MAKING CONNECTIONS

ANALYZING HABITAT CONNECTIVTY FOR THE GRAY WOLF IN COASTAL WASHINGTON

by

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A Thesis
Submitted in partial fulfillment
of the requirements for the degree
Master of Environmental Studies
The Evergreen State College
September 2020

This Thesis for the Master of Environmental Studies Degree

by Marisa Pushee

has been approved for The Evergreen State College

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ABSTRACT

Making Connections:
Analyzing Habitat Connectivity for the Gray Wolf in Coastal Washington

Marisa Pushee

The Gray Wolf (*Canis lupus*) is a federally-listed endangered species in the U.S. that requires large habitat ranges and is highly human-avoidant. The compounding impacts of climate change and increasing land development in Washington State threaten to further impede Wolf recovery. As a result, preserving Wolf habitat and movement routes over the long-term may be essential to achieving Washington's recovery goals as outlined in the state's Wolf Conservation and Management Plan. Identifying and maintaining core habitat and corridors may assist wildlife managers in mitigating the impact of both anthropogenic development and climate change on Wolves. These efforts may also assist land-use managers and planners in considering how landscape configuration could serve to minimize human-Wolf conflicts in the future. One of the first steps in this type of habitat planning is understanding how the Gray Wolf utilizes the landscape. To do this, I estimated habitat suitability scores and landscape resistance scores for land cover, streams, roads, elevation bands, buildings, and other landscape features by consulting Wolf experts and conducting a literature review on Wolf habitat use. Habitat suitability scores describe Wolf habitat quality and landscape resistance scores indicate the degree to which landscape features impede or direct Wolves as they move through landscape. The results of this work can be used to conduct landscape permeability analyses and inform recommendations for Wolf conservation. In collaboration with the Washington Wildlife Habitat Connectivity Working Group, this project will contribute to the ongoing analysis of habitat connectivity for the Gray Wolf in Washington State as well as support the state's goal for Wolf recovery.

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Acknowledgements

I owe my gratitude to a number of people who have supported me throughout the thesis process. I'd like to thank my reader, Tim Quinn, for his exceptional guidance. I'd also like to thank the MES faculty and staff, including John Withey, Mike Ruth, Kevin Francis, Andrea Martin, and Averi Azar. Thank you to the Washington Wildlife Habitat Connectivity Working Group, especially Kelly McAllister and Glen Kalisz with Washington Department of Transportation, for welcoming me into this project. Thank you also to Gregg Kurz with U.S. Fish and Wildlife Service, Julia Smith with Washington Department of Fish and Wildlife, and an anonymous Wolf expert for their integral input on this project. Thank you to my coworkers and managers at Wolf Haven International and Sustainability in Prisons Project. A special thanks to my MES colleagues, including my peer reviewers Christine Davis and Sam Alfieri. Finally, thank you to my friends and family for their support, including my mom, my partner Preston, and my dog Hiji.

CHAPTER 1: INTRODUCTION

Introduction

On an ever-increasing scale, anthropogenic development and climate change detrimentally impact global biodiversity (LeCraw et al., 2014). Human populations continue to grow, development expands, landscape becomes fragmented, and biodiversity is often reduced (Brodsky and Safronova, 2017). Identifying and maintaining core wildlife habitat and wildlife corridors provides a potential management strategy to help mitigate these impacts. However, landscape fragmentation is a complex issue. Promoting landscape connectivity has the potential to contribute to conserving native flora and fauna, but designing and building functional corridors and crossing structures requires an understanding of animal movement ecology In cases where connectivity does address all the life history requirements of a species, additional conservation strategies may be needed. Further, wildlife corridors and crossing structures encompass a wide range of structures, landscape features, and purposes.

A focal species approach offers one method for improving landscape connectivity. A focal species approach can serve multiple benefits, especially if that focal species serves as an umbrella species and impacts a range of other wildlife. Maintaining connectivity for species requiring large areas may also benefit a larger suite of species that use similar habitats at smaller spatial scales. Additionally, creating core areas and corridors to protect apex predators or other keystone species can similarly multiply the conservation effects of single species management. For example, the Gray Wolf in the greater Yellowstone Ecosystem presents a compelling case for the disproportionate effects of a single apex predator on ecosystem structure and function (Wilmers and Getz, 2005). The reintroduction of the Gray Wolf in Yellowstone National Park (YNP) included the regrowth of Aspen (*Populus tremuloides*) stands and Willow (*Salix* *melanopsis*), especially in riparian areas, as well as an increase in Beaver (*Castor canadensis*) population as a result of the Wolf's impact on elk (*Cervus canadensis*) populations and habitat use (Smith et al, 2003; Smith et al, 2009).

For this thesis, I examined the Gray Wolf as a focal species for mapping habitat connectivity in coastal Washington State, including the Olympic Peninsula and expanding to the Cascades and south to the Columbia River. I developed habitat suitability and landscape resistance scores for landscape factors based on peer-reviewed literature and expert opinion. This project has the potential to support wildlife managers in navigating potential conflict areas between the Gray Wolf and humans in western Washington. In this thesis, I first provide background on the Gray Wolf in Washington State followed by a literature review with a focus on habitat connectivity and the Gray Wolf. I then discuss my use of a targeted literature review on the Gray Wolf's landscape use as well as inclusion of expert opinion in developing habitat suitability and landscape resistance scores. The detailing of my methodology is followed by the resulting scores from my project and a discussion of the potential uses and impacts of this work including conserving potential Gray Wolf habitat and mitigating human-Wolf conflict.

Wolves in Washington

The Gray Wolf has a long and complex history in Washington State. Common to Washington prior to 1800 and persisting at least until the 1850s, the Gray Wolf was extirpated from the state in the 1930s (Wiles et al., 2011; Scheffer, 1995). Euro-American colonization of the pacific northwest resulted in Wolf control through the fur trade and bounty incentives (Harding, 1909; Adamire, 1985). While scattered Wolf sightings persisted throughout the following decades, they were largely unsubstantiated (Wiles et al., 2011).

The Gray Wolf recolonized eastern Washington in 2008 likely from populations in

Canada, Montana, and Idaho, and Wolf management has been challenging in the years since (Wiles et al., 2011). After their return to Washington State, tensions around the Gray Wolf in Washington have been high, especially in eastern Washington where the Gray Wolf is most prevalent and most likely to conflict with humans when they prey on livestock in open range areas. Managing the Gray Wolf on land grazed by livestock is often logistically difficult, expensive, and deeply controversial. Despite intense conflict with some human interests, however, the Gray Wolf plays an important role in the ecosystem (Shepherd and Whittington, 2006). As an apex predator and keystone species, the Gray Wolf directly and indirectly affects the composition, structure, and functioning of ecosystems as well as the provisioning of ecosystem goods and services (Callan, 2013). Ecosystem services, including supporting, provisioning, regulating, and cultural services can be critical for serving human needs as well as maintaining functional ecosystems (Millennium Ecosystem Assessment, 2002). By maintaining the Gray Wolf population in Washington State, wildlife managers may be able to increase the resilience of ecosystems to human stressors such as climate change and habitat conversion. Nonetheless, conflict between humans and endangered species, like the Wolf, present difficult and ongoing challenges to many stakeholders.

The Gray Wolf is expanding its range in Washington State. At the end of 2019, The Washington Department of Fish and Wildlife (WDFW) counted 108 known Gray Wolves in 21 packs and the Confederated Tribes of the Colville Reservation counted an additional 37 Wolves in five packs (WDFW, 2020). The Gray Wolf is currently most prevalent in the northeastern region of Washington State (Figure 1). Compared to the eastern side of Washington State, the western side is more heavily populated with humans, has more infrastructure, and is more fragmented, making much of the potential habitat less ideal for the Gray Wolf. Despite western

Washington's higher level of anthropogenic development, the landscape still offers potential suitable habitat for the Gray Wolf, a habitat generalist. One major barrier to Wolves colonizing western Washington is Interstate 90, a major east-west highway that acts as a barrier to many wildlife species, including the Gray Wolf. However, recently constructed wildlife crossing structures may eventually aid in Wolf dispersal.

Figure 1: Pack distribution of the Gray Wolf in Washington State (WDFW, 2020).

Despite management challenges surrounding the Gray Wolf, the species offers an instructive candidate for mapping habitat connectivity in western Washington. Because the Gray Wolf is highly human-avoidant and thus tends to constrain its movement near anthropogenic development (Rio-Maior et al., 2018), preserving habitats and travel routes may be essential for meeting and maintaining the state's recovery goals for the Gray Wolf. Careful selection of Wolf core areas and travel corridors also provides a proactive management approach to avoid or minimize unwanted human-Wolf interactions. Wolf conservation efforts will need to consider human development in addition to prey resources and habitat suitability when evaluating potential habitat in support of stable Wolf populations. A key component of coexistence will likely require minimizing or avoiding human activity within carnivore habitat (Rio-Maior et al., 2018), and discouraging wolf use of human habitat.

In addition to preserving potential Wolf habitat separate from humans on the landscape, maintaining likely travel routes and general connectivity may be critical for Gray Wolf recovery in areas inhabited by humans (Clark et al. 1996, Noss et al. 1996, Weaver et al. 1996). As human development increases, the persistence of Wolves will likely depend on their ability to move through the western Washington landscape to meet a variety of needs including finding food, dispersing, mating, and rearing pups, while avoiding areas that lead to human-Wolf conflict. As outlined in Washington's Wolf Conservation and Management Plan, WDFW aims to restore a self-sustaining Wolf population in the state (Wiles et al., 2011). This would ideally include at least 15 breeding pairs for a minimum of three years with a minimum of four pairs in eastern Washington, four in the North Cascades, four in the South Cascades, and an additional three throughout the state (Wiles et al., 2011). However, apex predators like the Gray Wolf are especially vulnerable to the impacts of habitat fragmentation, because they have requirements for large contiguous areas with low potential for human contact (LeCraw et al, 2014). Wolves living within fragmented patches can become isolated from larger populations and may be at risk of environmental, demographic and genetic (genetic drift and inbreeding depression) stochasticity. Additionally, as climate change impacts increase, improving species resilience now through careful planning may help ensure that Gray Wolf populations can adapt to future environmental disruptions.

As Washington continues to develop, wildlife managers and landscape planners will need to identify strategies to mitigate the impacts of anthropogenic activity on the most vulnerable wildlife. Perhaps more importantly, in order to meet recovery goals for the Gray Wolf, the state may need to proactively identify and protect Wolf habitat, while at the same time considering how to manage the landscape in order to minimize conflict.

Further study on the effects of habitat fragmentation on the Gray Wolf may prove useful in mitigating human-Wolf conflict. Since the Gray Wolf is human-avoidant and sensitive to habitat fragmentation, human-caused landscape fragmentation can reduce Wolf habitat suitability, which in the extreme includes direct mortality of Wolves by humans (Gude et al. 2012; Hanley, 2019). On the other hand, the Gray Wolf is also resilient and may recover once human exploitation is reduced or discontinued (Hayes and Harestad 2000, Fuller et al., 2003).

This thesis contributes to Washington’s recovery goals for the Gray Wolf by identifying areas to prioritize protection and restoration of potential Wolf habitat and connectivity. Drawing from the literature and expert opinion, I developed habitat suitability and landscape resistance scores for the Gray Wolf. These scores can be used to map habitat suitability and landscape connectivity, and may also be useful in identifying areas for acquisitions as well as focusing investment in constructing crossing structures or improving existing wildlife corridors for linear barriers such as major roads, large rivers, streams, and other features.

CHAPTER 2: LITERATURE REVIEW

Introduction

Anthropogenic development and climate change will increase the challenges that many species face. As greenhouse gas emissions alter global climates, the distribution of vegetation community changes as a result (Williamson et al., 2016). Additionally, the increase in lands to support human activities impacts ecosystem health and stability, leading to decline as a result of pollution, loss in biodiversity, and habitat fragmentation (Hautier et al., 2015). Kabenick and Jennings (2017) state that we are in the midst of the sixth major extinction event reaching as high as 150 species per day. Others describe the current crises in terms of "a global wave of anthropogenically driven biodiversity loss," noting both species and population extirpations as well as declines in local species abundance caused by habitat conversion including both habitat loss and fragmentation, over exploitation, invasive species, and disease (Dirzo et al., 2014).

