A MULTIFUNCTIONAL LANDSCAPE APPROACH TO RECONCILING RENEWABLE ENERGY AND CRUCIAL HABITAT NEEDS IN WASHINGTON STATE

by

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ABSTRACT

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Habitat conservation and renewable energy development are both environmentally beneficial initiatives. Habitat conservation aims to protect and restore biodiversity and important habitats. Renewable energy development is an important climate mitigation strategy. Although both land uses are important to address the environmental challenges of today, management of these environmental initiatives has stayed segregated and sometimes works at cross purposes. One approach to reducing this conflict is to design multifunctional landscapes, where ecological, cultural, economic, and energy resource values of the land are optimized. For this to happen, management and analysis must be approached from a landscape perspective. Within a landscape-level perspective, this study aims to understand "how do wind and solar energy development and habitat conservation priorities conflict with one another in Washington State?" This research question is analyzed using GIS basic spatial analysis and spatial autocorrelation (Moran's Local I) within three spatial contexts: existing wind farms, suitable wind and solar development lands, and Washington habitats. Results show that there is a moderate to low conflict between habitat conservation priorities and both existing wind farms and suitable wind or solar energy development lands. Wind energy development could be restricted to less crucial habitat lands 3-6 and still grow by an estimated 440% of current wind energy production. Solar energy development could be restricted to the least crucial habitat levels and still increase existing total state energy production by 50%. Regarding Washington habitats, there are significant wind and solar resources in grasslands and shrublands, but also a high risk of conflict with most crucial habitats. However, the agriculture, pasture, and mixed-environments habitats present the greatest opportunities to explore multifunctional landscape designs. With this type of assessment, landscape planners can begin exploring how to approach landscape management from a multifunctional landscape design, balancing the value of renewable energy potential and habitat conservation priorities.

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Chapter 1: Introduction

As the human population continues to grow, more and more of the landscape will be required to support societal needs and wants. However, as more of the landscape is used to meet these demands, a conflict ensues regarding how to balance the needs of society and maintain ecological health and integrity across the landscape. The history of anthropogenic land use has resulted in serious, large, negative impacts to Earth's biodiversity and a general decline in ecological health across the globe (Lubowski, Plantinga, and Stavins 2008; Hanski 2011). This reinforces the importance of finding a balance between human societies and the rest of the natural world. Two environmentally beneficial initiatives that work toward this objective are habitat conservation and renewable energy development.

Conservation biology, a field of science dedicated to protecting and restoring ecologically important habitats, has never been more important to mitigate the many negative ecological changes from anthropogenic land use (Trombulak et al. 2004). One way to accomplish this is to apply active habitat conservation and management practices to the landscape that will preserve important habitats, ecological services, and maintain local biodiversity. However, while conservation biology aims to restrict land use and restore impacted landscapes back to healthy ecological systems, human population growth and economic pressures encourage continued landscape development and change.

Energy is a critical resource for any society. The production of energy draws from various natural resources and impacts the landscape in a number of ways through the process of development, operation, and eventual deconstruction (Burger and Gochfeld

2012). Due to growing climate change concerns there has been an increase in demand for the development of renewable energy resources to meet societal energy needs. Over the past decade wind and solar energy resources have seen the most growth both globally and nationally and are expected to exhibit similar levels of growth over the next several years, making these technologies important topics of study (Demirbas 2009; US Department of Energy 2011). Despite being a favorable alternative for energy production in many ways, various scales of land use are required for both wind and solar renewable energies and negative impacts to the environment are still incurred (Northrup and Wittemyer 2013).

As humans continue to grow and expand the consumption and use of land, conflicts between habitat conservation initiatives and renewable energy production are bound to occur. Historically, land use has been approached from a single-function perspective giving land management priority to a single land use (Harden et al. 2013). However, new, more holistic approaches to land management including multifunctional landscapes and energyscapes have been explored.

Under a multifunctional landscape design, the priorities of both the ecological systems and energy potential of the land are considered from a more expansive landscape-level perspective with the aim of optimizing the land use according to the needs of both functions (Reyers et al. 2012; Howard et al. 2013). This will enable an understanding of the risks and opportunities of future renewable energy development and provide the information needed to work toward optimizing the landscape interaction between both initiatives. While a multifunctional landscape approach to reconciling the conflict between habitat conservation initiatives and renewable energy development seems promising, there has been no real application of multifunctional landscape designs within this context (Reyers et al. 2012; Howard et al. 2013). This is mainly due to the large requirements of capital, time, as well as the challenges associated with stakeholder agreement needed to implement multifunctional landscapes (Waltner-Toews, Kay, and Lister 2008; Harden et al. 2013). Despite this, the first steps in moving toward a multifunctional landscape design, is to gain an understanding of the landscape-level interaction and levels of conflict between renewable energy development and habitat conservation initiatives.

One of the largest challenges to investigating land use from a multifunctional landscape perspective within this context has been that existing conservation planning and management focuses on individual conservation priorities and specific species within local and regional contexts (Washington Department of Fish and Wildlife 2005). There has been no standardized indicator available to assess all conservation priorities from a landscape-level perspective in relation to land use, until quite recently. The recent publication of the Crucial Habitat Assessment Tool by the Western Governors' Association now enables an understanding of the landscape according to the priorities of multiple conservation initiatives (Western Governors' Wildlife Council 2013a).

Crucial Habitat is a landscape-level environmental indicator that quantifies the conservation value of the land. It was derived from the aggregation and prioritization of many conservation programs in the state of Washington according to three primary conservation themes: habitat for species of concern, habitat for species of economic and recreational importance, and native and un-fragmented habitats. In general, lands with a crucial habitat rank of 1 are considered to be most crucial habitats and are lands with the highest conservation value. At the other end of the spectrum, lands with a crucial habitat rank of 6 are considered to be the least crucial habitats and are lands with the lowest conservation value. With this new environmental indicator, the interaction between habitat conservation and renewable energy resources can now be better understood within a landscape perspective. By understanding spatial distributions, interactions, as well as risks and opportunities for future renewable energy development, land use planning concerning renewable energy development and habitat conservation can begin to be approached from a multifunctional perspective and work toward optimizing the lands use among both.

To explore how management of renewable energy development and habitat conservation might be approached from a multifunctional landscape perspective, this study investigates the research question "How do wind and solar energy development and habitat conservation priorities conflict with one another in Washington State?" This is achieved within the contexts of three different spatial perspectives: existing wind farms, suitable wind and solar energy development locations, and Washington Habitats. These contexts were chosen to enable an understanding of the levels of conflict from past development actions, of future development actions, and to better understand specific impacts to certain habitat types.

From the perspective of existing wind farms, this study informs of how well or poorly the 20 existing Washington wind farms have been sited according to landscape-level conservation priorities. Further, from the perspective of suitable wind or solar energy development lands, this study identifies the risk of landscape conflict for future energy development and the potential to optimize the land use between these two initiatives. Finally, from the perspective of Washington habitats, this study explores the risk or opportunity of future energy development within different habitat types. Using Geographical Information Systems (GIS) as the method of analysis, this study found that in general there is a moderate to low landscape level conflict between habitat conservation priorities and renewable energy development in Washington State. This thesis will argue that the findings of this research produce new and much needed information for Washington land managers as they attempt to identify and respond to conflicts between these two beneficial land uses.

There are six chapters in this thesis. The present chapter introduces the topics of this research and begins to frame the importance of investigating the landscape conflicts between renewable energy development and habitat conservation. The second chapter continues to frame the importance of this research by providing historical background and a review of the existing scientific literature illuminating our current knowledge of the themes explored in this research. Focus is given to the various fields that have contributed to defining habitat conservation, identifying trends in renewable energy growth, investigating environmental impacts associated with wind and solar energy development, and exploring the potential for creating multifunctional landscapes. This review establishes the specific need to understand the levels of conflict between renewable energy development and habitat conservation at a landscape-level perspective.

Chapter 3 identifies the state of Washington as the research study area and outlines the five specific research questions and hypotheses that were analyzed as part of this study. These specific research questions guide the investigation of the levels of landscape conflict within the three spatial contexts identified above. These are the following:

- Existing wind farms
    1. How do crucial habitat distributions in existing Washington wind farms compare to the crucial habitat distributions across the entire state of Washington?
- Suitable wind and solar development lands
    2. How do crucial habitat distributions in suitable wind and solar development lands compare to the crucial habitat distributions across the state of Washington?
    3. At what levels of crucial habitat could future wind and solar energy development be restricted in order to both protect habitat quality and contribute substantially to future Washington energy production?
- Washington habitats
    4. Which habitat types are more suitable for future wind and solar energy development in Washington State?
    5. What is the risk of significant landscape conflicts between crucial habitat and wind or solar resources within those habitats?

The remainder of this chapter describes the research methodology using geographical information systems (GIS). The many data sources utilized in this research are defined and the GIS and statistical analyses conducted in this study are outlined, including basic spatial analyses and local Moran's I spatial autocorrelation analyses.

Chapter 4 presents the results of the GIS and statistical analyses for each of the five specific research questions. Chapter 5 provides a thorough discussion of the study results and associated opportunities and implications of utilizing the crucial habitat variable as a land use planning indicator. This includes exploring ways to reduce land use conflict, exploring ways to begin optimizing landscape planning in an effort to obtain multifunctional energyscapes, and identifying specific opportunities and risks of wind and solar energy development within different habitats. Cautions associated with the study results are also discussed as well as opportunities for future research and improvements to the methods of analysis as conducted in this study. The end of this chapter concludes this study by presenting a concluding summary of this study and final thoughts on the importance and capability of working toward establishing and managing landscapes according to a multifunctional model.

Chapter 2: Literature Review

2.1 Introduction

This chapter presents the most relevant background, history, and current research surrounding the study themes of habitat conservation, wind and solar renewable energy resources and the implications to wildlife and the environment, and the concept of reducing landscape conflicts by creating multifunctional landscapes. Having an understanding of the philosophies, history, motivations and trends, current scientific progress, and future directions of study that influence each of these themes begins to frame the importance of this research. After a thorough review of the literature, gaps in knowledge and opportunities for future research surrounding these important topics emerges. With this information, this study aims to address the identified gaps in knowledge and contribute to the development of landscape planning and management philosophies and techniques.

2.2 Conservation of Habitats

Natural habitats have become fragmented across the landscape and even lost completely as a predominant effect of anthropogenic land use change (Trombulak et al. 2004; Bennett and Saunders 2010). This has had catastrophic impacts on local biodiversity and is contributing to rapid rates of extinction throughout the world (Pimm and Jenkins 2010). In an effort to guard against these fatal consequences, the field of conservation biology was established as a mission-oriented science working toward halting and reversing the ecological damage caused by humans and their interaction with the environment. Only in the mid-1980s has conservation biology developed as an independent, interdisciplinary science with primary goals to maintain biodiversity, ecological integrity, and ecological health (Trombulak et al. 2004; Fetene, Yeshitela, and Desta 2012; Meine 2010). During this time, philosophies and fundamental concepts from several other areas of study within the biological sciences were incorporated into the foundation of conservation biology (Meine 2010). Population dynamics, island biogeography, and landscape ecology are key fields of study that inform conservation efforts centered on habitat conservation. These fields of study are particularly important to understand when considering how renewable energy development may impact the landscape.

Population Dynamics

The population size and demographics of a species is a critical component in assessing the ecological integrity of a specific landscape and is often used as a critical indicator in managing the effects of landscape change, habitat loss, and threat of species extinction. Ecological integrity refers to the "degree to which an assemblage of organisms maintains its composition, structure, and function over time" (Trombulak et al. 2004, 1181). There are many components involved in assessing the ecological integrity of an area. However, population dynamics plays a critical role in understanding the relationships between anthropogenic landscape change and the habitat requirements for a species or biological community to persist and ecosystems to function (ed. N. S. Sodhi and Ehrlich 2010).

