges were located in the Northeast. According to Beerman (2009), the biggest range had a total of 147.75 km^2 and the smallest range had a total of 56.31 km^2.

When compared to this study, obvious differences stand out. First, the three prioritized areas located in this habitat suitability analysis were all substantially larger than any of the ranges identified in the study conducted by Beerman (2009). Second, although the total number of wolves potentially able to be reintroduced was similar, this study prioritized large public lands and many prioritized areas in the study conducted by Beerman (2009) were not located on large public lands. In addition, there was a slight difference in the style of approach taken between the two studies. Beerman (2009) identified potential suitable habitat for gray wolf reintroduction by utilizing a raster calculator to multiply reclassified variables together. In this study input variables were ranked on a common scale, applied a weighted value based on perceived influence, and compiled into one map through map overlay. Presumably, this is why different results were generated.

Another similar study looked at the feasibility of reintroducing wolves into the Adirondack Park, NY. Paquet, Strittholt, and Staus (1999) also utilized GIS in order to create a habitat suitability model. However, the methodology of their study was more diverse because they used multiple GIS softwares to produce four distinct submodels. The results generated in their analysis determined that the Adirondack Park comprises sufficient habitat to support a small population of gray wolves, but regional conditions are not favorable to support a population over the long term. Their results also indicated that essential environmental

conditions to maintain a viable population of gray wolves would deteriorate over the next 100 years due to recent trends in regional development throughout the state (Paquet et al., 1999). Overall, the results of their study are similar to that of this study because both studies determined that a small population of gray wolves could be reintroduced into historical gray wolf range.

In terms of implementation of this study, the results can certainly be applied to the real-world. For instance, even though the Pennsylvania Game Commission specifically stated that they do not support the notion of reintroducing gray wolves, the results of this study could be used to convince the United States Fish and Wildlife Service and other wolf advocate organizations that wolf reintroduction to Pennsylvania is feasible and favorable. The current management strategies taken by the PGC to regulate white-tailed deer through hunting and increase forest productivity through deer-proof fencing have proven to have some success. Nevertheless, white-tailed deer are still overpopulated and it is unrealistic to install fencing everywhere to help promote forest regeneration throughout vast portions of the state. By reintroducing gray wolves, white-tailed deer populations would be better regulated and overbrowsing would theoretically not be an issue because wolves alter the feeding behavior of deer.

In terms of future work, this habitat suitability analysis could be improved to provide more accurate results. For example, as mentioned previously, more accurate deer data could be implemented into this study. Since the prey base in this study only considered antlerless deer kills per wildlife management unit (WMU), the true amount of deer availability can certainly be improved. In addition, it would be beneficial for future studies to find and incorporate more information on how distance to protected lands influences and affects wolves. There seemed to be a minimal amount of information on this topic, but it could help to identify the absolute best

sites for wolf reintroduction. Moreover, more information on how different heights of elevation affect wolves could help to enhance the analysis. Literature found on this subject was minimal, solely stating that wolves prefer to use flat terrain. Furthermore, it might be beneficial to determine if private lands are feasible for reintroduction. In this study, prioritized sites solely included large public lands. Large public lands were reasoned to be more ideal for reintroduction than private lands because of the sheer difference in size and the fact that the majority of wolves that have been reintroduced in the contiguous United States have been in areas owned by federal and state agencies. Since areas like the Allegheny National Forest, Susquehannock State Forest and Sproul State Forest are managed by federal and state agencies, it was reasoned that wolf reintroduction on these lands would be the most ideal scenario because federal and state officials could actively manage and closely monitor wolves. Last but not least, as previously discussed in the limitations section, more accurate results pinpointing optimal gray wolf habitat could be generated by determining the total amount of land in an area classified as very high suitability and deciphering how much of that land is actually contiguous.

In conclusion, according to the three prioritized sites in this study, a total of 44 wolves could potentially be reintroduced when solely considering land classified as very high suitability. According to the United States Fish and Wildlife Service Recovery Plan for wolves, a viable population consists of at least 100 individuals in a region (United States Fish and Wildlife Service, 1992). Essentially a viable population means that the population will continue to breed and maintain itself over time. In addition, a viable population means that it is large enough to prevent genetic problems, such as inbreeding. Furthermore, a viable population means that the population is large enough and distributed over a large enough area that catastrophic events such as disease and severe weather won’t significantly reduce the population. Based on this

calculation proposed by the U.S. Fish and Wildlife Service, a total of 44 wolves distributed throughout the Northcentral and Northwestern regions of Pennsylvania would not successfully thrive. Although the Allegheny National Forest, Susquehannock State Forest, and Sproul State Forest are not large enough combined to support a viable wolf population, in terms of total km^2 of land classified as very high suitability, it is still vital to note that the results generated in this study indicate that suitable gray wolf habitat definitely exists in Pennsylvania.

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