Abrahms (2017) suggests approaching these impacts of climate change from a place of adaptation, where wildlife managers consider the benefits of both maintaining wildlife reserves and connecting existing habitat, while monitoring and evaluating outcomes in order to optimize future success in a changing environment. This adaptive management approach could prove beneficial for many conservation initiatives. For example, the western U.S. has witnessed an increase in drought and wildfires, which may ultimately transform once forested areas into shrub or grasslands. Where drought and fire occur in proximity to endangered species (Williamson et al., 2016), these species may need to alter their ranges in order to survive. Many species have already begun to shift the timing of their lifecycles, including migration, as well as their geographic ranges in response to changes in temperature (Abrahms, 2017). Additionally, where vegetation community shifts are more subtle, climate change may decrease habitat quality by decreasing access to much needed resources. Isolated populations are most at risk when they lack the ability to travel to other areas in search of habitat. Additional stressors like anthropogenic development and exotic species invasions compound the effects of climate change on vulnerable native species. In order to maintain native species populations and biodiversity, wildlife managers will need to consider local climate projections and how vulnerable species respond to changes, and account for uncertainty in their predictions (Abrahms, 2017).

Landscape fragmentation can have some of the most severe impacts on large carnivores like the Gray Wolf. As a result of their sensitivity to and avoidance of anthropogenic activity, carnivore conservation efforts will need to consider human development when evaluating the potential for carnivores to establish stable populations (Rio-Maior et al., 2018). In this literature review, I focus on: 1) the effects of habitat conversion and fragmentation on Gray Wolf populations, 2) genetic problems associated with small and isolated populations, and 3) how connectivity can address small population issues. Finally, I apply these concepts to recovery of the Gray Wolf in Washington State.

Habitat Fragmentation

Anthropogenic development has resulted in widescale habitat loss and fragmentation for a wide variety of species in many parts of the world (Ezard and Travis, 2006). These threats are part of a larger group of related anthropogenic activities that contribute to shifts in climate and increased frequency of large-scale disturbance events, spread of invasive species, the over-harvesting of natural resources, and pollution that combine to threaten global biodiversity (Brody and Safronova, 2017; Reed F. Noss, 1987).

Two of the primary threats of habitat fragmentation include a decrease in habitat area and isolation of existing habitat patches (Fahrig and Merriam, 1994). For example, high-traffic roads not only reduce habitat, they can also act as effective barriers to movements by preventing animal crossings, and by causing high levels of mortality to crossing animals (Forman, 2002). Fragmented landscapes are often depicted as a series of isolated patches of habitat that each contain relatively small populations of individuals of a particular species. To a lesser or greater degree, depending on population size and connectivity among patch populations, these isolated populations are subject to stochastic forces associated with the small population paradigm. These stochastic forces include environmental, demographic and genetic issues (Ezard and Travis, 2006).

Habitat Connectivity and Genetic Drift

Landscape connectivity can be crucial for promoting species resilience to stochastic processes affecting small populations, including genetic drift and inbreeding depression, by promoting the exchange of genes among populations. Genetic drift, also referred to as genetic stochasticity, is a key factor in maintaining biodiversity and genetic variation in species populations (Cortazar-Chinarro et al., 2017). Genetic drift is the process whereby alleles are lost to a population from generation to generation due to chance events, thereby decreasing the genetic variation of a population (Cortazar-Chinarro et al., 2017). Loss of alleles in small populations also increases the probability of inbreeding depression—that is the mating of closely related individuals, which can result in loss of adaptive potential as well as increased sensitivity to environmental and demographic stochasticity (Weckworth et al., 2013). Genetic variation (sometimes measured by allele frequency) is thought to confer advantages to species by virtue of the fact that variation can better equip species to survive in a rapidly changing environment. Thus, small populations, i.e., those isolated in disconnected habitat patches, experience genetic drift faster than larger connected populations.

Additionally, habitat availability and effective population size have a strong influence over genetic variability (Weckworth et al., 2013). Habitat geometry, including size, shape, and connectivity among patches (via immigration and emigration) affects population size and thus rates of genetic drift. Further, effective population size (N_e), which considers the number of sexually reproducing adults in a population (rather than the overall population size), is an important parameter in determining population dynamics (Weckworth et al., 2013). An abrupt change in habitat availability can surpass thresholds after which a species cannot persist. Species' responses to habitat loss may depend on both the amount of habitat that is lost as well as the pattern in which it is lost (Ezard and Travis, 2006). Factors contributing to extinction and thresholds at which species become functionally extinct are species-specific. Since these processes are typically unknown to wildlife managers, it may be critical to err on the side of caution to ensure that species viability thresholds are not crossed (Ezard and Travis, 2006). Finally, it is important to keep in mind that the complex relationships between ecological (biotic) and landscape (abiotic) processes are often not well-understood (Ezard and Travis, 2006).

Because habitat quality and quantity, and population size are commonly related to species viability, wildlife managers and landscape planners need to consider multiple factors when designing landscapes to maintain connectivity. Habitat connectivity is a relative term and is both species and landscape specific, that is – connectivity is a function of species ecology and landscape features (Tischendorf and Fahrig, 2000). Habitat fragmentation is likely a greater threat to viability of species that rely on long distance movements e.g., migration to complete their life history, such as Monarch Butterfly (*Danaus plexippus*) or Salmon (*Salmo salar*), and long-distance dispersal from natal home ranges for species like the Gray Wolf (Mech et al., 2001).

Wildlife Corridors and Crossing Structures

Wildlife corridors typically refer to naturally occurring landscape features that promote species movement, whereas wildlife crossing structures are man-made features that are designed to facilitate species movement. Corridors can be defined as linear patches that are either left intact post land-use change or reconstructed after a disturbance in order to maintain or re-establish connectivity between formerly connected habitat patches (Mech et al., 2001). Wildlife crossing structures consist of a relatively narrow patch of landscape that wildlife use to travel from one patch of larger habitat to another. Culverts are also one type of crossing structure and are utilized as corridors by some aquatic species (Beier and Noss, 1998). While corridors and crossing structures vary widely in their design, they perform the same primary function, enabling wildlife to travel in order to locate mates, food, and other resources (Beier and Loe, 1992).

For some species, these landscape features primarily serve as dispersal corridors and for others they function as linear habitats. Dispersal corridors link otherwise unconnected landscape patches, providing a travel route from one habitat patch to another. In contrast, linear habitats function as core habitat space rather than as a route solely for movement (Beire and Loe, 1992), although they may also function as such. For example, wildlife corridors may serve as linear habitat for amphibians or reptiles, which have relatively small home ranges. However, for large mammals like the Gray Wolf, corridors are designed to move species through the landscape rather than providing habitat per se and thus serve to provide dispersal routes for species that require exceptionally large and relatively undisturbed areas. When corridors and crossing structures are successful in facilitating species movement, they contribute to overall landscape connectivity (Tischendorf and Fahrig, 2000).

Although corridors and crossing structures are becoming increasingly popular tools to mitigate population impacts (e.g., increases in demographic, environmental, and genetic stochasticity) of habitat loss and fragmentation, the variety in their structure and implementation reflects a wide range of different objectives. While some initiatives focus on constructing structures designed to prioritize a suite of focal species, others seek to improve existing crossing structures over constructing new ones. Corridor design may also reflect the needs of the species the corridor is meant to serve, the type of movement it is intended to facilitate, and other considerations including: the proximity, type and intensity of human activity, and ownership and current and future management plans, and the availability and distribution of suitable habitat (Beier and Noss, 1998).

Concerns and Criticisms

While wildlife crossing structures have their fair share of advocates, they have also received criticism. Concerns around improving landscape connectivity include the threat of spreading invasive species and wildfires, and the impacts of increasing edge habitat and edge predators (Beier and Noss, 1998). The cost to state agencies of preventing the spread of disease has also been cited as an additional concern (Beier and Noss, 1998). Further, there is an inherent risk of not knowing enough to make crossing structures work for a focal species. Criticisms surrounding the use of crossing structures for species like the Gray Wolf run even deeper.

Some researchers have proposed translocation as an alternative to maintaining and constructing wildlife corridors and crossing structures, but this management strategy is not without its own shortcomings, especially for the Gray Wolf. For this family-oriented pack species, removal of individuals from their territory can lead to homing behaviors as well as a disruption of multi-generational hunting strategies that may be region-specific (Bradley et al., 2005). Simberloff and Cox (1987) suggest that while translocation, as opposed to improving connectivity, may be a viable option to address threats of inbreeding in isolated populations/fragmented habitat, the scale of translocation required to combat inbreeding may be too large and expensive of an undertaking. Translocation can also be detrimental to many species, especially social animals that are removed from their family units.

In a comparison of translocation efforts across the northwestern United States, translocated Wolves demonstrated strong homing tendencies resulting in either returning to capture sites or traveling toward them (Bradley et al., 2005). Additionally, translocated Wolves had lower success rates forming packs and had lower survival rates than non-translocated Wolves, with government removal following depredation events as the primary cause of mortality (Bradley et al., 2005).

Critics have also expressed concerns that funneling financial resources into constructing and maintaining crossing structures and corridors will take money away from other much needed conservation initiatives. Importantly, landscape connectivity is just one of many tools needed in order to maintain biodiversity and healthy wildlife populations. Crossing structures and corridors alone cannot address the ever-expanding problem of habitat loss and fragmentation. However, since the potential negative impacts of losing corridors is unknown, maintaining existing corridors that survived land-use development is worth the added cost according to Beier and Noss (1998). And although more research is needed, current findings demonstrate the positive impact of corridors in facilitating species dispersal, thereby expanding habitat range and promoting genetic diversity in species of concern.

While wildlife crossing structures and corridors are widely used, they will likely remain controversial until we know more about their contribution to conservation efforts. Studies of their effectiveness are limited in number and are often restricted to a single species. Not surprisingly, research has yet to determine the full ecological effects of corridors (Shepherd and Whittington, 2006). However, studies like the one detailed in the next section clearly demonstrate the potential benefits of connectivity for the Gray Wolf (Shepherd and Whittington, 2006).

The Gray Wolf

The Gray Wolf serves as a unique focal species, because of its importance to and impact on the environment and because of its sensitivity to habitat fragmentation. Although the Gray Wolf is a habitat generalist, they are territorial and require large home ranges (Mech and Boitani 2003). Because they are territorial, high dispersal rates help stabilize Gray Wolf populations (Carroll et al, 2014).

The Gray Wolf plays a critical role as an apex predator and indicator species (Ripple et al., 2015). Apex predators like Wolves are of critical import to ecosystems due to their impact on trophic levels through a trophic cascades effect (Fortin et al., 2005). Changes in Gray Wolf populations at the top of the food chain influence changes in their prey (mostly members of the Cervidae family) as well as additional lower trophic levels, thereby influencing the greater ecosystem. In Yellowstone National Park (YNP), the Gray Wolf has been shown to impact scavenger food webs by providing additional food left uneaten from their kills (Wilmers and Getz, 2005). When the Gray Wolf was absent from the landscape, YNP saw a reduction in winter carrion, which had the potential to lead to genetic bottlenecking for scavenger species like the Bald Eagle (*Haliaeetus leucocephalus*) and the Red Fox (*Vulpes vulpes*) (Wilmers and Getz, 2005). This influence of the Gray Wolf may also mitigate some impacts of the shorter winters experienced in YNP as a result of climate change (Wilmers and Getz, 2005). Researchers predict that early snow thaw may lead to a decline in late-winter carrion in the absence of the Gray Wolf (Wilmers and Getz, 2005). Wolves mitigate this impact of climate change by providing additional carrion for scavenger species (Wilmers and Getz, 2005). The impact of Wolf behavior on other trophic cascades has also been documented on Isle Royale where Wolves have been shown to limit Moose (*Alces alces*) abundance and thereby increase productivity of fir (*Abies sp.*) trees (Post et al., 1999). Considering the cascading impacts of maintaining stable Wolf populations detailed above, recovery of the Gray Wolf may be very valuable.

The Endangered Species Act (ESA) has played a large role in defining the path to recovery for the Gray Wolf. The spatial distribution of Wolves is of particular important in terms of maintaining stable populations. The ESA emphasizes the importance of considering a species' role on the landscape in addition to the importance of conserving variation among populations of species (Carroll et al., 2009). Language in the ESA has been disputed, though. The Endangered Species Act (ESA) was distinct in that it included language on recovery over a "significant portion of a species' range" (Vucetich et al., 2006).