Population size of a species in an area is generally dependent on the interaction of four factors: births, deaths, immigration, and emigration. If these factors interact in such a way that species population levels become too low, the species can become at risk of extinction and important environmental services can diminish. This can trigger a negative cascading effect, impacting many other organisms in the ecosystem, including humans (Pimm and Jenkins 2010). Understanding how the environment impacts species demographics and changes in population growth is a fundamental goal of population ecology. Much research has been conducted modeling the complexity of population dynamics in an effort to predict the effects of environmental and demographic change on species populations (Schaub and Abadi 2011). As population modeling becomes more integrated to incorporate numerous environmental variables, more reliable insights into specific drivers of population growth and decline can be achieved within various environmental settings. This is essential to effective management of biological conservation efforts (Schaub and Abadi 2011).

The number one cause of population decline and threat to species extinction on local and global scales in more recent times is habitat loss from anthropogenic land use changes (Trombulak et al. 2004; ed. N. S. Sodhi and Ehrlich 2010; Hanski 2011). The threat of extinction becomes even more concerning since the rates of extinction have been occurring at faster rates than observed during any previous time in history (Trombulak et al. 2004; Pimm and Jenkins 2010). Many conservation activities focus on preserving and increasing available habitat to stabilize declining species populations, both in local and global regions, to avoid the detrimental impacts associated with species extinction. If a species becomes extinct on a global scale, these effects become irreversible; biodiversity is altered and often reduced indefinitely (Trombulak et al. 2004; ed. N. S. Sodhi and Ehrlich 2010). On a larger scale, these conservation efforts combined contribute to the overarching conservation biology goals to maintain the biodiversity within a landscape, thereby also maintaining the ecological health of that area.

While the focus on biodiversity and ecological health through population management is certainly a fundamental goal within conservation biology, there is some debate within the field surrounding the approach to ecological policy and management. In a paper written by Robert Lackey (2007), a professor of fisheries science at Oregon State University and prior member of the U.S. Environmental Protection Agency's national research laboratory, perspectives on scientific advocacy and affiliation to policy preferences are explored. Lackey points out that the opinions of some conservation biologists is to manage the environment strictly from the perspective that ecosystems unaltered by anthropogenic influences is inherently good and preferable to those changed by humans. Further, he describes the following environmental policy preferences as common: "human-caused extinctions are inherently bad and should be avoided; unaltered ecosystems are preferable to altered; reducing complexity in ecosystems is undesirable; natural evolution is good, human intervention is not; more biological diversity is preferable to less biodiversity; and native or indigenous species are preferable to non-native species" (Lackey 2007, 14). While these perspectives are often true, there have been cases where the inverse has proven to be beneficial for particular species' populations, resulting in thriving ecosystems. Nature is a complex entity that requires careful study and analysis to determine the most appropriate methods of management concerning the interaction between species population dynamics and human land use, to ensure the optimal state of environmental health for both. Concerning population dynamics, this effort is reflected in the continued research around population models to better understand the specific environmental factors that affect species populations in specific areas.

Island Biogeography

In addition to the field of population ecology, the field of island biogeography also contributes substantially to the growing body of knowledge and efforts associated with conservation biology. Originally presented by MacArthur and Wilson, the theory and study of island biogeography refers to the relationship of species population and richness in a relatively confined geographical area (such as an island) and the related geometric size and level of isolation of those lands (MacArthur and Wilson 1967; Bennett and Saunders 2010). This field of study has made important contributions to conservation biology when studying the effects of habitat fragmentation on the population dynamics and species area relationships for individual species as well as entire biological communities (Bennett and Saunders 2010; Campos et al. 2012; Campos et al. 2013).

When humans develop natural lands, major landscape changes may occur, leaving little natural habitat. The habitat that does remain is often fragmented into small pieces and scattered across the newly developed anthropogenic landscape (Bennett and Saunders 2010). These habitat fragments often exhibit habitat characteristics similar to those observed in habitats on islands, hence the connection to island biogeography. However, the population dynamics in these habitat fragments are different from actual islands in that the space separating the habitat fragments are not barren. In this environment, it is often easier for non-resident species to access the habitat fragments through the adjacent lands, which can make it harder for resident and specialist species to persist with this additional competition (MacArthur and Wilson 1967).

Habitat fragmentation is often viewed as a negative environmental impact of anthropogenic land use since habitat is reduced and the scattered nature of the remaining fragments can have negative implications to species population dynamics (Bennett and Saunders 2010; Laurance 2010; Hanski 2011; Campos et al. 2013). Studies have shown that, as natural habitat is reduced in size, the capacity of the habitat to support species sustenance and breeding requirements is also reduced and leads to biodiversity loss (Bennett and Saunders 2010; Lloyd, Campbell, and Neel 2013). However, there is an ongoing debate within the field of ecology concerning the effects of habitat fragmentation on species within the landscape (Villard and Metzger 2014).

While there is a clear relationship between habitat loss and biodiversity loss, habitat fragmentation has proven to have both positive and negative effects on different species according to specific species' habitat requirements, as well as the landscape configuration of habitat (Villard and Metzger 2014). In a study conducted by Rueda et al. (2013), seven specialist forest bird species were used in a modeling exercise to understand the impacts of habitat fragmentation on species populations. The results of the study show that four of the seven bird species were negatively affected by habitat fragmentation exhibiting population loss and eventual extinction. However, contrary to these results three of the bird species showed a positive affect from habitat fragmentation, exhibiting population growth in and among multiple habitat fragments on the landscape

(Rueda et al. 2013). These species were observed to have higher dispersal capabilities, allowing them to more easily move between habitat fragments so that they could thrive within the edges of the remaining natural habitat, where predators were not as prevalent (Bennett and Saunders 2010; Rueda et al. 2013). As the main finding of the Rueda et al. (2013) study, habitat fragmentation impacts can vary depending on species' sensitivity to landscape change. This study reinforces the idea that, while many species may be negatively impacted by habitat fragmentation, this general assumption cannot be applied to all species and to all habitat configurations across a landscape.

Depending on the distance between habitat fragments across a landscape, some of the more subtle characteristics of population dynamics help inform conservation biology on the importance of landscape configuration and habitat connectivity within a fragmented landscape (Villard and Metzger 2014). Metapopulation dynamics and the importance of genetic variation help conservation biologists better understand the ecological risks that can be associated with habitat fragmentation. When habitat fragments become isolated from other, similar habitats, this may hinder the immigration and emigration within species' metapopulations, restricting gene flow and reducing genetic variation (Gotelli 2001; Trombulak et al. 2004; Hanski 2011; Bennett and Saunders 2010).

A metapopulation is a group of local subpopulations of a particular species where each of the subpopulations exhibit a genetic makeup that is different from the others, but are linked to one another through immigration and emigration (Gotelli 2001; Bennett and Saunders 2010; Hanski 2011). When genetic variation associated with population movement is lost, the isolated subpopulation will become less able to adapt to changing environmental conditions and negative effects associated with inbreeding may become more frequent (Trombulak et al. 2004; Bennett and Saunders 2010; Shirk et al. 2010; Lloyd, Campbell, and Neel 2013). This weakens the resilience of the subpopulation and further increases the chance of population loss and extinction within the fragmented habitat.

Researchers have begun to use gene flow monitoring and dispersal capability as indicators to assess the impacts of landscape fragmentation and anthropogenic barriers on threatened species in specific geographic locations. These studies assess the risks and monitor the effects of anthropogenic landscape change in those areas. Such studies also inform of the necessity for conservation management to mediate negative landscape effects (Shirk et al. 2010; Lu et al. 2012; Lloyd, Campbell, and Neel 2013). With this information, conservation biologists can more effectively understand the value of maintaining large habitat areas as well as re-establishing habitat corridors to connect different habitat fragments across the landscape (Bennett and Saunders 2010; Lu et al. 2012). In this way, conservation biology efforts, in concert with landscape planning and management, can work to reduce the hazards of habitat fragmentation and improve future landscape designs.

Landscape Ecology

Landscape ecology is the third scientific field of study that informs conservation biology how to best protect wildlife habitat in an effort to prevent local species extinction and minimize the loss of biodiversity from the landscape. While the field of landscape ecology has been interpreted and applied to many different disciplines in many ways

(Kirchhoff, Trepl, and Vicenzotti 2013), conservation biology uses the term to represent a spatial configuration of habitat within a particular geographical area. Multiple habitat types, ecosystem types, as well as many habitat fragments and connecting corridors are typically present within a single landscape area (Bennett and Saunders 2010; Villard and Metzger 2014). It becomes important to understand and manage conservation activities at the landscape level because species often exist in, use, and move between the multiple ecosystems and habitat fragments in a particular landscape (ed. N. S. Sodhi and Ehrlich 2010; Mueller et al. 2011).

While many conservation activities tend to focus on the species level, a landscape-level approach to conservation has proven to be more effective in managing the overarching goals of conservation biology—biodiversity, ecosystem integrity, and ecosystem health (Trombulak et al. 2004; ed. N. S. Sodhi and Ehrlich 2010). In landscape ecology, habitat fragments are assessed and compared across the whole landscape, and the most appropriate conservation strategies can then be applied for maximum conservation efficiency (Fetene, Yeshitela, and Desta 2012). However, managing conservation activities at a landscape level is particularly challenging because measuring and tracking landscape biodiversity and other environmental variables is very difficult to achieve. As the scope of management and analysis increases to reach a landscape-level, the number of interacting environmental variables also increases, emerging as a complex system with much uncertainty (Waltner-Toews, Kay, and Lister 2008).

Despite the challenges, understanding and managing conservation at the landscape-level will become increasingly important as human development continues to occur, climate change increases the rate of environmental change, and many of the species at risk of extinction come to depend upon conservation management for population viability (Trombulak et al. 2004; ed. N. S. Sodhi and Ehrlich 2010; Bellard et al. 2012; Goble et al. 2012). However, managing conservation initiatives at the landscape-level becomes even more challenging when landscape uses have both a societal and ecological value. This is particularly evident with the growth and development of renewable energy technologies.

2.3 Renewable Energy Development

Between the years 2000 and 2010, greenhouse gas emissions (GHG) produced from worldwide energy production have increased by 47% from the burning of fossil fuels (Intergovernmental Panel on Climate Change 2014). As climate change challenges continue to grow in importance at a global scale, climate mitigation strategies have become critical to managing human interaction with the natural environment and stabilize the global warming trend that has been occurring over the past several decades. If successful, extreme shifts in Earth's natural systems can be avoided, lessening the need for both ecological and social systems to adapt quickly to a rapidly changing environment (Intergovernmental Panel on Climate Change 2007).

According to the Intergovernmental Panel on Climate Change (IPCC), renewable energy technologies have become known for their "large potential to displace emissions of greenhouse gases from the combustion of fossil fuels and thereby mitigate climate change" (Intergovernmental Panel on Climate Change 2012, 1). In fact, according to the IPCC climate mitigation scenarios, a tripling to nearly quadrupling of renewable energy production would be required to achieve low-stabilization atmospheric GHG levels by

2100 (Intergovernmental Panel on Climate Change 2014). In addition, the de-carbonization of the energy production systems through increased renewable energy production is also viewed as a key component of the most cost-effective climate mitigation strategies (Intergovernmental Panel on Climate Change 2014). Because renewable energy production is environmentally important and is viewed to be cost-effective, a shift is now underway toward integrating renewable energy production into landscapes on a global scale.