There has been some dispute over interpretation of range in the ESA and whether it refers to current or historic range (Vucetich et al., 2006). Some interpret the language in the ESA to a species' range at time of listing, but this reading is deeply problematic. There is an inherent fallacy in interpreting the ESA's definition of range to mean "currently occupied" range when so many endangered species are imperiled because of habitat loss. Vucetich et al. (2006) draw attention to the idea of delisting the gray Wolves when they only occupy 5% of their historic range: they argue that because Gray Wolf ecology is not homogenous, species density depends on prey availability, and local extinction/recolonization may be frequent, true recovery may require that Gray Wolves occupy a far larger extent of their historic range than is typically discussed (Vucetich et al., 2006). This interpretation does not account for the spatial elements of population dynamics or the impoverished conditions of many current landscapes (Carroll et al., 2009; Gilpin, 1987). The definition of a species' historic range is further complicated by the question of what period in history to consider. It is not only important that Washington state have Wolves, but where in the state those Wolves occur (Carroll et al., 2009).

Anthropogenic development can greatly impact the Gray Wolf. Gray Wolves are sensitive to habitat fragmentation at various spatial scales and the presence of humans (i.e. human-avoidant). Moreover, many people are intolerant of Wolves living around them. Wolf mortality from humans can significantly impact the growth and size of Wolf populations (Gude et al. 2012; Hanley, 2019). Additionally, state agencies may underestimate the number of Wolves that are killed by humans each year (Treves et al., 2017). Some studies suggest that for Wolf recovery to be successful in the western United States, wildlife managers will need to factor a greater consideration for the impact of illegal hunting and vehicle collisions on Wolf populations (Treves et al., 2017, Hanley, 2019). On the other hand, the Gray Wolf is extremely resilient and populations can recover rapidly once human exploitation is reduced or discontinued (Hayes and Harestad 2000, Fuller et al. 2003). Further, Wolf populations impacted by humans will recover faster when immigration occurs from neighboring areas (Hayes and Harestad 2000, Larivière et al. 2000, Hanley, 2019).

Habitat connectivity can have positive population-level effects for Wolves. Shepherd and Whittington (2006) studied how wildlife corridors in Jasper National Park, Alberta, Canada impacted the movement of Wolves in the area. They used winter track counts of Wolves and their prey (deer and elk) before and after the construction of a 330 m (average width) corridor through the center of a golf course. Figure 2 shows Gray Wolf movement one year before (left) compared to two years after (right) corridor construction (Shepherd and Whittington, 2006).

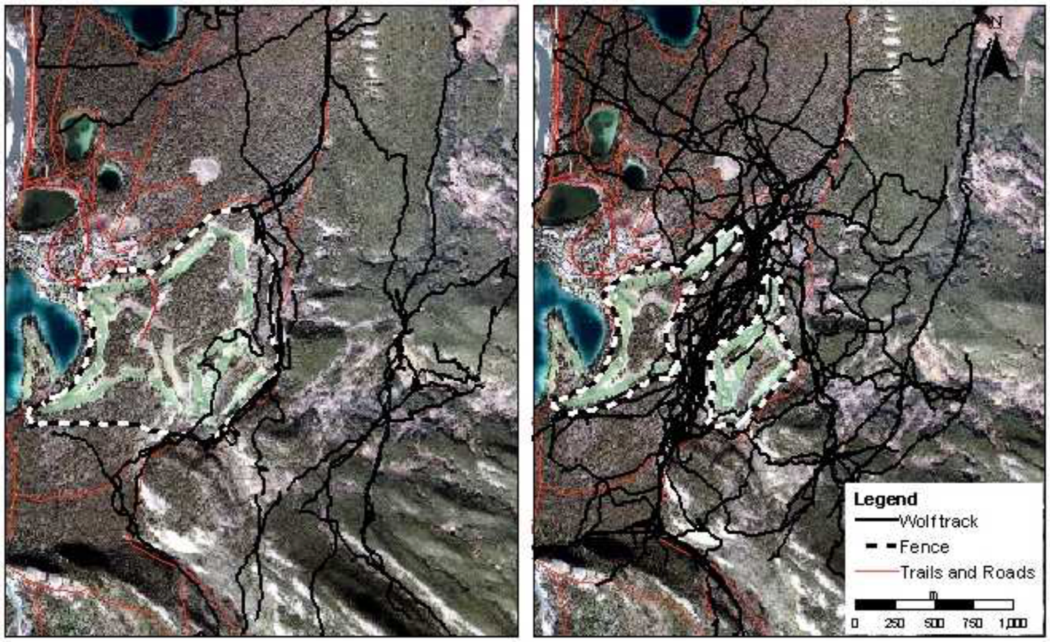

Figure 2: Gray Wolf movement patterns one year before corridor restoration (left) compared to two years after (right) (Shepherd and Whittington, 2006).

Shepherd and Whittington's study concluded that the Gray Wolf likely selected trails that were the least used by humans (2006). They also found that Wolves used the corridor in order to access prey, but not for feeding or resting, that is, the corridor was used for movement, but not habitat (Shepherd and Whittington, 2006). These considerations could be instrumental in navigating landscape connectivity for the Gray Wolf in Washington State.

Gray Wolves in Washington State may especially be of genetic importance. In a genetic study of Wolves in the PNW, Hendricks et al. (2019) found the first genetic admixture between different lineages, including coastal British Columbia (BC) and Northern Rocky Mountain (NRM) Wolves. The ideal ranges for these two genetic lineages are displayed in Figure 3.

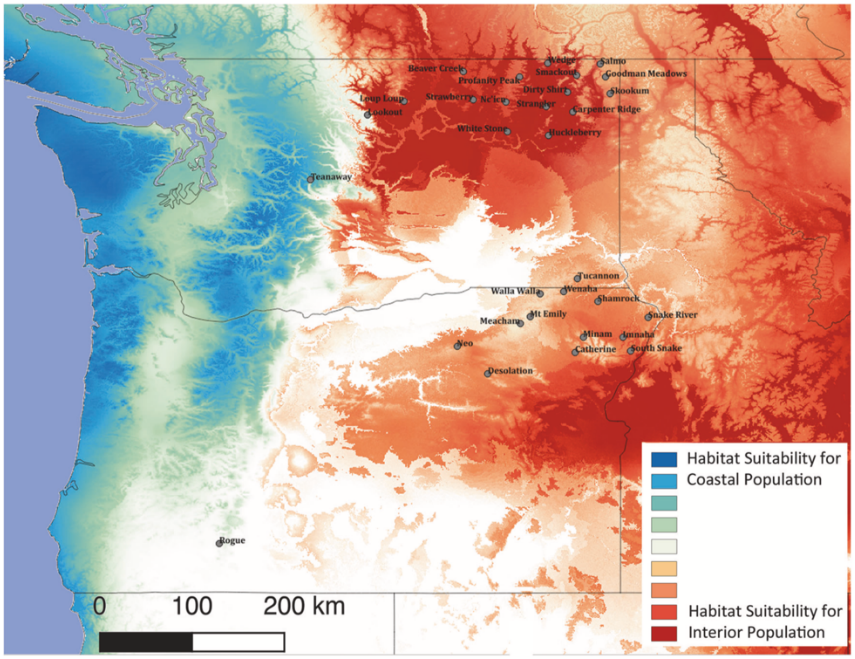

Figure 3: MaxEnt distribution model for coastal and interior Wolves within the area of the natural re-colonization zone. Warmer colors indicate more suitable habitat for interior Wolves and cooler colors indicate more suitable environment for coastal Wolves (Hendricks et al., 2019).

Hendricks et. al's study (2019) highlights the importance of Washington's Wolf population as well as the potential value in characterizing the landscape in coastal Washington with attention to Gray Wolf habitat suitability and landscape resistance. Gene flow between NRM and BC Wolf populations that is occurring in WA state may increase with genetic variation and enhance these Wolves' ability to adapt (Hendricks et al., 2019).

Habitat Connectivity in Washington State

Washington State's concern for wildlife habitat conservation exemplifies the growing trend for environmental initiatives as the state demonstrates a priority for maintaining and fostering biodiversity and ecosystem health (WWHCWG, 2019). The Washington Wildlife Habitat Connectivity Working Group is part of this effort and an example of how state agencies, nonprofits, and individuals are working together to promote habitat connectivity. Since 2007, the

Working Group has promoted a collaborative and science-based approach to identifying where to restore wildlife habitat (WWHCWG, 2019). The Working Group's current project is to map habitat connectivity in coastal Washington State for a suite of focal species, drawing on species-experts from across the state.

Even before 2007, Peter Singleton (2002), current Working Group member, performed a series of connectivity analyses for the state. Figure 4 shows Singleton's course scale statewide analysis of habitat concentration and fracture zones for large carnivores in Washington. Singleton's work now serves as a foundation for state connectivity work, having established initial permeability scores for large carnivores in Washington, including Gray Wolves, in 2002.

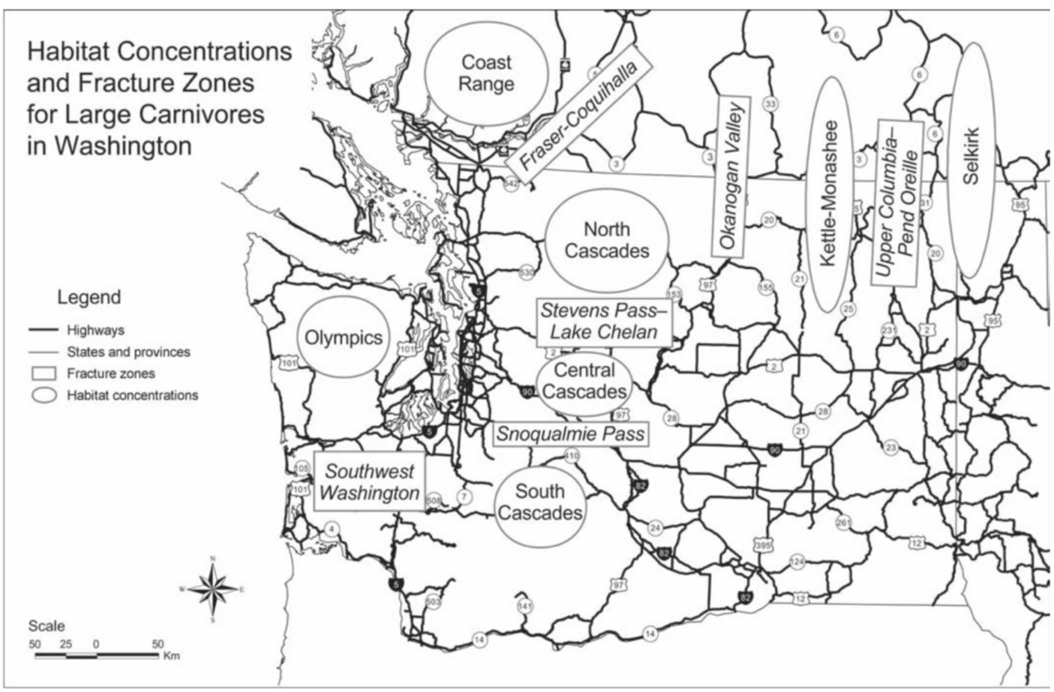

Figure 4: Coarse scale analysis of habitat concentration areas and fracture zones for large carnivores in Washington State (Singleton, 2002).

Singleton's project used least-cost analysis with attention to landscape cover, human population, roads, slope and elevation to evaluate landscape permeability for large carnivores (2002). As a part of this project, he identified habitat concentration areas (HCAs) and fracture zones for large carnivores in Washington. While Singleton's project provided a substantial boost to this type of work, updates in available analyses and changes to the landscape in the last two decades underscore a need to continue this work.

Additionally, Washington's Department of Transportation (WSDOT), along with partners like the U.S. Forest Service (USFS) and local conservation nonprofits including Conservation Northwest, have been working to support wildlife conservation in Washington (WSDOT, 2000). A current focus includes Interstate 90, which runs east-west through the Cascade Mountains dividing U.S. Forest Service lands and private timberlands for north-south migration and dispersal of wildlife. One initiative, Snoqualmie Pass Habitat Linkage project, was designed to develop crossing structures both above and below I-90 that would promote species passage across I-90. From 1998 to 2000, WSDOT performed an assessment of GIS least-cost path data, road kill distribution, camera surveys, existing documentation of how wildlife used bridges and culverts, and winter snow animal tracking to inform corridor location, design, and implementation (WSDOT, 2000). Additionally, the recent I-90 Snoqualmie Pass Habitat Linkage demonstrates how the state is adapting to help combat the impact of anthropogenic development on wildlife (WSDOT, 2000). In the face of impacts from climate change and anthropogenic development, these infrastructure changes may prove critical in ensuring that Washington maintains viable wildlife populations.

Gaps in the Research

Though well-studied compared to many species, the Gray Wolf can prove to be a challenging subject for research. Because large carnivores require relatively large areas, most studies of Gray Wolf movements are limited by small sample sizes - a common problem in ecology. Due to these small sample sizes, it can be difficult to do studies with high statistical power. As a result, small, individual studies may not reveal detailed habitat use patterns suitable for informing useful management actions such as corridor creation. Gray Wolves can also be a challenging species to study because they are human avoidant, highly intelligent, and can be difficult to collar and track. Moreover, because of these constraints, research projects involving Wolves can be very costly. Further, when the Gray Wolf has a protected status like in Washington state, their locations can be considered sensitive information and therefore can be difficult for researchers to access. Finally, the application of connectivity to large mammalian carnivores can be controversial and thus understudied.

A better understanding of how the Gray Wolf uses the landscape could help wildlife managers mitigate potential human-carnivore conflict. In support of better understanding, managers may be able to promote coexistence by identifying core habitat areas with attention to breeding pairs and den sites as well as corridors for dispersal movements (Rio-Maior et al., 2018). For example, Rio-Maior et al. (2018) noted that most research focused on coexistence has not provided what they call *prediction maps* to visualize how avoidance of human-related activities impact the spatial distribution of large carnivores and their habitats. By using the literature to inform and predict species movements and computer software like GIS or other mapping tools, landscape planners and wildlife managers can model how anthropogenic activity might constrain habitat for human-avoidant species like the Gray Wolf.

In another study, McGuire et al. (2016) measured the projected success or failure of landscape across the country to provide adequate landscape connectivity in the face of climate change. Their analysis suggests that some areas in Washington, most notably southeastern WA, have higher rates of general landscape connectivity than the eastern United States (McGuire et al., 2016). Compared to many other more fragmented and warmer areas in the country, Washington State has maintained large tracts of natural areas. However, there remain many areas of Washington that may increasingly lack connectivity due to climate change (McGuire et al., 2016). McGuire et al.'s study, while considering the current impact of anthropogenic development, does not consider potential impacts of continued human population growth or increased rates of severe climate disasters (2016). It may be increasingly important to consider projected population growth in WA and subsequent development as well as the increase of wildfire and flooding in the state for predictive mapping.

Human-Carnivore Conflict

Research into information that Way and Bruskotter (2012) call *human dimensions data* reveals that attitudes toward Wolves largely depends on context. For example, public support of Wolf management strategies varies depending on what impact Wolf populations have on the humans who live in close proximity to Wolves. Because of this, recolonization of coastal Washington by the Gray Wolf may reveal a range of pro and anti-Wolf sentiment in the region. Context will be of great import when considering Gray Wolf recolonization of western Washington and may help state agencies implement adaptive management strategies. Because candid management can include some of the most divisive practices, including aerial shooting and foot-hold traps, knowing how the local public would react to these management policies may aid government agencies in their Wolf management (Way and Bruskotter, 2012). In Washington State, western Washington is typically more liberal than eastern Washington, but also has little experience living alongside Wolves. Residents in western Washington may not currently support lethal removal of Wolves as practiced in eastern Washington, but their stance may change when Wolves enter their more immediate landscape. Regardless of their stance on lethal removal, residents in coastal Washington will likely want some management strategy to balance human and Wolf needs. Because of this, early and targeted outreach may be a critical tool for state agencies and wildlife organizations. A planned and timely outreach campaign could also help state agencies identify local stakeholder concerns and help them understand and implement strategies to avoid, minimize, and mitigate conflict (Way and Bruskotter, 2012).

Conclusion

In the face of climate change and growing anthropogenic development, conserving and restoring wildlife habitat and connectivity may be critical for the survival of many species. The Gray Wolf offers just one example of the importance of connectivity. Many threatened species are greatly impacted by habitat fragmentation, but identifying and conserving wildlife corridors as well as constructing wildlife crossing structures to connect otherwise isolated habitat patches may improve connectivity. Promoting connectivity may thereby enhance species viability, by increasing population size and gene flow among metapopulations and thus decreasing genetic drift and inbreeding depression. While maintaining large reserves is often preferable to connecting smaller patches, conserving core wildlife habitat and connecting corridors can play an important role in connecting fragmented habitat and linking otherwise isolated species populations (Beier and Noss, 1998; Cortazar-Chinarro, 2017).

CHAPTER 3: METHODS

Introduction

The goal of this research was to begin the process of identifying priority habitat and connectivity linkages for the Gray Wolf in coastal Washington, including the south Cascades from approximately Mount Rainier to the Columbia River down to southwestern Washington and the Olympic Peninsula. My thesis supports the work of the Washington Wildlife Habitat Connectivity Working Group (WWHCWG) with the goal of conserving the Gray Wolf by proactively addressing methods for avoiding human-Wolf conflict. This chapter describes the methods I used to determine habitat suitability and landscape resistance scores based on land cover and landscape factors.

Washington Wildlife Habitat Connectivity Working Group

My thesis builds on the continuing work by WWHCWG (hereafter the Working Group), a collaborative effort to map habitat connectivity in the state for a variety of species. This collaboration increases communication across agencies and provides opportunities to learn from diverse perspectives and experiences. In 2010, the Working Group performed a statewide connectivity analysis. Based on this initial effort, the Working Group identified the need for further analysis in the coastal Washington region. In 2018, the Working Group began using Linkage Mapper, a core-corridor approach, along with Omniscape, a coreless approach (WWHCWG, 2019). For the Coastal Washington Habitat Connectivity Modeling pilot, the Working Group identified their goal as: “Promoting the long-term viability of wildlife populations in Washington State through a science-based, collaborative approach that identifies opportunities and priorities to conserve and restore habitat connectivity.” They define their vision as: “Permanent protection of a robust, validated network of connected habitats to accommodate species movements, range shifts, and continued ecological functions that maximize retention of biodiversity and ecological integrity in light of existing land-use pressures and climate change." (WWHCWG, 2019).

The Study Area

The analysis area for this project includes the Southern Cascades Mountains from approximately Mount Rainier to the Columbia River down to southwestern Washington and the Olympic Peninsula, and encompasses part of a potential connective path from Eastern Washington to Coastal Washington (Figure 5). The Working Group concluded that their earlier statewide analysis was too general and that a finer-scale approach was needed for this region. This area is especially important for the Gray Wolf because this species is anticipated to recolonize western Washington (Hendricks et al., 2018). Understanding how Wolves use a human-dominated landscape will be beneficial for wildlife managers in their efforts to inform human-carnivore conflict mitigation strategies.

Figure 5: Study area for the coastal Washington connectivity analysis (WWHCWG, 2019).

The Working Group takes a conservation-based approach to landscape management. For this project, the group began with 188 potential species, then narrowed their selection down to 21 "focal species" based on the following considerations: federal listing status, Washington State listing status, NatureServe global rank, the Washington National Heritage Program state rank, the International Union of Conservation of Nature's red list, WDFW priority Species, WDFW species of greatest conservation need, population size, population trends, climate vulnerability, estimated percent of planning area comprised of species range, estimated size of species home range, and summary of conservation concern (Southwest Washington Habitat Connectivity Assessment, 2019). The Working Group decided on Cougar (*Puma con color*), Fisher (*Pekania Pennanti*), Western Gray Squirrel (*Scuirus griseus*), American Beaver (*Castor canadensis*), and Mountain Beaver (*Aplodontia rufa*). The Gray Wolf was carefully considered and initially won approval for becoming a focal species, but was not included in the final analysis because it does not currently occupy the coastal Washington landscape and because public opinion of the Wolf is so varied in Washington State. I elected to study landscape permeability for the Gray Wolf because it meets the criteria for a focal species in that their presence in an ecosystem has far-reaching impacts. Additionally, as a student I have more freedom to explore this species than either the Working Group or state agencies involved in connectivity work. My work lacks the visibility and impact that comes from being a member of the Working Group. My hope is that I can contribute to ongoing work in Washington State to conserve Wolves and their habitat.

Determining Habitat Suitability and Landscape Resistance Scores

For this project, I utilized surface resistance values as indicators of landscape permeability for the Gray Wolf in coastal Washington. I took a focal species approach to habitat connectivity modeling (Southwest Washington Habitat Connectivity Assessment, 2019). To determine habitat and resistance values, I utilized the landscape factors outlined by the Working Group for their connectivity analysis of coastal Washington. These landscape factors were organized into seven categories including: land cover (38 types), streams size (4 ranges of order), slope (3 categories), road types (16 designations), elevation (4 categories), building density (5 categories), and other miscellaneous (9 types) (see appendix A for a full description of the 38 land cover classes). From the Working Group's initial designation, I expanded several of the categories, including slope, elevation, and stream order, in order to offer a finer scale analysis, which could help me identify exactly where Wolf experts might disagree in their scoring. In total, I utilized 111 landscape factors.

I determined habitat suitability and landscape resistance scores for landscape factors by: 1) reviewing literature on Gray Wolf habitat use with a special focus on forested habitats, as well as examining other connectivity analyses for similar species and 2) cataloguing expert opinion from three Wolf biologists (Tables 1 and 2). This information was organized into a series of Excel spreadsheets. I then calculated the mean, standard deviation, and coefficient of variation based on the four scores, which included my literature informed scores along with scores from the three species experts. Habitat suitability scores are ranked on a scale of 0 to 1 with 0 reflecting unusable habitat and 1 as optimal habitat. Landscape resistance scores are ranked on a scale of 0 to 100 with a score of 0 indicating that the landscape feature class has no resistance, i.e. would not impede movement. A resistance score of 100 indicates that the landcover class or feature fully impedes Gray Wolf movement.

Literature Review

From the literature, I catalogued studies that evaluated how the Gray Wolf uses the landscape. I primarily relied on studies that used radio collar telemetry data from Gray Wolves in the U.S. and Europe. Additionally, I drew on other Gray Wolf connectivity analyses and from relevant work on large carnivores. I used this literature review (Appendix C) to determine Gray Wolf habitat suitability and landscape resistance for a total of 111 landscape classes. These classes were determined by the Working Group, which drew from available data for GIS mapping. Based on my review, I found that some classes were better informed than others, and some classes were not informed by the review. I also referenced the Working Group's work on other focal species, with particular attention to their Cougar resistance values, as a point of comparison for my Wolf analysis.

Soliciting Expert Opinion

In an effort to better inform my literature review, I consulted with Wolf experts in order to inform habitat suitability and landscape resistance scores. I reached out to biologists and researchers who had a knowledge of both the Gray Wolf and the Washington State landscape. I followed the general process that the Working Group used for working with species experts. Each species group used slightly different methods for determining resistance scores. However, most species groups relied on several species experts, each of whom developed their own scores. Those scores were then compared and discussed, and modified to reflect the best judgment of the group. The scores from each species group were also compared to those of the other focal species in order to ensure that results from each group could be modeled together. I followed a similar trajectory with species experts for the Gray Wolf. Along with scoring instructions (Appendix A) and National Oceanic and Atmospheric Association (NOAA) land cover classification data (Appendix B), I provided Wolf experts with my draft scores based on the literature review as well as the draft Cougar scores from Working Group's Cougar team; examples that were intended to serve as points of reference for Wolf experts. With this information to guide their process, each of the three Wolf experts determined their scores based on their professional knowledge of both the species and the Washington landscape.

CHAPTER 4: RESULTS

Habitat Suitability Scores

Three out of the four experts that I contacted responded, resulting in a 75% response rate. The three participating species experts included Gregg Kurz, Branch Manager of Listing and Recovery with U.S. Fish and Wildlife; Julia Smith, Wolf Coordinator with Washington Department of Fish and Wildlife; and an anonymous Wolf expert. The use of expert opinion is not quantitative (Beier et al., 2011) and often is nonrepeatable due to a lack of standardized sourcing. However, there is great value in mining the knowledge and experience of species experts for the purpose of predictive modeling.