Renewable energy is considered to be clean energy, producing little or no carbon emissions and having inexhaustible primary energy resources (Demirbas 2009). These energy sources include biomass, solar, wind, geothermal, hydropower, and the oceans. While renewable energy still only accounts for about 14% of global energy use today, renewable energy development has been increasing rapidly over the past several years (Demirbas 2009; US Department of Energy 2011; Intergovernmental Panel on Climate Change 2012). This is especially true for wind and solar technologies, with an annual average global growth rate of 40% and 27% respectively over the past decade (International Energy Agency 2012; Intergovernmental Panel on Climate Change 2014).

Rapid growth in solar and wind renewable energy technologies is not unexpected, since both of these resources have a tremendous global supply and are available in nearly every country and region of the world. Additionally, economic cost barriers have been declining and political support has encouraged growth in these industries (Demirbas 2009; Intergovernmental Panel on Climate Change 2012). For these same reasons, it is expected that solar and wind energy development will continue to exhibit rapid growth. Furthermore, various renewable energy growth models have shown that solar and wind energy will likely be large contributors of renewable energy production in the future (Demirbas 2009; Intergovernmental Panel on Climate Change 2012).

In the United States, renewable energy production has exhibited growth trends similar to those observed globally. Total renewable energy contribution in the U.S. was 11.7% in 2011 (US Department of Energy 2011) and wind and solar electricity generating capacity has seen the most growth over the past decade; installed wind energy capacity increased by a factor of 10 from 2001 to 2011 and installed solar energy capacity increased by a factor of 12 from 2006 to 2011 (US Department of Energy 2011). Future growth in these renewable energy resources is also expected to increase for the following three reasons. 1) There are ample wind and solar resources in the United States (Lopez et al. 2012). 2) Many states have set specific Renewable Portfolio Standard (RPS) growth targets for solar and other renewable energy technologies (US Department of Energy 2010; US Department of Energy 2013). 3) Most states have incentive and rebate programs to encourage renewable energy development (US Department of Energy 2010; US Department of Energy 2013). As renewable energy technology development grows, this means landscape changes will occur and negative environmental impacts are likely to be incurred.

2.4 Environmental Impacts of Renewable Energy Development

As mentioned in the prior section, it is commonly understood that renewable energy generation is immensely beneficial to the environment due to the GHG emission reductions. However, renewable energy technologies are not entirely beneficial. There are known negative impacts to the environment that coincides with the development of renewable energy technologies. These can occur throughout the entire technological lifecycle, including resource acquisition, initial manufacturing, energy production development on the landscape, continued maintenance, and finally deconstruction and removal from the landscape (Burger and Gochfeld 2012; Intergovernmental Panel on Climate Change 2012; Athanas and McCormick 2013). While the environmental impacts at all lifecycle stages are important, those specifically associated with the energy production landscapes from development, continued maintenance, and deconstruction is the primary focus of this thesis. To understand these negative environmental impacts, a comprehensive review of the ecological footprints (amount of space required, type of use, and conversion factor) and impacts to habitat and biodiversity for each specific renewable energy technology is required (Burger and Gochfeld 2012).

Infrastructure: Electrical Transmission Lines and Roads

To some extent, all renewable energy technologies will have common infrastructure components, including electrical transmission lines and roads. Studies have shown that the addition of this infrastructure to the landscape can cause varying degrees of negative environmental impacts. However, the extent of environmental impacts depends on the size of the renewable energy development, site habitat type, and local ecology (Trombulak and Frissell 2000; Kuvlesky Jr. et al. 2007; McDonald et al. 2009).

Electrical transmission lines present a smaller environmental risk than roads, but have been known to cause bird mortality from risks of collision and electrocution (Kuvlesky Jr. et al. 2007). Since this infrastructure is critical to move energy from production to consumption locations, all renewable energy developments could exhibit some level of associated environmental impacts. However, the extent of negative environmental impacts from electrical transmission line construction will likely depend on the proximity to specific bird populations and migration paths, as well as the quantity of transmission lines required for the renewable energy development (Kuvlesky Jr. et al. 2007; McDonald et al. 2009). For example, greater environmental impacts would be expected for renewable energy developments located in or near raptor migration routes and habitat, since raptor populations cannot absorb mortality as easily as other bird species (Kuvlesky Jr. et al. 2007; Intergovernmental Panel on Climate Change 2012). Further, wind farms would be expected to incur greater environmental impacts from transmission lines than solar because of the greater landscape requirements for wind farm facilities. Each wind turbine must be spaced approximately 100meters to 250 meters apart (2—6 blade widths) necessitating more transmission lines, whereas solar panels can be placed directly next to one another (Manwell, McGowan, and Rogers 2009; McDonald et al. 2009; Nelson 2009).

Road construction presents a more complex environmental risk than transmission lines due to the many potential ecological effects imposed by roads on the landscape. Trombulak and Frissell (2000) completed an extensive review of scientific literature regarding the ecological effects of roads and found several general concerns—mortality from construction, mortality from vehicle collision, animal behavior modification, physical environment alteration, increased spread of exotic species, and increased land use by people. All of these effects have some level of impact on the habitat, biodiversity, and species presence and movement patterns in the area where roads are constructed.

As the number of roads increases in an area, certain species become threatened with mortality from the physical act of clearing and construction. Additionally, natural habitat becomes fragmented, creating a barrier to natural dispersal for some species and altering movement behaviors for others (Trombulak and Frissell 2000; Kuvlesky Jr. et al. 2007; Intergovernmental Panel on Climate Change 2012). Increasing the network of roads will also increase the human traffic in an area, amplifying the risk of vehicle collisions, as well as changing the local biodiversity, including a greater risk for the spread of exotic and invasive species in native habitats (Gelbard and Belnap 2003; Trombulak and Frissell 2000). Any combination of the above effects related to the increase in road networks has been shown to have some level of impact on habitat quality and quantity, biodiversity loss, genetic isolation of local populations, and population decline (Trombulak and Frissell 2000; Kuvlesky Jr. et al. 2007). Again, due to the necessity of transmission lines and road construction, all of the above-mentioned environmental concerns should be considered during the siting and planning phases of any renewable energy development. This can ensure a thorough understanding of the specific risks to the local habitat and ecology.

Wind Energy Development

Wind energy facilities, often known as wind farms, have unique environmental impact concerns according to the ecological footprint of the facilities and nature of the technology employed. Wind energy technologies have been found to mainly impact the ground surface of a landscape as well as the “airshed,” (i.e., the space from the ground to the space above the turbine blades of a particular site) (Burger and Gochfeld 2012).

While the infrastructure footprint of the wind turbines is only about 3—5% of the total wind farm site, the total land required for wind farm facilities can be quite expansive because of the space required between turbines for maximum turbine efficiency (McDonald et al. 2009; Intergovernmental Panel on Climate Change 2012). This tends to cause environmental impacts such as habitat fragmentation and related biodiversity loss, species behavior modification, and direct mortality from the turbine blades (McDonald et al. 2009; Intergovernmental Panel on Climate Change 2012; Northrup and Wittemyer 2013).

Habitat fragmentation, biodiversity loss, and behavior modification of species related to wind farm development are largely connected to the expansive networks of roads required to construct and access each individual wind turbine in the wind farm (Kuvlesky Jr. et al. 2007; Intergovernmental Panel on Climate Change 2012). As discussed in the section above, roads can have many impacts on the local ecology of an area and are often observed as a negative effect of wind farm development. In addition to road construction, species behavior modification has also been attributed to the acoustic noise and vibration from turbine operation (Northrup and Wittemyer 2013). In general, the severity of these environmental impacts will vary substantially depending on the type and sensitivity of local habitat as well as the local biodiversity of each individual wind farm location.

Direct mortality of birds and bats from collision with turbine blades is an environmental impact unique to wind farm facilities (Kuvlesky Jr. et al. 2007; Arnett et al. 2008; Intergovernmental Panel on Climate Change 2012; Northrup and Wittemyer 2013). Many studies have been conducted over the past 20 years to better understand the impacts of wind farms on bat and bird populations. Findings have shown there is a significant increase in mortality for both species in relation to wind farm developments (Barclay, Baerwald, and Gruver 2007; Arnett et al. 2008). However, the severity of environmental impacts again relates to the specific ecology of each independent wind farm location as well as the specifications of turbine construction, operation, and arrangement.

The more pressing concerns related to bird and bat mortality are often anchored around species-specific impacts and proximity to migration paths (Kuvlesky Jr. et al. 2007; Arnett et al. 2008). Mortality of raptors and some less resilient endemic bird species is generally of greater concern because their population levels and global presence are less able to absorb mortality than other, more prolific species (Kuvlesky Jr. et al. 2007; Intergovernmental Panel on Climate Change 2012). Likewise, proximity to bird and especially bat migration paths is of great concern because of the increased rate of mortality as opposed to sites away from migration routes (Barclay, Baerwald, and Gruver 2007; Arnett et al. 2008).

While there are several known environmental impacts associated with wind farm developments, as discussed above, there are also many unknown environmental impacts. Additionally, the overall biological significance of each environmental impact is unique to each specific ecological landscape and remains largely unclear (Intergovernmental Panel on Climate Change 2012; Park, Turner, and Minderman 2013). Much of the literature expresses a clear need for more extensive studies that aim to understand the impacts of wind farm development related to specific habitats and ecological impacts

(Intergovernmental Panel on Climate Change 2012; Northrup and Wittemyer 2013; Park, Turner, and Minderman 2013).

Solar Energy Development

Like wind farms, solar energy facilities also have unique environmental impact concerns according to the ecological footprint of the facilities and nature of the technology employed. Solar farms generally impact the surface and subsurface components of the landscape according to solar panel placement and connection to groundwater systems for facility cooling (Burger and Gochfeld 2012; Intergovernmental Panel on Climate Change 2012). As a general benefit of solar energy development, land requirements for construction are often lower compared to the requirements of other renewable energy facilities. However, development often requires utilization of the entire landscape sited for the facility, impacting nearly 100% of the physical area (McDonald et al. 2009). While there is a clear understanding of the ecological footprint associated with solar farms, a crucial limitation to understanding the associated environmental impacts of solar farms is the serious lack of peer reviewed literature investigating the topic (Intergovernmental Panel on Climate Change 2012; Northrup and Wittemyer 2013). However, there have been speculations into the types of environmental concerns that are likely to occur from solar farm development including habitat loss, fragmentation, and potentially microclimate alteration around the solar arrays (Northrup and Wittemyer 2013).

Construction of solar farms typically requires the clearing of all land within the site since solar panels are typically placed close to one another (McDonald et al. 2009).

This can be seen in Figure 1 below, an image of the solar and wind facilities at the Wild Horse Wind Facility in Ellensburg, Washington. Depending on the size of the solar facility and location of the site, this could have important effects on local ecological systems. These could include the loss of food production areas and biodiversity reduction from habitat reduction (Burger and Gochfeld 2012). Also, depending on the solar facility distribution, habitat fragmentation can occur from the increase in required road networks and general placement of the solar arrays (Intergovernmental Panel on Climate Change 2012). Finally, concerns about microclimate alteration resulting from solar panel heat loss have been theorized. However, scientific studies are needed to better understand the significance of this concern and the technicalities of disturbance (Intergovernmental Panel on Climate Change 2012; Northrup and Wittemyer 2013). The severity of these environmental concerns will again depend on the unique ecological and habitat characteristics of the solar development sites. However, since attractive solar farm siting locations often occur in ecologically sensitive desert habitats, environmental impacts of solar farms may be greater than we have anticipated (Burger and Gochfeld 2012; IPCC 2012).

Figure 1. Wild Horse Wind and Solar Facilities (Ellensburg, WA)

Image taken by Puget Sound Energy:
https://www.flickr.com/photos/pugetsoundenergy/4494987410/

Environmental Impact Assessments

Many countries, including the United States, require the completion of an environmental impact assessment (EIA) as part of the permitting process for energy development (Jay 2010; Intergovernmental Panel on Climate Change 2012). The EIA process functions to assess potential impacts to the environment from development along with mitigation strategies, when possible (Jay 2010). While being a regulatory control in place that encourages the protection of the environment from the effects of significant development projects, the environment can still be negatively impacted and development does not always occur within least impactful alternative.