I included my owns scores with those from the three outside experts, and from the four scores, I calculated the mean, standard deviation, and coefficient of variation (Tables 1 and 2). The mean values, which incorporate the input from each expert, would be used in the final mapping output. The standard deviation and coefficient of variation illuminate the level of concurrence between experts for each class.

Table 1: Table of habitat suitability scores for the Gray Wolf with consideration for 111 landscape covers and features. These scores were provided by the following experts: expert 1- Marisa Pushee (based on a review of the literature), expert 2- Julia Smith with WDFW, expert 3- anonymous Wolf expert, expert 4- Gregg Kurz with USFWS. Following each individual's scores, are the mean of the four scores, the standard deviation (SD), and the coefficient of variation (CV) for each class of land cover/landscape feature.

Land cover/feature	Expert				Mean	SD	CV
	1	2	3	4			
High intensity developed	0.00	0.00	0.00	0.00	0.00	0.00	NA
Medium intensity developed	0.00	0.00	0.00	0.01	0.00	0.01	2.00
Low intensity developed	0.10	0.15	0.10	0.20	0.14	0.05	0.35
Developed open space	0.20	0.15	0.10	0.30	0.19	0.09	0.46
Prairie/native grassland	0.30	0.50	0.10	0.35	0.31	0.17	0.53
Cultivated	0.15	0.15	0.00	0.20	0.13	0.09	0.69
Pasture/Hay	0.10	0.15	0.10	0.20	0.14	0.05	0.35

Table 1 continued

Deciduous Forest	0.99	1.00	0.99	1.00	1.00	0.01	0.01
Evergreen Forest	0.99	1.00	0.99	1.00	1.00	0.01	0.01
Mixed Forest	0.99	1.00	0.99	1.00	1.00	0.01	0.01
Scrub/Shrub	0.80	0.90	0.40	0.90	0.75	0.24	0.32
Palustrine Forested Wetland	0.60	0.70	0.60	0.60	0.63	0.05	0.08
Palustrine Scrub/Shrub Wetland	0.50	0.40	0.60	0.60	0.53	0.10	0.18
Palustrine Emergent Wetland	0.50	0.40	0.60	0.45	0.49	0.09	0.18
Estuarine Forested Wetland	0.50	0.70	0.60	0.60	0.60	0.08	0.14
Estuarine Scrub/Shrub Wetland	0.50	0.40	0.60	0.50	0.50	0.08	0.16
Estuarine Emergent Wetland	0.20	0.40	0.60	0.30	0.38	0.17	0.46
Unconsolidated Shore, Riverine	0.90	1.00	0.20	1.00	0.78	0.39	0.50
Bare land	0.20	0.10	0.00	0.30	0.15	0.13	0.86
Freshwater	0.01	0.01	0.00	0.00	0.01	0.01	1.15
Palustrine Aquatic Bed	0.10	0.05	0.20	0.10	0.11	0.06	0.56
Estuarine Aquatic Bed	0.10	0.05	0.20	0.10	0.11	0.06	0.56
Snow/Ice	0.10	0.10	0.00	0.10	0.08	0.05	0.67
Sparse Forest (CANCOV<10)	0.20	0.30	0.20	0.50	0.30	0.14	0.47
Open Forest (CANCOV 10-39)	0.20	0.50	0.60	0.70	0.50	0.22	0.43
Broadleaf, Sap/pole, mod/closed	0.90	0.95	0.90	0.90	0.91	0.03	0.03
Broadleaf, sm/med/lg, mod/closed	0.90	0.95	0.90	0.90	0.91	0.03	0.03
Mixed, sap/pole, mod/closed	0.90	0.95	0.90	0.90	0.91	0.03	0.03
Mixed, sm/med, mod/closed	0.90	0.95	0.90	0.90	0.91	0.03	0.03
Mixed, lg + giant, mod/closed	0.90	0.95	0.90	0.90	0.91	0.03	0.03
Conifer, sap/pole, mod/closed	0.90	0.95	0.90	0.90	0.91	0.03	0.03
Conifer, sm/med, mod/closed	0.90	0.95	0.90	0.90	0.91	0.03	0.03
Conifer, lg, mod/closed	0.90	0.95	0.90	0.90	0.91	0.03	0.03
Conifer, giant, mod/closed	0.90	0.95	0.90	0.90	0.91	0.03	0.03
Unconsolidated shore, coastal	0.20	0.20	0.20	0.30	0.23	0.05	0.22
Saltwater	0.01	0.01	0.00	0.00	0.01	0.01	1.15
Dunes	0.10	0.20	0.00	0.10	0.10	0.08	0.82
Dry Douglas Fir	0.80	0.99	0.80	0.90	0.87	0.09	0.10
Oak Woodland	0.80	0.99	0.80	0.90	0.87	0.09	0.10
Prairie	0.20	0.50	0.10	0.40	0.30	0.18	0.61
Highly structured agriculture	0.02	0.05	0.00	0.00	0.02	0.02	1.35

Table 1 continued

Built Linear Features							
Transmission lines < 100 volts	0.50	0.00	0.10	0.35	0.24	0.23	0.96
Transmission lines 100-220 volts	0.50	0.00	0.50	0.35	0.34	0.24	0.70
Transmission lines 221-287 volts	0.50	0.00	0.50	0.35	0.34	0.24	0.70
Transmission lines 288-345 volts	0.50	0.00	0.50	0.35	0.34	0.24	0.70
Transmission lines > 345 volts	0.50	0.00	0.50	0.35	0.34	0.24	0.70
Active rail lines	0.00	0.00	0.00	0.00	0.00	0.00	NA
Abandoned rail lines	0.20	0.30	0.00	0.10	0.15	0.13	0.86
Rail bank	0.40	0.30	0.00	0.30	0.25	0.17	0.69
Streams by Order							
Order 1	0.10	0.10	0.00	0.10	0.08	0.05	0.67
Order 2	0.10	0.10	0.00	0.10	0.08	0.05	0.67
Order 3	0.10	0.10	0.00	0.10	0.08	0.05	0.67
Order 4	0.10	0.10	0.00	0.10	0.08	0.05	0.67
Order 5	0.10	0.10	0.00	0.10	0.08	0.05	0.67
Order 6	0.10	0.10	0.00	0.10	0.08	0.05	0.67
Order 7	0.10	0.10	0.00	0.10	0.08	0.05	0.67
Order 8	0.10	0.10	0.00	0.10	0.08	0.05	0.67
Order 9	0.10	0.10	0.00	0.10	0.08	0.05	0.67
Order 10	0.10	0.10	0.00	0.10	0.08	0.05	0.67
Slope							
0-20 degrees	1.00	1.00	0.90	1.00	0.98	0.05	0.05
21-30 degrees	0.90	1.00	0.90	0.95	0.94	0.05	0.05
31-40 degrees	0.90	1.00	0.90	0.95	0.94	0.05	0.05
41-50 degrees	0.90	0.70	0.90	0.85	0.84	0.10	0.11
51-60 degrees	0.90	0.50	0.90	0.85	0.79	0.19	0.25
61-70 degrees	0.90	0.50	0.70	0.85	0.74	0.18	0.24
71-80 degrees	0.90	0.30	0.10	0.65	0.49	0.36	0.73
81-90 degrees	0.90	0.30	0.10	0.45	0.44	0.34	0.78
Roads							
Highways:50 - 500 vehicles/day	0.00	0.00	0.00	0.05	0.02	0.02	1.35
Highways: 501 - 1,000 vehicles/day	0.00	0.00	0.00	0.00	0.00	0.00	NA
Highways: 1,001 - 2,000 vehicles/day	0.00	0.00	0.00	0.00	0.00	0.00	NA
Highways: 2,001 - 5,000 vehicles/day	0.00	0.00	0.00	0.00	0.00	0.00	NA
Highways: 5,001 - 10,000 vehicles/day	0.00	0.00	0.00	0.00	0.00	0.00	NA
Highways: >10,001 vehicles/day	0.00	0.00	0.00	0.00	0.00	0.00	NA

Table 1 continued

Forest—Unpaved	0.30	0.40	0.90	0.30	0.48	0.29	0.60
Paved—Unknown	0.20	0.10	0.00	0.25	0.14	0.11	0.81
Paved—urban	0.02	0.00	0.00	0.01	0.01	0.01	1.28
Rural—Unknown	0.20	0.30	0.00	0.20	0.18	0.13	0.72
All trails	0.99	0.99	0.00	1.00	0.75	0.50	0.67
Elevation							
0-500 ft	0.90	1.00	0.90	1.00	0.95	0.58	0.06
501-1000 ft	0.90	1.00	0.90	1.00	0.95	0.58	0.06
1001-1500 ft	0.90	1.00	0.90	1.00	0.95	0.58	0.06
1501-2000 ft	0.90	1.00	0.90	1.00	0.95	0.58	0.06
2001-2500 ft	0.90	1.00	0.90	1.00	0.95	0.58	0.06
2501-3000 ft	0.90	1.00	0.90	1.00	0.95	0.58	0.06
3001-3500 ft	0.90	1.00	0.90	1.00	0.95	0.58	0.06
3501-4000 ft	0.90	1.00	0.90	1.00	0.95	0.58	0.06
4001-4500 ft	0.90	1.00	0.90	1.00	0.95	0.58	0.06
4501-5000 ft	0.90	1.00	0.70	1.00	0.90	0.14	0.16
5001-5500 ft	0.90	1.00	0.70	1.00	0.90	0.14	0.16
5501-6000 ft	0.90	1.00	0.70	1.00	0.90	0.14	0.16
6001-6500 ft	0.90	1.00	0.50	1.00	0.85	0.24	0.28
6501-7000 ft	0.50	1.00	0.10	0.40	0.50	0.37	0.75
7001-7500 ft	0.50	1.00	0.10	0.40	0.50	0.37	0.75
7501-8000 ft	0.50	1.00	0.10	0.40	0.50	0.37	0.75
8001-8500 ft	0.50	1.00	0.10	0.40	0.50	0.37	0.75
8501-9000 ft	0.50	1.00	0.10	0.40	0.50	0.37	0.75
9001-9500 ft	0.50	0.50	0.10	0.40	0.38	0.19	0.50
9501-10000 ft	0.50	0.50	0.10	0.40	0.38	0.19	0.50
10001-10500 ft	0.50	0.50	0.10	0.40	0.38	0.19	0.50
10501-11000 ft	0.50	0.50	0.10	0.40	0.38	0.19	0.50
11001-11500 ft	0.50	0.50	0.10	0.40	0.38	0.19	0.50
11501-12000 ft	0.50	0.50	0.10	0.40	0.38	0.19	0.50
12001-12500 ft	0.50	0.50	0.10	0.40	0.38	0.19	0.50
12501-13000 ft	0.50	0.50	0.10	0.40	0.38	0.19	0.50
13001-13500 ft	0.50	0.50	0.10	0.40	0.38	0.19	0.50
13501-14000 ft	0.50	0.50	0.10	0.40	0.38	0.19	0.50
14001-14500 ft	0.50	0.50	0.10	0.40	0.38	0.19	0.50
Building Density							
No buildings	1.00	1.00	1.00	1.00	1.00	0.00	0.00
Isolated buildings	0.20	0.50	0.20	0.20	0.28	0.15	0.55
Clusters of buildings	0.02	0.20	0.10	0.05	0.09	0.08	0.85
High density buildings	0.00	0.00	0.00	0.00	0.00	0.00	NA

Landscape Resistance Scores

The following landscape resistance scores are ranked on a scale of 0 to 100 with a score of 0 indicating that the landscape feature class has no resistance value, i.e. would not impede movement, for the Gray Wolf. A resistance score of 100 indicates that the landcover class or feature fully impedes Gray Wolf movement. The following tables follow the structure of the habitat tables above. The four Gray Wolf experts are listed in the following order: Marisa Pushee (based on literature review), Julia Smith with WDFW, anonymous Wolf expert, and Gregg Kurz with USFWS. From the four experts' landscape resistance scores, I calculated the mean, standard deviation, and coefficient of variation. The mean values, which incorporate the input from each expert, would be used in the final mapping output. The standard deviation and coefficient of variation illuminate the level of concurrence between experts for each class.

Table 2: Table of landscape resistance scores for the Gray Wolf with consideration for 111 landscape covers and features. These scores were provided by the following experts: expert 1- Marisa Pushee (based on a review of the literature), expert 2- Julia Smith with WDFW, expert 3- anonymous Wolf expert, expert 4- Gregg Kurz with USFWS. Following each individual's scores, are the mean of the four scores, the standard deviation (SD), and the coefficient of variation (CV) for each class of land cover/landscape feature.

Land cover/feature	Expert				Mean	SD	CV
	1	2	3	4			
High intensity developed	100	99	100	99	99.50	0.58	0.01
Medium intensity developed	70	60	95	60	71.25	16.52	0.23
Low intensity developed	40	30	75	35	45.00	20.41	0.45
Developed open space	30	30	80	25	41.25	25.94	0.63
Cultivated	35	30	90	20	43.75	31.46	0.72
Pasture/Hay	35	30	60	20	36.25	17.02	0.47
Grassland	20	0	30	10	15.00	12.91	0.86
Deciduous Forest	1	0	1	1	0.75	0.50	0.67
Evergreen Forest	1	0	1	1	0.75	0.50	0.67
Mixed Forest	1	0	1	1	0.75	0.50	0.67
Scrub/Shrub	1	0	20	1	5.50	9.68	1.76
Palustrine Forested Wetland	1	0	5	2	2.00	2.16	1.08
Palustrine Scrub/Shrub Wetland	1	0	5	1	1.75	2.22	1.27

Table 2 continued

Palustrine Emergent Wetland	5	10	5	4	6.00	2.71	0.45
Estuarine Forested Wetland	1	0	5	1	1.75	2.22	1.27
Estuarine Scrub/Shrub Wetland	1	0	5	1	1.75	2.22	1.27
Estuarine Emergent Wetland	5	10	5	4	6.00	2.71	0.45
Unconsolidated Shore, Riverine	1	0	5	1	1.75	2.22	1.27
Bare Land	20	0	10	7	9.25	8.30	0.90
Freshwater	25	30	20	15	22.50	6.46	0.29
Palustrine Aquatic Bed	25	25	20	15	21.25	4.79	0.23
Estuarine Aquatic Bed	25	25	20	15	21.25	4.79	0.23
Snow/Ice	5	5	10	5	6.25	2.50	0.40
Sparse Forest (CANCOV<10)	10	0	10	2	5.50	5.26	0.96
Open Forest (CANCOV 10-39)	20	0	10	2	8.00	9.09	1.14
Broadleaf, Sap/pole, mod/closed	1	0	1	1	0.75	0.50	0.67
Broadleaf, sm/med/lg, mod/closed	1	0	1	1	0.75	0.50	0.67
Mixed, sap/pole, mod/closed	1	0	1	1	0.75	0.50	0.67
Mixed, sm/med, mod/closed	1	0	1	1	0.75	0.50	0.67
Mixed, lg + giant, mod/closed	1	0	1	1	0.75	0.50	0.67
Conifer, sap/pole, mod/closed	1	0	1	1	0.75	0.50	0.67
Conifer, sm/med, mod/closed	1	0	1	1	0.75	0.50	0.67
Conifer, lg, mod/closed	1	0	1	1	0.75	0.50	0.67
Conifer, giant, mod/closed	1	0	1	1	0.75	0.50	0.67
Unconsolidated shore, Coastal	35	10	10	20	18.75	11.82	0.63
Saltwater	20	40	20	15	23.75	11.09	0.47
Dunes	20	0	70	15	26.25	30.38	1.16
Dry Douglas Fir	1	0	1	1	0.75	0.50	0.67
Oak Woodland	1	0	1	1	0.75	0.50	0.67
Prairie	2	0	25	1	7.00	12.03	1.72
Highly structured agriculture	40	30	50	35	38.75	8.54	0.22
Built Linear Features							
Transmission lines < 100 volts	2	0	5	2	2.25	2.06	0.92
Transmission lines 100-220 volts	2	0	5	2	2.25	2.06	0.92
Transmission lines 220-287 volts	2	0	5	2	2.25	2.06	0.92
Transmission lines 287-345 volts	2	0	5	2	2.25	2.06	0.92
Transmission lines > 345 volts	2	0	5	2	2.25	2.06	0.92
Active rail lines	50	30	30	10	30.00	16.33	0.54
Abandoned rail lines	2	0	5	1	2.00	2.16	1.08
Rail bank	1	0	40	1	10.50	19.67	1.87

Table 2 continued

Streams by Order							
Order 1	1	0	5	1	1.75	2.22	1.27
Order 2	1	0	5	1	1.75	2.22	1.27
Order 3	1	0	5	1	1.75	2.22	1.27
Order 4	1	0	5	1	1.75	2.22	1.27
Order 5	1	0	5	1	1.75	2.22	1.27
Order 6	1	0	5	1	1.75	2.22	1.27
Order 7	5	5	5	3	4.50	1.00	0.22
Order 8	5	5	5	3	4.50	1.00	0.22
Order 9	5	5	5	5	5.00	0.00	0.00
Order 10	5	5	5	5	5.00	0.00	0.00
Slope							
0-20 degrees	1	0	1	1	0.75	0.50	0.67
21-30 degrees	1	0	1	1	0.75	0.50	0.67
31-40 degrees	1	0	1	1	0.75	0.50	0.67
41-50 degrees	1	10	1	1	3.25	4.50	1.38
51-60 degrees	1	20	1	1	5.75	9.50	1.65
61-70 degrees	1	20	1	1	5.75	9.50	1.65
71-80 degrees	1	30	60	5	24.00	27.22	1.13
81-90 degrees	2	30	95	20	36.75	40.53	1.10
Roads							
Highways:50 - 500 vehicles/day	20	10	10	15	13.75	4.79	0.35
Highways: 501 - 1,000 vehicles/day	50	30	40	30	37.50	9.57	0.26
Highways: 1,001 - 2,000 vehicles/day	60	50	60	40	52.50	9.57	0.18
Highways: 2,001 - 5,000 vehicles/day	80	70	60	50	65.00	12.91	0.20
Highways: 5,001 - 10,000 vehicles/day	90	90	80	70	82.50	9.57	0.12
Highways: >10,001 vehicles/day	100	99	90	99	97.00	4.69	0.05
Forest Unpaved	1	0	1	1	0.75	0.50	0.67
Paved Unknown	20	10	20	10	15.00	5.77	0.38
Paved Urban	30	30	95	20	43.75	34.49	0.79
Rural Unknown	10	10	20	7	11.75	5.68	0.48
All trails	1	0	1	1	0.75	0.50	0.67

Table 2 continued

Elevation							
0-500 ft	1	0	1	1	0.75	0.50	0.67
501-1000 ft	1	0	1	1	0.75	0.50	0.67
1001-1500 ft	1	0	1	1	0.75	0.50	0.67
1501-2000 ft	1	0	1	1	0.75	0.50	0.67
2001-2500 ft	1	0	1	1	0.75	0.50	0.67
2501-3000 ft	1	0	1	1	0.75	0.50	0.67
3001-3500 ft	1	0	1	1	0.75	0.50	0.67
3501-4000 ft	1	0	1	1	0.75	0.50	0.67
4001-4500 ft	1	0	1	1	0.75	0.50	0.67
4501-5000 ft	1	0	1	1	0.75	0.50	0.67
5001-5500 ft	1	0	1	1	0.75	0.50	0.67
5501-6000 ft	1	0	1	1	0.75	0.50	0.67
6001-6500 ft	10	0	1	1	3.00	4.69	1.56
6501-7000 ft	10	0	1	1	3.00	4.69	1.56
7001-7500 ft	10	0	1	1	3.00	4.69	1.56
7501-8000 ft	10	0	20	5	8.75	8.54	0.98
8001-8500 ft	10	0	20	5	8.75	8.54	0.98
8501-9000 ft	10	0	20	5	8.75	8.54	0.98
9001-9500 ft	10	0	80	5	23.75	37.72	1.59
9501-10000 ft	10	0	80	5	23.75	37.72	1.59
10001-10500 ft	10	0	80	5	23.75	37.72	1.59
10501-11000 ft	10	5	80	5	25.00	36.74	1.47
11001-11500 ft	10	5	80	5	25.00	36.74	1.47
11501-12000 ft	10	5	80	5	25.00	36.74	1.47
12001-12500 ft	10	5	80	5	25.00	36.74	1.47
12501-13000 ft	10	5	80	5	25.00	36.74	1.47
13001-13500 ft	10	5	80	5	25.00	36.74	1.47
13501-14000 ft	10	5	80	5	25.00	36.74	1.47
14001-14500 ft	10	5	80	5	25.00	36.74	1.47
Building Density							
No buildings	1	0	1	1	0.75	0.50	0.67
Isolated buildings	50	0	25	10	21.25	21.75	1.02
Clusters of buildings	80	70	90	20	65.00	31.09	0.48
High density building	100	100	100	99	99.75	0.50	0.01

CHAPTER 5: DISCUSSION

The statistics displayed in Tables 1 and 2 demonstrate the degree of concurrence among experts on habitat suitability and landscape resistance for the Gray Wolf. In each of these tables, the coefficient of variation (CV) suggests where Wolf experts most strongly agreed or disagreed. Classes with a high CV likely require further exploration and conversation among experts. Some of these discrepancies may have resulted from varying interpretations of the landscape classes, whereas others may have resulted from differing opinions on how the Gray Wolf uses the landscape. In both the literature review and expert feedback, roads were revealed to be one of the most interesting categories, as they can facilitate Wolf movement but also pose a mortality risk. Additionally, a comparison of the standard deviation across all CV values for habitat suitability (0.370) and for landscape resistance (0.464) suggests that Gray Wolf experts tended to agree more on habitat suitability than they did on landscape resistance as a whole. These results may in part be due to habitat suitability being more widely studied than landscape permeability.

While the next steps of this work were beyond the scope of this thesis, these steps should include continuing conversations with the Gray Wolf experts who participated in the work in an attempt to find common ground on scoring. Following these conversations and the fine tuning of habitat suitability and landscape resistance scores, the results can then be used in Esri Geographic Information Systems (GIS) maps. Additional components for consideration could also include prey distribution and sociological factors including land ownership and social tolerance of Wolves. This visualization and spatial analysis will be useful for informing Wolf management and conservation issues. In particular, these maps can help explore questions about how the Gray Wolf will use this landscape as core habitat and as movement habitat. In turn this information may be critical for engaging stakeholders in finding creative ways to manage the landscape in ways that minimize human-Wolf conflict.

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Appendix A:

The following scoring instructions were sent to prospective Gray Wolf experts in order to guide them in the scoring process.

Scoring Instructions

Goals:

This project builds on the current coastal connectivity mapping project by the Washington Wildlife Habitat Connectivity Working Group (WWHCWG). The Working Group's project seeks to identify areas with high ecological value for conserving and/or restoring conditions that promote desirable wildlife movements. The Working Group intends to support the broadest possible range of native species by analyzing habitat for a suite of focal species, which includes Cougar, Fisher, Western Gray Squirrel, American Beaver, and Mountain Beaver.

My thesis project is intended to complete this process for the Gray Wolf. The goal of my work is to both build on the Working Group's analyses and to help managers understand how different landscape configurations could help reduce the potential for future human-Wolf conflict in coastal Washington.

Process:

The attached Excel sheet lists *land cover* types, e.g., forest types, agricultural land types, etc., and *land features*, which include attributes of land cover types, (e.g., elevation, slope, and presence of linear features such as streams, roads, transmission lines, and railroad tracks). Each *land cover type* has a value to Wolves as habitat for meeting life requirements (feeding, breeding, rearing, resting). Each *land feature* can affect the quality of the habitat in general terms (elevation or slope) and in more site-specific ways like the presence of roads or streams.

We would like you to rank habitat value of land cover and land features as the first step in the process. Habitat values are ranked on a scale of 0 to 1, where a value of 0 indicates no habitat value, and 1 indicates ideal habitat. For example, using the Working Group's Cougar scores as a proxy, "high intensity developed" land cover ranked as a 0 habitat score for Cougars whereas "prairie" ranked as 0.38 (medium value) and "conifer, large, mod/closed" ranked as a 1 as ideal cougar habitat. Similarly, the highways as a land feature with more than 500 cars per day has no habitat value (score of 0) for Cougars whereas all trails ranked as idea habitat.