Several studies have found problems with the EIA process, including poor-quality EIAs, failure to conduct an EIA in some cases, and EIAs that fail to identify mitigation plans (Jay 2010; Athanas and McCormick 2013; Vandergast et al. 2013). Athanas and

McCormick completed a review of 195 active renewable energy development project EIAs and Strategic Environmental Assessments (an SEA is a more rigorous form of EIA) in the World Bank Renewable Energy Database; a collection of renewable energy projects in developing countries (The World Bank 2014). Results of the review found that 14% of projects sited were in areas highly likely to have “significant adverse environmental impacts that are sensitive, diverse, or unprecedented” (2013, 26). Additionally, 18% of the projects were sited in areas that “have potential adverse environmental impacts on human populations or environmentally important areas” (Athanas and McCormick 2013, 26). While these EIAs did identify the environmental impacts, none of the projects had environmental safeguards included in their development plans. This means that 32% of the renewable energy projects had been sited in environmentally sensitive and/or important areas and were actively being developed or in the pipeline for investment and future development despite the environmental risks.

In some cases, renewable energy projects have been developed on landscapes that should have been protected and preserved. In another study conducted by Vandergast et al. (2013), evolutionary hotspots were analyzed in the Mojave Desert, California, in relation to existing and proposed renewable energy development projects. Evolutionary hotspots are important environmental regions that contain an overlap of species with high genetic divergence and diversity. This collection of species is vital to preserving genetic variation within a species’ population and will contribute to improving species resilience (ed. N. S. Sodhi and Ehrlich 2010; Vandergast et al. 2013). Landscapes with evolutionary hotspots should be preserved to protect the species’ population size and biodiversity in the region. However, according to Vandergast et al. (2013), renewable energy development projects had the potential to impact 6 of the 10 identified hotspot regions, given that 10–17% of these hotspot regions overlapped with renewable energy development sites. The results of this study indicate that, in some cases, there is a conflict of land use between priority habitat conservation lands and renewable energy development. Although both forms of land use are important to meet the environmental challenges of today, management of these environmental challenges has stayed segregated and sometimes the two are at cross purposes. One approach to reducing this conflict is to move toward designing multifunctional landscapes.

2.5 Multifunctional Landscapes

Historically, land use has often been centered on a single objective or function, which was determined by the landowner and supported by private property laws. This system of land use and resource management gave preference to private property owners where resources of the commons, such as watersheds and biodiversity, were not managed according to the greatest public interest but left to the management of the individual landowners (Vejre et al. 2012). In more recent times, human population growth has transformed the landscape into a patchwork of both private and public lands with many different functions across the landscape. This growth and continued land development has spurred the regulation and collective management of some aspects of common resources such as water quality and protection of important habitats such as wetlands. However, these regulations are targeted to specific environmental concerns, and landscape management is still often approached from a single-function perspective (Vejre et al. 2012). With the pressures of continued development, in concert with land scarcity, some scientists and sustainability advocates have begun focusing on constructing multifunctional land use strategies. These strategies serve many functions or objectives and work to consider ecological, cultural, and economic values on the land (Lovell and Johnston 2009; Groot, Jellema, and Rossing 2010; Vejre et al. 2012).

Multifunctional land use strategies have typically been associated with agriculture, where the extent of functional integration tends to be a patchwork of various land use systems without an emphasis on full integration across an entire landscape (Harden et al. 2013). This occurs due to the challenges associated with a system where land functions compete with one another and includes many different stakeholders, landowners, land use drivers (i.e., environmental, social, or economic), and trade-offs (Groot, Jellema, and Rossing 2010; Vejre et al. 2012; Harden et al. 2013). The conflicts among these various challenges create a complex situation that requires a lot of research, assessment, and communication to effectively plan, design, and manage multifunctional landscapes (Reyers et al. 2012; Harden et al. 2013; Howard et al. 2013). The extreme commitment and investment of time, money, and resources required to work through these conflicts often prevents multifunctional landscape designs from transcending property boundaries and including large portions of the landscape (Harden et al. 2013).

Many land managers and scientists in the field of landscape ecology have explored various frameworks to guide the transition from segregated functional land use to a multifunctional model. These frameworks often emphasize completing an extensive environmental assessment to understand the ecological state of the landscape and risks of land changes, identifying land use objectives including trade-offs and potential synergies, as well as continually addressing stakeholder and land owner resistance (Waltner-Toews, Kay, and Lister 2008; Reyers et al. 2012; Vejre et al. 2012; Harden et al. 2013). Additionally, an interdisciplinary approach should be applied so, at least, ecologists and land managers might work together for a successful transition to a multifunctional landscape (Lovell and Johnston 2009; Groot, Jellema, and Rossing 2010).

One of these frameworks moving toward a more integrated form of landscape assessment and management is what Waltner-Toews, Kay, and Lister have called “the ecosystem approach” (2008). Under this framework, landscape systems are researched using an interdisciplinary approach and diagramed to gain an understanding of all the interactions and feedbacks between the landscape variables of interest. Using this information, a general sense of landscape health can be obtained, negative landscape interactions can be identified, and mitigation techniques can be explored to better optimize the interactions within the landscape system.

The University of Guelph conducted a case study of the ecosystem approach framework, investigating agroecosystem health in the Great Lakes Basin (Waltner-Toews, Kay, and Lister 2008). This study divided landscape variables into two general categories—ecological and socio-economic—aiding in the development of a landscape system model. This process engaged all relevant stakeholders to collect information about the agricultural systems, ecological systems, relevant biodiversity, and history of land use in the area. The outcome of the landscape system model and stakeholder engagement identified negative impacts of agriculture on stream health in the Great Lakes Basin (Waltner-Toews, Kay, and Lister 2008).

With the landscape system model as a starting point, more rigorous analyses were conducted to understand the specific landscape variables that influenced this negative outcome. The final results of the analysis showed that cattle grazing in stream habitats were detrimental to fish communities, and that wealthier farms had better stream health due to a greater ability to protect stream habitats from livestock grazing (Waltner-Toews, Kay, and Lister 2008). All in all, the ecosystem approach helped researchers and stakeholders to organize and understand many landscape variables within an agroecosystem, and to identify the different influences on agroecosystem wellbeing. However, this approach to landscape management is largely dependent on stakeholder engagement to take management to the next steps of intervention, mitigation, and improved policy action, which is viewed as the largest challenge and potentially greatest weakness of this framework (Waltner-Toews, Kay, and Lister 2008). While applied in a few case studies, the stakeholder engagement challenge, as well as the time and cost required for this framework, have prevented successful application of the ecosystem approach to landscape management in many cases.

Regarding habitat conservation and renewable energy development, there is a clear potential for land use conflict between these two initiatives. Conservation biology aims to protect habitats from destruction, fragmentation, and loss of ecosystem services, while renewable energy developments impose new features on the landscape that in some cases degrade and fragment natural lands. However, due to the importance of both of these initiatives, scientists have begun working to identify how landscapes could be designed and managed to best optimize the land use for both. Howard et al. (2013) encourages a shift in mindset to think of renewable energy development in terms of what he calls an "energyscape." Under this model, planning and developing renewable energy facilities should aim to find the balance between maximizing energy system requirements and minimizing disruption to ecosystem services and landscape ecology (Howard et al. 2013). Here, a landscape-level management approach is considered, where environmental impacts are assessed not only for the renewable energy development site but in the connecting landscape as well.

In a different multifunctional landscape approach, Reyers et al. (2012) include energy generation as a key component of the landscape function. Reyers et al. argue that landscapes should be designed to “provide multiple environmental, social, and economic functions and are able to achieve multiple societal needs including energy and food production, management of waste, conservation of biodiversity, and the management of water quantity and quality across the landscape” (Reyers et al. 2012, 1122). Both the energyscape and the multifunction landscape approach to landscape planning and management express innovative, interdisciplinary, and systems approaches to tackling the land use conflicts that have been surfacing between habitat conservation and renewable energy development. While some multifunctional frameworks, such as the ecosystem approach explored above, have been applied to landscape management, approaches related to energy production landscapes are only theoretical at this point and no real application has been studied.

2.6 Conclusion

Conservation biology is a mission-oriented science that aims to reverse anthropogenic ecological damage and protect biodiversity, ecological integrity, and ecological health. Population dynamics as a function of biodiversity management, island biogeography related to habitat fragmentation and connectivity, and landscape ecology inform the study of conservation biology and are fundamental components of many wildlife conservation and management strategies. Although these goals are applicable on a global scale, conservation initiatives tend to focus on individual species and their related habitats from a local perspective. However, philosophies of landscape ecology suggest that conservation programs will be more effective in managing these goals when approached from a landscape-level perspective. Current research looks to expand existing conservation programs to include a larger landscape perspective when assessing and managing conservation initiatives.

With regards to renewable energy technologies, there has been substantial growth in these industries over the past decade, both globally and nationally, in response to increasing concerns for climate change. Wind and solar energy technologies have seen the most growth, and many energy researchers forecast continued rapid growth in these industries. While these technologies do mitigate anthropogenic carbon emissions, there are still negative environmental impacts associated with development and operation. Electrical transmission lines threaten wildlife with potential electrocution, road construction fragments native habitats, and habitat loss occurs from development. Increased human traffic brings threats of invasive species and wildlife vehicle collisions, wildlife avoidance has been observed, wind turbines kill birds and bats, and solar panels could potentially have microclimate impacts. All of these impacts directly conflict with habitat conservation initiatives.

To manage the potential environmental impacts of renewable energy technologies, environmental impact assessments are required and appropriate mitigation strategies should be identified. However, as seen in several studies, this is not always accomplished and serious environmental impacts resulting in grave consequences to conservation goals have occurred. This is often because land use management has historically been conducted from the perspective of a single objective or function. However, more sustainable approaches have been suggested to plan landscapes with a multifunctional perspective. Multifunctional landscapes would approach land use management with consideration of the ecological, cultural, economic, and energy resource values of the land with the goal of improving and optimizing land function. However, the few attempts at implementing this type of landscape design related to other industries have been fraught with challenges to achieve stakeholder agreement and costly environmental assessments to understand how to best design and manage the lands. Despite these challenges, the concept of the multifunctional landscape approach is still an important land use aspiration given the increasing land scarcity of current times.

To begin working toward a multifunctional landscape design, land management first needs to be viewed and analyzed from a landscape-level perspective rather than from individual land ownerships or independent functional designations. This is something that has not been readily researched or practiced up to this point (Howard et al. 2013). As previously mentioned, conservation activities as well as energy development projects have not been investigated or managed from a landscape spatial scale. A primary reason for this has been the lack of measureable data to describe the conditions of the land at a landscape level (Waltner-Toews, Kay, and Lister 2008). Given the importance of both habitat conservation and renewable energy development, further research needs to be conducted from this more expansive perspective, to better understand the extent of the land use conflict that occurs between these two initiatives. With this knowledge, landscape planners and managers will be better able to understand how landscape management might be approached from a multifunctional perspective. Further, attempts to balance the landscape requirements and priorities for both environmentally beneficial initiatives can be explored.

Fortunately, newly released crucial habitat assessment data from the Western Governors' Association, now allows a landscape-level assessment of habitat conservation priorities (Western Governors' Association 2013). By utilizing landscape-scaled data to investigate the conflicts between renewable energy development and habitat conservation, this study investigates land use and design from a new perspective and will address a gap in the literature. With an understanding of the land use conflicts between these two initiatives, opportunities and risks associated with conservation and renewable energy development activities can be identified. Landscape planning can then look into the possibility of working toward designing multifunctional landscapes where land use is more optimally managed according to both the ecological and energy resources of the landscape. The following chapter identifies the specific research design and methodology that were used in this study, to investigate the opportunities and implications of looking toward a multifunctional landscape design across the state of Washington.