The second task is to rank land cover and land features by resistance. Resistance values range from 1 to 100 and indicate the degree to which land cover and land features facilitate or impede species movements. High resistance scores e.g., 100, indicates that land cover or feature strongly impedes a species movement. For example, "high intensity developed" land and "highways with greater than 10,001 vehicles per day" were both ranked very high (100) for resistance scores for cougars. Broadleaf, mixed, and conifer forest categories all received a resistance score of 1 as they maximally facilitate cougar movement.

In the attached spreadsheet, you will find the Working Group's draft values for the habitat and resistance scores for cougar as well as my initial draft values for gray wolves. My Gray Wolf values are based on my ongoing literature review and will also be informed by input from Wolf experts including yourself. The species scores for this project are relational and as such I am asking you as a wolf expert assign habitat and resistance scores for Wolves based on the Cougar scores, which are provided as a proxy.

I value your expert opinion in determining these scores. Please use your judgement to best fill out each score even if you are more confident in some of your scoring decisions than others. For this project, you don't need empirical information to support your scoring and I don't expect you to refer to the literature. I am placing value on your judgement as a Wolf expert.

For my thesis, I will be averaging scores from four Wolf experts with local knowledge to Washington state and comparing those totals with the results from my literature review. I will also report simple metrics of uncertainty across experts by the calculating measures of dispersion around mean estimates.

Please let me know if I can credit you for your input or if you would prefer to remain anonymous. Let me know if you have any questions. Thank you for participating in this work.

Appendix B:

The following land cover classification data scheme was shared with Wolf experts in order to help inform their decisions on determining habitat and landscape resistance scores.

Coastal Change Analysis Program (C-CAP) NOAA Office for Coastal Management

Regional Land Cover Classification Scheme

The following information provides a description of land cover classes used with NOAA's Coastal Change Analysis Program (C- CAP) Regional land cover products. These classes have been targeted as important indicators of coastal ecosystems and have been identified as features that can be consistently and accurately derived primarily through remote-sensing means.

These descriptions have been revised from those originally published in NOAA Coastal Change Analysis Program (C-CAP): Guidance for Regional Implementation.

Unclassified

Background (0) – areas within the image file limits but containing no data values.

Unclassified (1) – areas in which land cover cannot be determined; these include clouds and deep shadow.

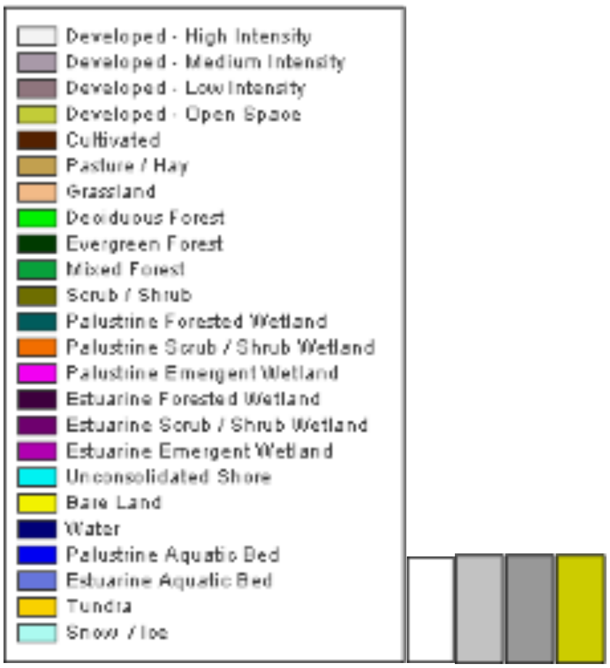
Developed Land

Developed, High Intensity (2) – contains significant land area and is covered by concrete, asphalt, and other constructed materials. Vegetation, if present, occupies less than 20 percent of the landscape. Constructed materials account for 80 to 100 percent of the total cover. This class includes heavily built-up urban centers and large constructed surfaces in suburban and rural areas with a variety of land uses.

Developed, Medium Intensity (3) – contains areas with a mixture of constructed materials and vegetation or other cover. Constructed materials account for 50 to 79 percent of total area. This class commonly includes multi- and single-family housing areas, especially in suburban neighborhoods, but may include all types of land use.

Developed, Low Intensity (4) – contains areas with a mixture of constructed materials and substantial amounts of vegetation or other cover. Constructed materials account for 21 to 49 percent of total area. This subclass commonly includes single-family housing areas, especially in rural neighborhoods, but may include all types of land use.

Developed, Open Space (5) – contains areas with a mixture of some constructed materials, but mostly managed grasses or low-lying vegetation planted in developed areas for recreation, erosion control, or aesthetic purposes. These areas are maintained by human activity such as fertilization and irrigation, are distinguished by enhanced biomass productivity, and can be recognized through vegetative indices based on spectral characteristics. Constructed surfaces account for less than 20 percent of total land cover.



C-CAP Regional Land Cover Classification Scheme — 2

Agricultural Land

Cultivated Crops (6) – contains areas intensely managed for the production of annual crops. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.

Pasture/Hay (7) – contains areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle and not tilled. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.

Grassland

Grassland/Herbaceous (8) – contains areas dominated by grammanoid or herbaceous vegetation, generally greater than 80 percent of total vegetation. These areas are not subject to intensive management such as tilling but can be utilized for grazing.

Forest Land

Deciduous Forest (9) – contains areas dominated by trees generally greater than 5 meters tall and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.

Evergreen Forest (10) – contains areas dominated by trees generally greater than 5 meters tall and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.

Mixed Forest (11) – contains areas dominated by trees generally greater than 5 meters tall, and greater than 20 percent of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover. *Both coniferous and broad-leaved evergreens are included in this category.*

Scrub Land

Scrub/Shrub (12) – contains areas dominated by shrubs less than 5 meters tall with shrub canopy typically greater than 20 percent of total vegetation. This class includes tree shrubs, young trees in an early successional stage, or trees stunted from environmental conditions.

Barren Land

Barren Land (20) – contains areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits, and other accumulations of earth material. Generally, vegetation accounts for less than 10 percent of total cover.

Tundra (24) – is categorized as a treeless region beyond the latitudinal limit of the boreal forest in pole-ward regions and above the elevation range of the boreal forest in high mountains. In the United States, tundra occurs primarily in Alaska.

Perennial Ice/Snow (25) – includes areas characterized by a perennial cover of ice and/or snow, generally greater than 25 percent of total cover.

C-CAP Regional Land Cover Classification Scheme ─ 3

Palustrine Wetlands

Palustrine Forested Wetland (13) – includes tidal and nontidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent.

Palustrine Scrub/Shrub Wetland (14) – includes tidal and nontidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent. *Species present could be true shrubs, young trees and shrubs, or trees that are small or stunted due to environmental conditions.*

Palustrine Emergent Wetland (Persistent) (15) – includes tidal and nontidal wetlands dominated by persistent emergent vascular plants, emergent mosses or lichens, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation cover is greater than 80 percent. *Plants generally remain standing until the next growing season.*

Estuarine Wetlands

Estuarine Forested Wetland (16) – includes tidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.

Estuarine Scrub/Shrub Wetland (17) – includes tidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.

Estuarine Emergent Wetland (18) – Includes all tidal wetlands dominated by erect, rooted, herbaceous hydrophytes (excluding mosses and lichens). These wetlands occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent and are present for most of the growing season in most years. Total vegetation cover is greater than 80 percent. *Perennial plants usually dominate these wetlands.*

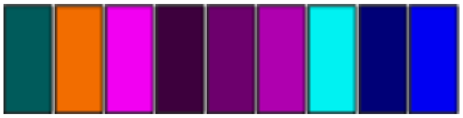
Barren Land

Unconsolidated Shore (19) – includes material such as silt, sand, or gravel that is subject to inundation and redistribution due to the action of water. Substrates lack vegetation except for pioneering plants that become established during brief periods when growing conditions are favorable.

Water and Submerged Lands

Open Water (21) – includes areas of open water, generally with less than 25 percent cover of vegetation or soil.

Palustrine Aquatic Bed (22) – includes tidal and nontidal wetlands and deepwater habitats in which salinity due to ocean-derived salts is below 0.5 percent and which are dominated by plants that grow and form a continuous cover principally on or at the surface of the water. These include algal mats, detached floating mats, and rooted vascular plant assemblages. Total vegetation cover is greater than 80 percent.



C-CAP Regional Land Cover Classification Scheme ─ 4

Estuarine Aquatic Bed (23) – includes tidal wetlands and deepwater habitats in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent and which are dominated by plants that grow and form a continuous cover principally on or at the surface of the water. These include algal mats, kelp beds, and rooted vascular plant assemblages. Total vegetation cover is greater than 80 percent.

Appendix C:

Appendix Table 1: Literature review for Gray Wolf landscape use. This table displays a limited selection of the sources that I used in my literature review to inform my habitat suitability and landscape resistance scores. While this table is not comprehensive, it provides some amount of transparency in how I cataloged and tracked previous research by organizing studies with attention to their date, location, main conclusions, habitat type, methods, and other considerations. Additional sources that I referenced to determine my habitat suitability and landscape resistance scores can be found in the bibliography of this thesis.

Source and study location /environment	**Main conclusions of the study**	**Habitat type**	**Methods**	**Other considerations**
Ciucci et al., 2018 Apennines, Italy (Pollino National Park)	Wolves preferentially located rendezvous sites close to meadows, wetlands or other water sources, and forests, (some variability concerning forest types, canopy closure, soil type, and topography) Avoided areas featuring high densities of humans, paved roads, and trails Selected for higher forest cover and rough terrain enhanced concealment and ensured reduced accessibility by humans Selected open areas and (at coarse grain) areas of high density of dirt roads and trails Selected for forest cover, avoided low-use anthropogenic	Boreal and temperate ecosystems in North America	Snow tracking Howling surveys Telemetry (5 wolves in 6 packs) 10 environmental, topographic, and anthropogenic variables in GIS	Documented rendezvous sites Wolves living in human-dominated landscapes

	linear features and rough terrain--revealed trade-offs in selection decisions across spatial and temporal scales			
Demma and Mech, 2009 Northeastern Minnesota, Superior National Forest	Mean daily range overlap was 22% (SE = 0.02) Average daily range overlap was greater (t216 = -2.12, P = 0.04) for breeders (25%, SE = 0.03, n = 143) than nonbreeders (16%, SE = 0.03, n = 75) Wolves used MCP areas of 100-396 km^2 Homesites made up an average of 31% (SE = 5, n + 6) of each Wolf's GPS locations Breeding wolves (2F, 1M) were present at homesites on 81-100% of days & nonbreeder use was more varied	1,300-km^2 area in the central Superior National Forest	May-July 2003 and 2004, researchers trapped, immobilized, and examined 8 Wolves Researchers fitted wolves with store-on-board and remote downloadable GPS radio collars; 6 Televit collars at 10 min intervals as well as 1 ATS and 1 Vectronic collar at 15 min intervals each Excluded data from the first 5 days post capture Plotted GPS data in ArcMap	Prey included white tailed deer, which occurred at a density of 12-15/10 km^2 Wolves were 1-2 years old (only 1 showed signs of breeding)
Hebblewhite and Merrill, 2008 Banff National Park in Alberta, Canada	Wolves strongly avoided steeper slopes and strongly selected for areas closer to 'hard' edges Selected burned and alpine areas during summer, but selected	Subarctic climate dominated by Lodgepole Pine at lower elevations and Engelmann Spruce in higher ones below the treeline, above which is	16 wolves from five packs with GPS collars RSF-models of GPS-data	Objective: to extend the application of mixed-effect RSFs--resource selection by the Gray Wolf

	burns less and avoided alpine completely in the winter Stronger avoidance of rock during winter Open conifer and cutblocks areas were selected during summer, but were as equally avoided as forested habitats during winter Summer, during the day: correlation between all Wolves within packs, ρ(*pack*), and between Wolves for a specific pack, ρ(*wolf*, *pack*), were similar, 0·62 and 0·69 Summer, night: Wolves within packs were less correlated than with other packs (0·15 vs. 0·55) Winter: different packs were not correlated during either night or day (ρ = 0·11, 0·03); Wolves within a specific pack were highly correlated (ρ = 0·909, 0·907). ρ(*wolf*, *pack*) > ρ(*pack*) As human activity increased, packs were constrained to select	primarily rocks and ice		