Chapter 3: Methods and Analysis

3.1 Methods

The main objective of this research is to better understand the interaction between renewable energy development and habitat conservation priorities within a landscape-level perspective. More specifically, how do wind and solar energy development and habitat conservation priorities conflict with one another in Washington State? To address this research question several Geographical Information Systems (GIS) analyses were performed using wind and solar resource data and the newly released crucial habitat indicator, among others. As previously mentioned, crucial habitat is a new, non-regulatory environmental indicator that quantifies the conservation value of the land with the purpose to provide consistent and comprehensive wildlife information to decision makers assessing landscapes for planning and development. Using this new environmental indicator, this research provides new knowledge about the opportunities and implications of looking toward an improved, multifunctional landscape design, where land use could be more optimally managed according to both the ecological qualities and energy resources of the landscape. To begin this research, the study area of Washington State is more specifically described and five specific research questions are defined and analyzed.

Study Area

Washington State was chosen as the study area for this research because increasing renewable energy development and improving habitat conservation are both important state goals. Renewable energy production in the United States has been on the rise over the past decade and as of 2011, Washington State produced the most electricity from renewable resources than any other state in the United States (US Department of Energy 2011). While much of this energy came from the state's large hydroelectric facilities, the Washington renewable energy standard, passed in 2006, mandates the continued growth of renewable energy resources across the state. Under this renewable energy standard, 15% of the state's electricity consumption is to come from new, non-hydroelectric renewable energy resources by the year 2020 (DESIRE 2013). In order to meet this renewable energy standard target, renewable energy development is expected to increase across the state of Washington over the next several years.

While state renewable energy standards are important state policies working toward climate mitigation, the state of Washington also has an extensive wildlife and habitat conservation program that is important for protecting, preserving, and restoring state wildlife and important habitats. Managed by the Washington Department of Fish and Wildlife (WDFW), the state's comprehensive wildlife conservation plan represents a unique approach to wildlife management. This plan not only approaches conservation with species-specific priorities, but it is also one of the first state conservation plans to include landscape-level biodiversity considerations as part of its conservation strategy. As this approach has evolved, the state has increasingly identified and prioritized its habitat conservation activities to include a diverse array of conservation initiatives (Washington Department of Fish and Wildlife 2005). This is particularly apparent when reviewing the various conservation initiatives used to define the crucial habitat indicator for the state of Washington and is discussed in more detail in the “Data Sources” section of this chapter beginning on page 45.

However, despite both being important and well supported state goals, it seems reasonable that in some instances these initiatives are likely to conflict with one another on the landscape due to the contrasting land use requirements. To better understand the conflict between these two important statewide initiatives, the entire state of Washington was chosen as the scope of analysis. This is primarily because the data for such an assessment was available and a statewide scope would include a full representation of statewide conservation activities as well as lands that could contribute to statewide energy production.

Research Questions and Hypotheses

To address the research objective of this study within the state of Washington, five main research questions were defined. First, how do crucial habitat distributions in existing Washington wind farms compare to the crucial habitat distributions across the entire state of Washington? This research question illuminates how well or poorly existing wind farms have been sited from a landscape-level habitat conservation perspective. As a general hypothesis, it was expected that existing wind farms will have been developed on less crucial habitat lands. For any energy development proposal, an environmental impact assessment (EIA) is required to obtain the necessary permits. While the EIA process is a local assessment unique to each development site, federal and state environmental policies governing in the EIA process were presumed to have regulated and protected priority conservation initiatives. This process leads to the expectation that existing wind energy development on the most crucial habitat lands has been minimized.

An analysis of crucial habitat in existing Washington solar farms was not included as part of this study. According to the Northwest Power and Conservation Council, there is only one existing commercial solar farm in the state of Washington—part of the Wild Horse renewable energy facility in Ellensburg, Washington (Northwest Power and Conservation Council 2013). Given the large effort that would be required to complete this analysis for a single solar farm and lack of existing data, it was excluded as part of this study.

Second, how do crucial habitat distributions in suitable wind and solar development lands compare to the crucial habitat distributions across the state of Washington? And, third, at what levels of crucial habitat could future wind and solar development be restricted in order to both protect habitat quality and contribute substantially to future energy production? The second research question will inform of the risk of landscape conflict for future wind and solar energy development. Then, the third research question estimates potential annual energy contributions according to the inclusion or exclusion of specific crucial habitat levels. This will inform of the opportunity or challenge of optimizing the land use between future wind and solar development and habitat conservation. As a general hypothesis it was expected that the distribution of crucial habitat levels across suitable wind and solar energy development landscapes is similar to the distribution of crucial habitat statewide. It was also hypothesized that at least lands with the highest conservation value (most crucial habitats—level 1) could be placed off limits to future wind and solar development while still allowing substantial future renewable energy production. Only 15% of the Washington landscape is rated crucial habitat level 1, leaving 85% of the state to be considered for future wind or solar energy development.

Fourth, which habitat types are more suitable for future wind and solar energy development in Washington State? And, fifth, what is the risk of significant landscape conflicts between crucial habitat and wind or solar resources within those habitats? These research questions categorize all lands in the entire state of Washington into five general habitat types and then identify those with high wind and solar resource potential, as well as high or low landscape conflicts between wind and solar energy resources and habitat conservation priorities. This will inform of the risk or opportunity of future energy development within specific habitat types. Since statistical methods are used to address this research question, there is a null hypothesis stating that there is no spatial clustering or interaction between wind and solar energy resources and crucial habitat within specific habitat types. The alternative hypothesis is that there will be some significant spatial clustering and interactions between the variables within specific habitat types. It is expected that there will be significant spatial clustering and interactions since the crucial habitat and energy resource variables are highly influenced by the contiguous lands as they change in value over the landscape.

To investigate these research questions and test these hypotheses, data were analyzed using basic spatial analyses as well as spatial autocorrelation analyses, using the Moran’s I statistic. The next section describes the methods used to conduct this research.

Methods

For this study, spatial analyses were completed using the ArcGIS 10.2 for Desktop computer program (Esri Inc. 2013). All data sources incorporated into the analyses were projected into the USA Contiguous Albers Equal Area Conic USGS version coordinate system and transformations were performed when necessary to use the NAD 1983 datum. The Albers Equal Area Conic coordinate system was chosen in order to reduce the projection distortion for geometric area across the state of Washington (Bolstad 2012). Proper geometric area is an important spatial element to maintain, since this study takes into account landscape area suitable for wind and solar resources for potential future development. The NAD 1983 datum was chosen as it has become the standard datum used in most current GIS analyses (Bolstad 2012).

Data Sources

To address the identified research questions, this study has incorporated many different data sources to complete the GIS spatial analyses. The following section describes these data sources in detail:

Wind and Solar Data Resources

The wind and solar GIS data used in this study are publicly available from the National Renewable Energy Laboratory (NREL) of the U. S. Department of Energy (National Renewable Energy Laboratory 2013a; National Renewable Energy Laboratory 2014). The NREL has focused on renewable energy and energy efficiency research and development over the past 35 years. Its history of many major accomplishments has established the NREL as a trusted, leading expert in this field of study.

Wind Power Density Dataset

The NREL wind power density data were derived from over 3,200 wind resource assessment stations set up across the United States, beginning in 1979, to measure daily wind speeds within heights of 10 to 60 meters above ground surfaces. Wind resource measurements were then summarized and extrapolated into 0.25° latitude by 0.33° longitude grid cells across the United States. Each grid cell was assigned a wind power class level from 1 to 7 (7 being the strongest) according to observed wind measurements as well as various topographic and meteorological indicators including elevation changes, eolian landforms, vegetation conditions, and coastal conditions. Several wind power assessments have been made with this information and summarized into twelve regional wind energy atlases that identify annual and seasonal average wind resources across the United States (Elliott et al. 1986).

For the purposes of this study, the annual wind energy datasets for the Pacific Northwest Region, at a 50-meter wind resource resolution, were used in the analyses. The associated annual wind power class value is the primary attribute used to analyze wind energy resources within the study area of Washington State. This data set is updated regularly with current wind resource information and was last updated in June of 2012 (National Renewable Energy Laboratory 2014).

Solar Irradiance Dataset

The NREL solar irradiance data were derived using the State University of New York (Albany) Satellite-To-Irradiance model developed by Dr. Richard Perez and his collaborators (Perez et al. 2002; National Renewable Energy Laboratory 2013b). This model uses geostationary weather satellites to monitor hourly solar irradiances, cloud cover, daily snow cover, atmospheric water vapor, trace gases, and aerosols (Perez et al. 2002; National Renewable Energy Laboratory 2013c). All satellite-collected information is then used in combination with terrain elevation, local ground albedo variations, and sun-satellite angle adjustments to produce a grid of 0.1° longitude by 0.1° latitude annual solar irradiance estimates across the United States. To gauge the model's accuracy, the solar irradiance output was tested against 10 ground weather stations in different climatic environments across the United States. The results showed improved accuracy and reduced bias from previously used satellite irradiance models, and it is believed that each grid cell is accurate to approximately 15% of true, measured solar irradiance values (Perez et al. 2002; National Renewable Energy Laboratory 2013c).

For the purposes of this study, the latitude equals tilt irradiance dataset estimating solar resources appropriate for photovoltaic technologies at a 10-kilometer resolution was used in the analyses. The annual solar resource estimate value is the primary attribute used to measure the solar resources across the state of Washington. This dataset was derived from satellite and meteorological information collected between 1998 and 2009, with the most current dataset update made in September of 2012 (National Renewable Energy Laboratory 2013a).

Existing Wind Turbines

The existing wind turbine GIS data used in this study is publically available from the United States Geological Survey (USGS). The USGS provides impartial and reliable scientific information about the environment and natural resources across the nation (US Geological Survey 2013). One of their more recently published GIS datasets is an inventory of onshore commercial wind turbine locations for the United States through July 2013. This dataset is a synthesis of wind turbine location and technical specifications from the Federal Aviation Administration Digital Obstacle File, the U.S. Energy Information Administration, the Wind Energy Data and Information dataset from the Oak Ridge National Laboratory, and various industry reports, environmental assessments, and planning documents. All turbine data were verified with visual interpretation using high-resolution aerial imagery in ArcGIS (Diffendorfer et al. 2014). For the purpose of this study, USGS wind turbine data for the state of Washington were used in analyses.

Crucial Habitat Assessment

The crucial habitat assessment GIS data used in this study are publically available from the Western Governors' Association Crucial Habitat Assessment Tool (CHAT), recently released in December, 2013. The CHAT application is a first-ever landscape-level approach to assessing and prioritizing wildlife habitat and connection corridors according to state conservation objectives (Western Governors' Wildlife Council 2013a). According to the Western Governors' Wildlife Council, crucial habitat has been defined as:

> *Places containing the resources, including food, water, cover, shelter and "important wildlife corridors," that are necessary for the survival and reproduction of aquatic and terrestrial wildlife and to prevent unacceptable declines, or facilitate future recovery of wildlife populations, or are important ecological systems with high biological diversity value* (Western Governors' Wildlife Council 2013a, 6).

To classify crucial habitat across the landscape, a six-level relative ranking scheme was employed according to state conservation objectives and existing wildlife data for the western United States. A CHAT ranking model aggregated and prioritized state and regional wildlife information according to three high-level themes—habitat for species of concern, native unfragmented habitat, and species of economic and recreational importance. (For a more extensive list of the wildlife information used to define crucial habitat values see table 1.) The outcome of this model produced a one-square-mile hexagonal grid spanning the western United States, with a single crucial habitat value for each grid (Hamerlinck and Terner 2013; Western Governors' Wildlife Council 2013a). It is generally understood that the higher the crucial habitat ranking (rank 1 being the highest), the higher the relative wildlife and overall conservation value for that area. Additionally, the higher the ranking the more likely there will be wildlife resources that may require mitigation or avoidance if development were to occur (Western Governors' Wildlife Council 2013a).

For the purposes of this study, the crucial habitat ranking data for the state of Washington were used in the analyses. While these data were not meant to replace specific environmental and habitat assessments at the local scale, nor is it meant to be applied as a regulatory tool at this time, the crucial habitat value is a good landscape-level indicator of habitat importance across the state of Washington.

Table 1. Data Categories and Sources for Assigning Crucial Habitat Values (Western Governors' Wildlife Council 2013a, 8–10)

Data Category	Data Definition
Habitat for Species of Concern	Species of greatest conservation need within State Wildlife Action Plans or similar assessments: • Locations of federally- or state-listed threatened or endangered species • Key or priority habitat boundary delineations from State Wildlife Action Plans or Comprehensive Wildlife Conservation Strategy • Plant and animal species with special protective-rankings • High priority areas for management of core conservation populations
Native and Unfragmented Habitat	Areas that are contiguous, possess a high degree of intact core areas or diversity of natural habitat, or supply ecological functions to meet wildlife objectives. These areas are unfragmented, or relatively unfragmented, by transportation routes, human habitation, industrial infrastructure, or other human-caused disturbances: • Natural Vegetation Classification habitats maps • Ecological systems of concern • Plant communities of concern (Heritage Rankings) • Priority habitat areas identified in updated State Wildlife Action Plans (SWAPs)
Riparian and Wetland Habitat	Areas that represent unique environments and function to support animal and plant diversity with respect to wildlife objectives and connectivity: • Spring/Seep/Cienega Locations • National Wetlands Inventory • National Hydrologic Database • Wetland components from State Comprehensive Outdoor Recreation Plans • Priority wetland areas and priority riparian habitats identified in updated SWAPs
Connectivity or Linkage Assessment	Areas described explicitly for aquatic or terrestrial wildlife habitat connectivity: • Major animal movement corridors or pathways • Landscape connectivity zones
Quality Habitat for Species of Importance	This category provides for species consideration if not otherwise included as "Habitat for Species of Concern": • Sport Fish Quality Habitat: Areas recognized as important to meeting biological requirements and objectives of fish species whose harvest is regulated (i.e., blue ribbon streams) • Game Animal Quality Habitat: areas recognized as important to meeting biological requirements and objectives of game species regulated by harvest, such as winter concentration areas or important breeding areas (i.e., crucial big game ranges, grouse lek locations or core grouse habitats if designated)
Terrestrial or Aquatic Native Species Richness	Areas where species composition represents a native, intact community and where habitats are associated with a relatively high and distinctively described species assemblage: • Aquatic species distribution maps • Ecoregional Assessments – Biodiversity Areas • Audubon Important Bird Areas • Gap-ReGap species composite maps • Christmas bird count and breeding bird survey data

Valued Lands	Lands that are protected or designated for their wildlife or aquatic values: • Protected Areas Database (PAD) • Priority areas identified from ecoregional analyses • Dedicated conservation land locations • Outdoor recreation priority/favored areas
Important Restoration Habitat	Lands that are proximate to other important habitats and have the potential to restore function or resiliency to target populations of fish and wildlife: • Spawning or rearing habitat for fishes that are isolated from current populations • Habitat that was historically in one of the crucial habitat categories (2 or 3) and could provide fish or wildlife benefits with restoration

Washington Wildlife Habitats

The Washington wildlife habitat GIS data (Johnson and O'Neil 2001) used in this study are publicly available from the Northwest Habitat Institute (NHI). The NHI is a non-profit scientific and educational organization in the Pacific Northwest that develops data-rich and verifiable information to facilitate and promote state conservation efforts (Northwest Habitat Institute 2011). The Washington wildlife habitat GIS dataset is a synthesis of existing habitat information, field surveys, and Landsat TM imagery interpretation (Kiilsgaard 1999). The existing habitat information sources contributing to this project included the National Wetlands Inventory; the Washington Department of Fish and Wildlife (WDFW) Blue Mountains habitat/vegetation mapping project; the WDWF shrub-steppe vegetation mapping project; the Washington Department of Natural Resources (WDNR) Heritage Program mapping project; US National Park Service; and US Biological Service GAP Analysis Project.

Washington wildlife habitat was primarily classified according to vegetation patterns across the Washington landscape. Wildlife habitat was first identified digitally according to the existing wildlife habitat information, followed by field surveys in the defined habitat areas for verification. Areas where vegetation information and Landsat imagery were ambiguous were also followed up with field surveys for verification. The final product identified 32 unique terrestrial or oceanic wildlife habitats across the state of Washington (Kiilsgaard 1999). These data were last updated in 1999.

Protected Areas of the United States

The protected areas database of the United States (PADUS) GIS data (US Geological Survey, Gap Analysis Program 2012) are also publically available from the USGS science organization. Protected areas “are lands that have been dedicated to the preservation of biological diversity and to other natural, recreation and cultural uses, and managed for these purposes through legal or other effective means” (Protected Areas Database-US Partnership 2009, 1). The PADUS GIS inventory of all US protected areas is aggregated from several sources, including The Nature Conservancy (TNC), the US Endowment for Forestry and Communities, as well as local, state and federal agency data stewards (Protected Areas Database-US Partnership 2009; US Geological Survey, Gap Analysis Program 2013). As of 2009, it is expected that approximately 90% of all protected areas are present in the PADUS inventory. For the purposes of this study, the PADUS GIS data are used to identify landscape exclusions in analyses for suitable renewable energy development locations. Version 1.2 of this data was used; this was last updated in May of 2011.

National Wetland Inventory

The National Wetland Inventory GIS data are publically available from the United States Fish and Wildlife Service, a federal agency within the Department of the Interior. The U.S. Fish and Wildlife Service works to guide conservation, development, management, and education regarding fish, wildlife, plants, and their habitats for the benefit of the American people (US Fish & Wildlife Service 2013). Wetlands are important landscape features that contribute to the hydrologic and nutrient cycles across the landscape and are included within the scope of the U.S. Fish and Wildlife Service's mission. The National Wetland Inventory is a collection of wetland and deep-water landscape features across the entire United States and associated territories. These data were produced using U.S. Geological Survey topographic maps, analysis of high-altitude imagery, and a wetland classification system based on vegetation, visible hydrology, and geography (Cowardin et al. 1979; US Fish and Wildlife Service, National Standards and Support Team 2012; US Fish & Wildlife Service 2014). For the purposes of this study, the National Wetland Inventory data are used to identify landscape exclusions in analyses for suitable wind and solar energy development locations. This data was originally published in 1979 and was last updated in 2012.

National Historic Places

The National Historic Places GIS data are publically available from the National Park Service, a federal agency within the U.S. Department of Interior. The Register of National Historic Places Program coordinates efforts to identify, evaluate, and protect America's historic, cultural, and archeological resources as authorized by the National Preservation Act of 1966 (National Park Service 2011). The official list of National Historic Places has been tracked and managed in a federal database called FOCUS since 1966, when the National Preservation Act was first enacted. More recently, this information has been digitized according to the NPS cultural resource spatial data transfers standards, to be useable within ArcGIS as spatial data (National Park Service 2012). For the purposes of this study, the National Register of Historic Places data is used to identify landscape exclusions in analyses for suitable wind and solar energy development locations. These data were last updated in 2012.

Washington Cities and Urban Growth Areas

The Washington cities and urban growth areas (UGA) GIS data are publicly available from the Washington Department of Ecology, a state agency that collects and records data concerning Washington's air, water, and land (Washington Department of Ecology 2014). The cities and UGA data include GIS polygons identifying city boundaries and UGAs, as defined and managed by the Growth Management Act, across the state of Washington (WA Department of Ecology 2011). By definition, cities and UGAs are areas where urban growth and higher population densities are expected. They make "intensive use of land for the location of buildings, structures, and impermeable surfaces to such a degree as to be incompatible with the primary use of land for the production of food, other agricultural products, or fiber, or the extraction of mineral resources, rural uses, rural development, and natural resource lands" (Hunt et al. 2012, 13).

For the purposes of this study, the cities and UGA GIS data are used to identify landscape exclusions in analyses for suitable renewable energy development locations. Additionally, the cities and UGA GIS data are used to adjust the Washington Wildlife Habitats "Urban and Mixed Environments" habitat type to reflect more current land use patterns. These data were recently released in January of 2014.

Washington Agricultural Land Use

The Washington Agricultural Land Use GIS data are publically available from the Washington State Department of Agriculture (WSDA), a state agency that supports the producers, distributors, and consumers of Washington's food and agriculture products (Washington State Department of Agriculture 2014). This GIS dataset identifies agricultural land use across the state of Washington with detail down to the specific type of crops grown and types of irrigation used for each agricultural operation. The United States Department of Agriculture (USDA) and National Agricultural Statistics Service (NASS) manages the collection and annual publication of this dataset. Satellite imagery and other geo-referenced inputs from the Landsat 8 OLI/TIRS, Disaster Monitoring Constellation DEIMOS-1 and UK2 sensors, USGS National Elevation Dataset, and USGS land cover data are used to identify agricultural land use over an annual growing season down to a 30-meter ground resolution (US Department of Agriculture et al. 2014). The dataset is then verified by GIS technicians trained in crop identification by the USDA Farm Service Agency Common Land Unit Program. For the purposes of this study, the Washington Agricultural land use 2013 dataset is used to adjust the Washington Wildlife Habitats "Agriculture, Pasture, and Mixed-Environments" habitat type to reflect more current land use patterns.

Data Limitations

There are three main limitations to the data used in this study. The first is the age of the Washington Wildlife Habitats dataset. This dataset was published in 1999 and has not been updated since its original publication. This is not surprising, since the original data collection was field-survey verified and updating it is likely to be a costly and time-consuming process (Kiilsgaard 1999). However, the remainder of the data sources used in this study have been published or updated within the past two years (June 2012—January 2014), ensuring the utilization of the most current data available.

The Washington Wildlife Habitats dataset is an important component in addressing the fourth and fifth research questions in this study. However, there is likely to be some error in the results because of the age of the data. It is almost certain that landscape changes have occurred within the past 13 years that would alter the boundaries of the habitat types identified in the 1999 dataset. This would commonly be manifested in increasingly anthropogenic landscapes, though not in all cases. To account for this, the Washington Wildlife Habitat data should be adjusted to reflect the anthropogenic changes that have occurred, where possible. After adjustment, this dataset can still offer valuable information regarding the associations between crucial habitat levels and wind and solar energy potential within individual Washington habitat types.

A second limitation to the data used in this study is that many of the data sources were prepared for regional spatial investigations rather than at the local scale. These data sources maintain clear use statements indicating that they are not intended for regulatory purposes and that they were not prepared at the level of precision to replace small-scale, local analyses (Western Governors' Wildlife Council 2013b; US Fish & Wildlife Service 2014; Kiilsgaard 1999). As identified earlier, the scope of this study is to understand variable interactions at a landscape level for the entire state of Washington. While the scope of this study does not violate this data limitation, it should be acknowledged and echoed that any outcomes from this study should be taken at the landscape level and that local investigations for specific sites should use more precise methods in addressing these research questions. This data source limitation applies to the following data sources:

- Crucial Habitat Assessment Tool (CHAT)
- Washington Wildlife Habitats
- National Wetland Inventory

The final limitation to the data used in this study specifically involves the National Register of Historic Places dataset. This dataset is a collection of spatial polygons and point features identifying the historic places across the United States. While it is easy to incorporate the polygon features into the analyses of this study, the point features are more difficult to address. The point features can represent a variety of historic places, including buildings, archeological artifacts, or other cultural places like historic viewpoints (National Park Service 2012). However, there is no sense of size associated with a point feature, and no guidelines were identified by the National Park Service as to how to accommodate this dilemma.