	areas closer to human activity at home-range scale At high human activity levels, the response differed depending on time of day			
James and Smith, 2000 Northeastern Alberta, Canada	Wolf locations were closer (134 m) than random to linear corridors Wolf predation sites were not significantly closer to corridors than were wolf locations or random points Significant point type by habitat interaction ($F_{1,2173} = 9.2$, $P = 0.002$) Within caribou range, telemetry locations of Wolves were on average 134 m closer to corridors than were random points ($F_{1,1197} = 9.3$, $P = 0.002$) Significant pack effect ($F_{7,1197} = 5.7$, $P < 0.001$) Outside caribou range, significant point type by pack interaction (F6,976 = 5.8, P<0.001)	(56 degrees N, 112 degrees W) encompassed approximately 20,000 km^2 of boreal mixed wood and peatland vegetation Elevation ranged from 500-700 m Wetlands were dominated by Black Spruce/ Black Spruce-Tamarack, ferns, and bogs Well-drained sites were dominated by Aspen, White Spruce, and Jack Pine	From 1994 to 1997, researchers placed VHF collars on 20 Wolves from 7 packs and on 3 lone wolves Radio-collared Wolves were located every 2-3 weeks and researchers collected additional locations twice a day for 15 consecutive days during winters of 1996 and 1997 Examined the distribution of 2,616 telemetry locations of caribou, 27 caribou mortality sites, 592 telemetry locations of Wolves, and 76 sites where Wolves had preyed on large ungulates	Researchers tested the hypothesis that linear corridors (roads, seismic lines, power lines, and pipeline right of ways) affect caribou and wolf activities 25,500 km of the 26,850 km of linear corridors studied were seismic lines or pipeline right of ways (a few gravel roads and one paved road)

			relative to linear corridors in caribou range	
Kunkel and Pletscher, 2000 Northwestern Montana and southeastern British Columbia, Canada	Within their home ranges, Wolves selected areas that facilitated travel including lower snow depths and more vegetative cover or that enhanced encounters with prey Wolves selected topographic, cover, and slope similar to those selected by prey within their range Killed deer in areas with greater hiding-stalking cover, less slope and closer to water than expected Hiding cover was 1.2 times greater at kill sites than along travel routes Kill sites had 37% less slope than travel routes Predator concealment was more important than prey detectability—Wolves were more successful in dense stalking-hiding cover	1,024 to 1,375 m in elevation Transitional between the northern Pacific coastal and the continental types Dense Lodgepole Pine forests dominated most of the valley with additional occurrence of Alpine Fir, Spruce, Western Larch, and Douglas-fir Meadows and riparian areas also dispersed throughout	Captured and radio-tagged 30 Wolves in 3-4 packs Followed Wolf travel routes on skis and snowshoes Spatial analysis in GIS	1990-1996 Objective: determine effects of spatial and habitat features on hunting success of Wolves
Lleneza et al., 2012	Predictors related with landscape attributes (altitude, roughness and refuge) strongly	Galicia (NW Spain); covering c. 30,000 km^2	Data on the distribution of Wolves came from regional	Human-dominated landscape with human

NW Iberian Peninsula	determined Wolf occurrence, followed by humans and food availability Variance partitioning analysis revealed that the three most important components determining Wolf occurrence were related with: (1) the joint effects of the three predictor groups, (2) the joint effect of humans and landscape attributes and (3) the pure effect of landscape attributes Mean altitude had the highest proportion of independent contribution to explaining the probability of Wolf occurrence (35.6%), followed by density of buildings (23.8%), density of horses (13.4%) and density of roads (11.2%) Wolves showed a strong positive selection towards elevated and hardly accessible sites as well as areas where vegetation structure provided refuge	patchy and heterogeneous landscape of cropland, pasture, scrub, semi-natural deciduous forest (Quercus robur, Quercus pyrenaica and Betula alba) and forest plantations (Eucalyptus spp. and Pinus spp.). Cover percentage of pastures and crops in Galicia is 39%, 23% for forest plantations and 26.6% for scrublands, which have been transformed by human activities. Less than 10% of this area is occupied by woodland deciduous forest and most of them have been managed for timber harvest.	Wolf surveys carried out in the summer-autumn periods (breeding and pre-dispersal periods) between 1999 and 2003 Wolf presence was determined by indirect signs such as feces and ground scratch marks, excluding tracks owing to the difficulty of differentiating dog tracks from wolf tracks	settlements (> 10 buildings) widely scattered (1 human settlement/km^2; c. 50% of human settlements of Spain are located in Galicia) and a mean human population density around 93 inhabitants km^2. The percentage of people living in small villages in Galicia (< 10 buildings) is 16.5%, whereas this percentage for the overall country is four times lower. Researchers did not consider unpaved roads
Mech et al., 1998 Minnesota	Primary threat to Wolves, which is associated with high road densities, is the accessibility that	About 46% of Minnesota was considered	Wolf distribution (relative to road density) was mapped by the	The mean density of roads was 0.36 km/km^2

	roads allow humans to kill Wolves (shooting, snaring, and trapping) Road densities may be associated with different types of land use	An area of 100,576 km^2 The area inhabited by wolves totaled 59,900 km^2 The region was primarily coniferous and deciduous forest, but the southern and western portions also contained brushlands, scattered old fields, and pastures	three coauthors who had knowledge of Wolf distribution based on previous experience Surveyed 112 local canid trappers by mail and telephone in 1982 and 1983	The peripheral and disjunct parts of the Wolf range varied in size from 686 to 9,915 km^2 and density of roads averaged 0.54 km/km^2 The two contiguous regions uninhabited by Wolves had mean road densities of 0.88 and 0.81 km/km^2, and the part of the primary range devoid of wolves, >0.83 km/km^2
Theuerkauf et al., 2003 The Bialowieza Forest, Poland	Daily activity patterns of Wolves in the study area were mainly shaped by their pattern of hunting prey (rather than human activity or other factors) Wolves were active 45% of the day on average with activity highest at dusk and dawn Hourly activity and distance traveled was highest 2 hrs. before Wolves made a kill	Transition zone between boreal and temperate climate. Forest consists of deciduous, coniferous, and mixed tree stands Human density—approx. 7 inhabitants/km^2 in the Bialowieza Forest and 70 inhabitants/km^2 in the region	Radio tracked 11 Wolves During 24 hr. radio tracking session of usually 6 days, researchers noted locations every 15 min (1996-1999) or every 30 min (1994-1996)	The density of forest roads suitable for 2-wheel drive cars was about 1.2 km/km^2 in the commercial forest, but only about 0.1 km/km^2 are intensively used by the public

	Activity and movement were highest in March during mating season Did not find a correlation between human activity and temporal activities of Wolves where Wolves have the opportunity to avoid contact with humans	surrounding the study area		
Theurekauf et al., 2007 Bieszczady, Poland	Wolves avoided the area around main public roads more at night (up to a distance of 1.5 km) than in the day (up to 0.5 km) Wolves avoided a 0.5-km area around secondary public roads and paved forest roads both at night and in the day but did not avoid the surroundings of set Human activity is unlikely to be the reason for nocturnal activity in Wolves Wolves moved at any time of the day with a major peak of the distance travelled per hour around dawn and a small peak in the early night	Bieszcz Mountains Southeastern Poland 62% of the area was forested Forest mainly consisted of Beech, Fir, Spruce, and Grey Alder The degree of forest fragmentation was 74%	Radio tracked wolves from 3 packs: 24 hr radio tracking sessions in 2002-2006 (usually one session each month for each Wolf) Used a magnetic counter card placed in forest roads to document human activity	Wolves were hunted until 1998 in the study area Human density was higher than in any other Wolf study Paved road density as 0.64 km/ km^2 (considered the threshold for Wolf occurrence)
Whittington et al., 2005	Wolves selected low elevations, shallow slopes, and southwest aspects	Jasper lies in the confluence of several valleys--valley bottoms are dominated by	Recorded the movements of two Wolf packs	Researchers simplified Wolf paths into a series of points

The town of Jasper in Jasper National Park Alberta, Canada	Selected areas within 25 m of roads, trails, and the railway line and more strongly selected low-use roads and trails compared to high-use roads and trails One pack strongly avoided distances between 26 and 200 m of high-use trails; otherwise, the Wolves weakly selected or avoided this distance class Both packs avoided areas of high road and trail density The use of roads and trails was negatively coupled with road density Selected to be close to areas of low human activity but far from high human activity areas Wolves traveled within 25 m of roads, trails, and railway lines 21% of the time and traveled through the forests, rivers, and meadows the other 79% of the time Both Wolf packs traveled five times farther on low-use trails than high-use	open Lodgepole Pine forests that are interspersed with Douglas fir, Aspen, Poplar, White Apruce, and small meadow complexes. Sides of the valley are dominated by Englemann spruce and subalpine Fir. Snow depths along the valley bottoms range from 5 to 40 cm The study area contained 759 km of trails and 292 km of roads including a railway line The territories of both packs extended between 20 and 50 km along the three valleys that converge upon the town of Jasper The study area included a portion of these two pack territories, approximately 20 km each side of Jasper (52052' N, 118005' W, elevation 970-	for two winters (1999-2000) Snow tracking and simultaneously recording positions with a hand-held global positioning system Used matched case-controlled logistic regression to compare habitat covariates of Wolf paths (cases) to multiple paired random locations (controls)	separated by 100 m, which produced 481 wolf points for pack 1 and 467 wolf points for pack 2 Wolves in this study were not subjected to legal or illegal hunting. Wolves were subject to mortality from collisions with vehicles and trains. Researchers note the association that researchers found between roads, trails, and topography could create conservative estimates of road and trail avoidance The number of Wolves in Pack 1 ranged from seven to ten individuals The number of wolves in Pack 2 ranged from two to three individuals

	trails, yet only Pack 2 traveled farther on low use roads than on high use roads (Pack 2 rarely traveled on high use roads and the railway line) Other variables ranked from most to least important included: low-use roads, railways, high-use trails, and high-use roads	2800 m above sea level) The outer limits of the study area coincided with park boundaries, prominent geographic features, and Wolf territorial boundaries While the study area encompassed 2900 km^2, only 572 km^2 lay below 1600 m where 99% of wolf movements occurred		A major transportation highway (not divided or fenced) with substantial freight-truck traffic runs through the study area from northeast to west. Secondary highways extend throughout Jasper National Park. Jasper received 1 288 788 vehicles in 2000, a 22% increase from 1990 Seasonal variation in traffic volume
Zimmerman et al., 2014 Scandinavia	At the site scale (approximately 0.1 km^2), Wolves selected for roads when traveling, nearly doubling their travel speed At the patch scale (10 km^2), house density rather than road density was a significant negative predictor of Wolf patch selection At the home range scale (approximately 1000 km^2), breeding Wolves increased	Within the Wolf breeding range in south-central parts of the Scandinavian Peninsula (Sweden and Norway); 59–62°N, 10–15°E, approximately 100000 km^2. Wolf territories were primarily covered by boreal coniferous forest dominated by Scots Pine and Norway Spruce with some	Analyzed the summer movements of 19 GPS-collared resident Wolves in relation to roads	Differentiated between breeding and nonbreeding Wolves Behavioral response of Scandinavian Wolves to roads is a complex process dependent on time of day, road type, behavioral state, reproductive

	gravel road use with increasing road availability Of all 3154 hourly steps used in the SSF models, 328 (10.4%) ended on gravel roads and 30 (1.0%) on main roads While resting during day time, Wolves preferred intermediate distances to gravel roads, and they were 1.4 times more likely to bed at distances of 1–1.5 km from the closest gravel road as compared to directly at the road Selected day bed sites far away from main roads and at intermediate distances to houses, with a peak at 2 km from the closest house.	deciduous species, including Birch and Aspen Mire, agricultural fields, open areas (e.g. mountains, boulder fields), and built-up areas were also represented (in that order) Main road density averaged 0.19 ± 0.02 km/km^2, and the maximum distance to main roads ranged from 3.72 to 14.88 km Gravel road densities were on average 4.6 times higher than main road densities and the maximum distance to gravel roads within territories ranged from 1.25 to 6.09 km		status, and spatial scale Human density within the distribution of the Scandinavian wolf population is low, including vast areas with <1 person per km^2 House densities within the territories averaged 3.0 ± 0.4 per km^2