For fear of grossly misrepresenting the spatial footprints of the historic places represented by these point features, these data were excluded from the analyses in this study. This amounts to about half of the National Historic Places identified in the dataset. This means that, in the spatial analysis of suitable land for wind and solar energy development, some areas identified may not truly be suitable due to the presence of historic places. However, since many of the point features are historic buildings, it is probable that they will be located in urban areas. These features are likely to be accounted for in the exclusion of the city and urban growth areas dataset as an additional part of this analysis.

Data Preparation

Data preparation was required in most cases prior to use in analysis and can be grouped into three main data preparation tasks. First, many of the datasets contained information that exceeded the study area of Washington State and required redefinition according to the study area boundaries. For these datasets the intersect, clip, or select attribute by location GIS tools were utilized to create new GIS shapefiles with spatial data for Washington State only. This ensured all analyses were conducted within the study area and not influenced by data in neighboring states.

The second data preparation task addressed the Washington Wildlife Habitats data age limitation and out-of-scope habitat types. To address the data age limitation the habitat types of "Urban and Mixed-Environments" and "Agriculture, Pasture, and Mixed-Environments" were redefined to reflect more current spatial boundaries. To redefine these habitat types, a two-step process was employed using the 2014 Washington Department of Ecology Cities and Urban Growth Areas dataset, as well as the 2013 USDA Agricultural Land Use dataset. First, the merge and dissolve GIS tools were used to expand the urban and agriculture habitat type polygons to include the areas identified in the more current datasets. In the case of a conflict between the urban and agriculture habitat types, the conflicting areas were included in the "Urban and Mixed Environments" habitat since, by definition, this habitat type is often bordered by agriculture, and landscape modifications occur frequently (Chappell et al. 2001). Second, the erase GIS tool was used to reduce the boundaries in the adjoining habitat type polygons where the urban and agriculture habitats had expanded, as indicated in the more recent data sets. All but three of the 22 habitat types present in Washington State were affected by the growth of agriculture and UGAs across the state, so this data adjustment was important to improve the accuracy of analyses.

In addition to the data limitation adjustment, the number of habitat types identified in the Washington Wildlife Habitats was also adjusted to reflect the proper scope of analysis. The Washington Wildlife Habitat dataset includes both terrestrial and oceanic habitats. Since this study focuses exclusively on terrestrial landscapes and on-shore wind and solar energy development, this dataset was redefined to only include terrestrial habitat types. This was accomplished by using an attribute definition query to exclude all oceanic and related near-shore habitat types. In addition, the sheer number of habitat types identified was too granular and dispersed across the landscape to use in the analysis. To adjust for this data challenge, the habitat types were grouped by similar habitat characteristics into five general habitats to be used in the analysis (Table 2).

Table 2. Consolidation of Individual Habitat Types into General Habitats and Habitat Exclusions

General Habitats	Specific Habitat Types
Agriculture, Pasture, and Mixed-Environments	• Agriculture, pasture, and mixed-environments
Forest and Woodlands	• Westside lowland conifer-hardwood forest • Westside oak and dry Douglas-fir forest and woodlands • Montane mixed conifer forest • Eastside (interior) mixed conifer forest • Lodgepole pine forest and woodlands • Ponderosa pine and eastside white oak forest and woodlands • Upland aspen forest
Grasslands and Shrublands	• Subalpine parklands • Alpine grasslands and shrublands • Westside grasslands • Eastside (interior) canyon shrublands • Eastside (interior) grasslands • Shrub-steppe
Urban and Mixed-Environments	• Urban and mixed-environments
Wetlands, Rivers, Lakes, and Reservoirs	• Lakes, rivers, ponds, and reservoirs • Herbaceous wetlands • Westside riparian wetlands • Montane coniferous wetlands • Eastside (interior) riparian wetlands
Habitats Excluded from Analysis	• Costal dunes and beaches • Coastal headlands and islets • Bays and estuaries • Inland marine deeper waters • Marine nearshore • Marine shelf • Oceanic

Finally, the third data preparation task involved the USGS existing wind turbine dataset to generate wind farm polygons for use in analysis. The USGS existing wind turbine dataset is a collection of point features indicating turbine geographic location, technical specifications, and wind farm site identification. However, to address the first research question a polygon representing individual wind farm areas was required for the analysis. To accomplish this, a buffer was first established around each wind turbine with a radius of four turbine rotor diameters, as suggested in wind farm guidelines for turbine spacing within rows (Manwell, McGowan, and Rogers 2009; Nelson 2009). These buffers ensure that the wind farm polygon boundaries will be drawn to include appropriate turbine spacing requirements for the outermost turbines in each wind farm. Next, the minimum bounding geometry GIS tool with a convex hull geometry type setting (considered the natural bounding area for a set of points) and grouping level according to the wind farm site location was applied to the turbine buffers. The outcome of this GIS tool generated a convex polygon for each wind farm. While the wind farm boundaries do not exactly replicate landscape ownership boundaries, each wind farm polygon encompasses all wind turbines associated with the wind farm and is a good geometric estimate of the landscape that could be impacted by each wind farm.

3.2 Data Analysis

Existing Washington Wind Farms

To understand the levels of crucial habitat that occur within existing Washington wind farms, a basic spatial analysis was performed. First, wind farm sites that were listed in the original dataset but had unknown site affiliations and specification or were not fully operational were excluded from this analysis. This ensured that all existing Washington wind farms in scope for analysis were known and fully operational. To complete the spatial analysis, the intersect GIS tool was used to select only the crucial habitat data that occurred within the known, operating wind farm polygon boundaries. The outcome identified wind farm sites, crucial habitat rankings, and the geometric area of the crucial habitat landscape coverage within the existing wind farms. These data were then exported to Excel, where pivot table graphs were generated, presenting simple descriptive statistics of the crucial habitat levels within individual or groups of existing Washington wind farms across the landscape.

Wind and Solar Energy Development Landscapes

For the assessment of wind and solar energy development landscapes across the state of Washington, a second spatial analysis was performed. This was then followed by a simple estimation of potential renewable energy that could be produced, as indicated by the number of acres suitable for development according to the inclusion or exclusion of the various crucial habitat levels. This portion of the analysis describes the risk of landscape conflict and opportunity or challenge of optimizing the land use between crucial habitat and future wind and solar energy development. To begin the spatial analysis, landscapes "suitable" for commercial wind or solar energy development were first defined. Smaller, domestic energy production was not considered as part of this analysis because land use would not be as impacted as the lands required for commercial developments. In addition, the technologies available for domestic energy production have much more variable technical specifications and siting requirements than those available for commercial energy production. This would require more detailed calculations of potential energy production on suitable energy development lands that what was used in this analysis.

The American Wind Energy Association (AWEA) wind energy siting handbook was used as the primary reference in determining landscapes that were not suitable for commercial renewable energy development (American Wind Energy Association, Tetra Tech EC Inc., and Nixon Peabody LLP 2008). Since there are few published guidelines for the development of solar energy, a similar landscape suitability model used to identify wind energy development landscapes was applied to the analysis for solar energy development landscapes. According to the AWEA, landscapes that are not suitable for commercial renewable energy development are those that are protected areas, wetlands, or historic or cultural resources, as identified by the National Register of Historic Places. These lands are either protected through legislation or, in the case of wetlands, require such high mitigation costs that developments in these areas usually prove unprofitable (American Wind Energy Association, Tetra Tech EC Inc., and Nixon Peabody LLP 2008). For the purposes of this study, these lands were considered unsuitable for commercial renewable energy development and excluded from the analysis.

In addition, cities and urban growth areas were also excluded, since these areas are designated for alternative uses. Regarding suitable wind farm development locations only, existing wind farms were also excluded from the analysis since they are already developed and unavailable for further energy production. However, these lands were included in the assessment of suitable solar energy development locations, since wind turbines have large spacing requirements and there is a potential to develop solar technologies in between the wind turbines, if conditions are appropriate. The AWEA also identifies lands with known endangered species habitation as unsuitable for energy development. However, the AWEA also identifies mitigation and accommodation techniques as well as exceptions to work within and around such areas. Since this siting concern requires local investigation to determine the extent of unsuitability, lands with known endangered species were not excluded from the analysis. Instead, they will be reflected in the crucial habitat rating across the landscape as a high-level habitat conservation priority landscape.

To conduct the spatial analysis, the Erase GIS tool was used to remove lands that were unsuitable for wind and solar energy development (i.e., protected areas, wetlands, National Historic Places, cities and urban growth areas, and existing Washington wind farms—for wind energy assessment only). Next, the Select by Attribute GIS tool was used to remove lands that did not exhibit an annual wind or solar energy level that was suitable for commercial energy production. For wind, lands with a wind power class of one or two are considered too low for commercial wind energy production and were removed from the analysis (American Wind Energy Association, Tetra Tech EC Inc., and Nixon Peabody LLP 2008; National Renewable Energy Laboratory 2014).

Unlike wind energy, solar energy does not have a strict solar irradiance level defining suitable solar energy resources. In this case, the solar prospectus online GIS solar energy data mapping tool, developed by the NREL, was utilized to identify the lowest solar irradiance level of existing U.S. commercial Photovoltaic (PV) solar facilities. This solar irradiance level became the cutoff point between suitable and unsuitable solar energy levels for the purposes of this study. The South Burlington Solar Farm in Vermont was identified as the PV solar facility operating with the lowest average annual PV solar resource (latitude equals tilt irradiance) level of about 4.26 kWh/m^2/day (National Renewable Energy Laboratory 2009). Using this figure, any annual average solar tilt equals lateral irradiance levels below 4.25 kWh/m^2/day was considered unsuitable for solar energy production and was removed from the analysis.

Once the landscapes suitable for wind and solar energy development were defined, the Intersect GIS tool was used to identify the crucial habitat levels within these landscapes. These data were then exported to Excel, where pivot table graphs were generated presenting simple descriptive statistics of the crucial habitat levels across the landscapes suitable for wind or solar energy development. Finally, simple estimates were made of how much average annual energy could be produced if the landscape was developed within the various crucial habitat levels.

For wind energy, 2011 Washington wind energy production data were used to calculate the estimated number of acres required for commercial wind energy technologies to produce one gigawatt hour of energy per year (acre/GWh/year) (US Department of Energy 2011; Northwest Power and Conservation Council 2013). This was then applied to the total landscape area (acres) for each crucial habitat level within suitable wind energy development locations. This estimate is expected to capture the wind power variation across the landscape because the wind power class level distributions in existing Washington wind farms is similar to the wind power class level distributions for the remaining suitable wind energy development landscapes. In both cases, around 70-75% of the wind power across the landscapes is categorized as class 3 and below, between 20-25% as class 4, and the remaining 5% as class 5 and above. Additionally, the crucial habitat distributions within each wind power class level of suitable wind development lands are consistent with having a majority of the lands ranked as crucial habitat levels 3 and 2. By using existing Washington wind farm production data as the basis for this calculation, generating estimates for future wind energy production that are realistic to the conditions in the state of Washington was attempted. The outcomes of these estimates were then used to assess the impact of crucial habitat on potential future wind energy production in Washington State.

For solar energy, existing commercial solar energy production for the state of Washington is so small it is not explicitly tracked, so a different approach was applied. Ong et al., researchers for the NREL, recently published a study that investigated solar energy land use needs in the United States (Ong et al. 2013). This study collected site specifications for 150 PV solar facilities in the U.S. (operating or under construction) and calculated an energy generation weighted average total area requirement for different specific solar PV technologies (acres/GWh/year). The average of these figures represents the average number of acres required for solar PV technologies to produce one gigawatt hour of energy in one year. This was then applied to the total landscape area (acres) for each crucial habitat level of suitable solar energy development locations. The outcome was then used to assess the impact of crucial habitat on potential future solar energy production in Washington State.

Washington Habitats

To assess the landscape-level interactions between the most crucial habitats and high wind or solar energy potential within Washington habitats, an analysis of spatial autocorrelation using the Anselin Local Moran's I spatial statistic was performed. Then, the results were assessed according to the interaction between the crucial habitats and wind or solar results within the five general Washington habitat types. The Anselin Local Moran's I statistic identifies significant spatial clustering of both high and low values that occur across the landscape for a single numeric feature attribute. This statistic uses matrix algebra and a spatial weighting mechanism to assess the similarity or difference between an individual feature and its spatial neighbors (Anselin 1992; Fotheringham, Brunsdon, and Charlton 2000; Blyth et al. 2007; Esri Inc. 2013). The equation for the Anselin Local Moran's I statistic is:

$$I^* = \frac{x_i - \bar{X}}{S_i^2} \sum_{j=1, j \neq i}^{n} w_{i,j}(x_i - \bar{X})$$

where x_i is the feature attribute being assessed, $\bar{X}$is the mean of the corresponding and neighbor feature attributes, $w_{i,j}$ is the spatial weight between the feature attribute x_i and the neighbor feature attribute x_j, and S_i^2 is:

$$S_i^2 = \frac{\sum_{j=1, j \neq i}^{n} (x_i - \bar{X})^2}{n-1} - \bar{X}^2$$

The results from this analysis calculate a z-score and related p-value for each feature in the study area. Features that have a significant positive z-score indicate significant spatial clustering of features with high values and a significant negative z-score indicates significant spatial clustering of features with low values (Fotheringham, Brunsdon, and Charlton 2000; Esri Inc. 2013).

To conduct a local spatial autocorrelation analysis, certain assumptions must be met for the analysis to be valid. First, results are only reliable if more than 30 features are being assessed and each feature has at least one neighbor. Second, no feature should have all other features in the analysis as neighbors; ideally, each feature should have about 8 other features as neighbors in the analysis. Finally, the attribute of interest must be a numeric value and have some variation between feature values (i.e., more values than just 0 and 1) (Esri Inc. 2013). The local spatial autocorrelation analysis performed in this study met all of these assumptions.

To address this research question, three local spatial autocorrelation analyses were conducted across the entire state of Washington according to crucial habitat ranking, wind power class ranking, and average annual photovoltaic solar irradiation. The most important input in conducting these local spatial autocorrelation analyses is the conceptualization of the spatial relationships among features. There are many ways to define this conceptualization according to the feature types used in the analysis and how the features interact with one another across the landscape. Subtle differences in analysis configuration can produce drastic differences in the statistical outcomes (Esri Inc. 2013; Fotheringham, Brunsdon, and Charlton 2000). This means results should only be interpreted within the scope of the specific analysis. For this study, a spatial weights matrix was generated for each local autocorrelation analysis to define the conceptualization of spatial relationships for the features in each of the three datasets. The Generate Spatial Weights Matrix tool in ArcGIS was used to accomplish this.

Since the features of interest in this analysis are all polygon features that are, in most cases, contiguously connected across the landscape, a K nearest neighbor conceptualization of spatial relationships using the 8 nearest neighbors was defined. This ensured the assumptions of the analysis were met and the distance threshold of the features included for each feature analysis was kept at a minimum. This is particularly important because crucial habitats, wind energy resources, and solar energy resources in one area of the landscape are more likely to be influenced by the landscape conditions of areas that are direct neighbors than by those that are farther away. Row standardization was also defined to standardize the spatial weights mechanism used for the neighbors included in the individual feature analysis. In this case, the area of each neighboring polygon was used to adjust the weighted influence of each neighboring feature. This ensured that the influence of each neighbor was a factor of both distance from the centroid of the individual feature being analyzed and size of neighboring polygons.

Once the local spatial autocorrelation analysis was completed using the Cluster and Outlier Analysis (Anselin Local Moran's I) spatial statistic tool, the results were assessed between crucial habitats and wind energy resources as well as between crucial habitats and solar energy resources. Since the spatial autocorrelation analyses were conducted using the same study region with the same scope and the same analysis configurations, the results of the individual autocorrelation analyses are comparable with one another. These comparisons identified important patterns of spatial clustering between crucial habitat and wind or solar energy resources. These include:

- Areas of significant high wind or solar energy resource clustering
- Areas of significant low wind or solar energy resource clustering (not important for this analysis)
- Areas of significant most-crucial habitat clustering
- Areas of significant least-crucial habitat clustering

These patterns were then be used to identify:

- Significant areas of high conflict
    - Areas that are both significant high wind or solar energy resources clustering and significant most-crucial habitat clustering
- Significant areas of low conflict
    - Areas that are both significant high wind or solar energy resources clustering and significant least-crucial habitat clustering

With these spatial patterns identified, a final assessment was conducted to understand the distribution of these significant spatial patterns within the five general habitats across Washington State.

Chapter 4: Results

4.1 Existing Washington Wind Farms

The crucial habitat assessment of existing wind farms in the state of Washington shows that existing wind farms have been sited moderately well according to landscape-level habitat conservation priorities. With a total area of 170,104 acres, just over half (56.6%) of the lands developed for wind energy have a crucial habitat ranking of 3–6 signifying development on lesser crucial habitat lands. However, 36.7% of the lands developed for wind energy have a more crucial habitat ranking of 2, and 6.8% with the most crucial habitat rank of 1 (see Figure 2 and 3).

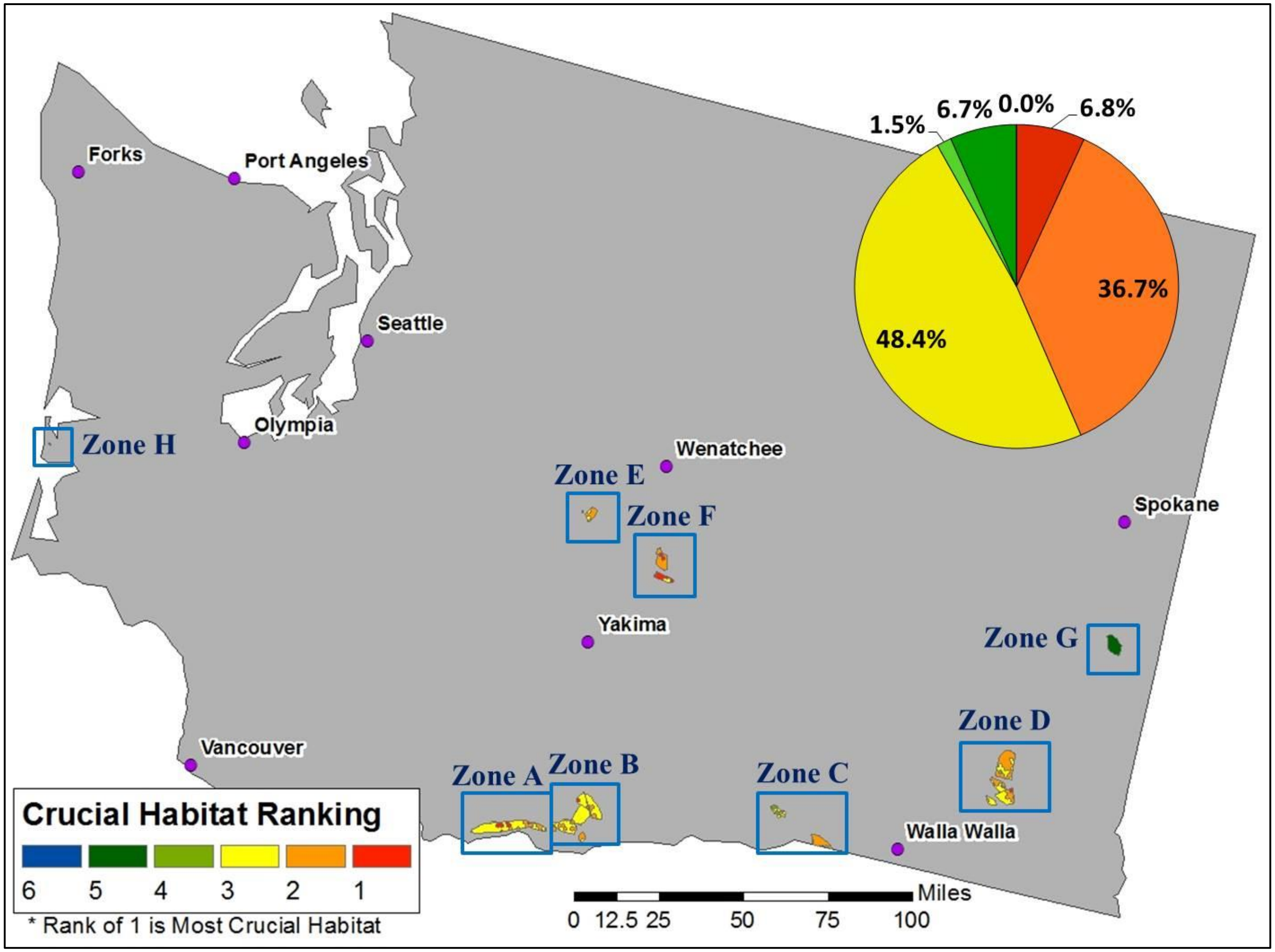


Figure 2. Crucial habitat on all existing and operating Washington wind farms.

Each zone is explored in further detail in figures 4a and 4b.

As noted in the crucial habitat assessment data sources section of chapter 3 (page 45), the crucial habitat ranking is an aggregation of statewide habitat conservation priorities, where the higher the crucial habitat ranking, the higher the relative wildlife and conservation value of the land (Western Governors' Wildlife Council 2013a). The most crucial habitat lands—with a rank of 1—will have documented threatened or endangered aquatic species spawning areas, documented threatened or endangered terrestrial species, level-1 priority habitat ecological systems of concern and confirmed heritage vegetation, or high-integrity estuaries present on the landscape. Crucial habitat lands with a rank of 2 will have documented or presumed endangered and threatened aquatic species, confirmed federal and state candidate and sensitive terrestrial species, level-2 priority habitat ecological systems of concern, moderate integrity estuaries, or are spawning areas for aquatic species of economic and recreational importance. Levels 3–5 will have lesser degrees of the ranking factors considered for ranks 1 and 2, as well as consideration and prioritization of various levels of freshwater integrity, large natural areas, terrestrial species of economic and recreational importance, landscape connectivity, and wildlife corridor factors (see Table 9 in the Appendix for a summary of the crucial habitat ranking factors associated with the six crucial habitat levels). Higher crucial habitat levels will often require habitat mitigation or habitat avoidance practices when development is considered, according to federal and state wildlife protection policies (Washington State 1971; Western Governors' Association 2013; Western Governors' Wildlife Council 2013a). Alternatively, less crucial habitat levels signify lands with wildlife and habitat areas that are not considered to have as high a conservation value as those with the more crucial habitat levels 1 and 2.

The resulting distribution of crucial habitat levels for existing wind farms is somewhat similar to the distribution of crucial habitat levels statewide; a majority of the landscape (92%) has a crucial habitat ranking of 1, 2, or 3 in both cases (Figure 3). However, a clear difference between the two distributions is observed when comparing the portions of land that have been categorized as crucial habitat rank 1. Existing wind farms have been developed on 66% less of the most crucial habitat lands (rank 1) than what are observed in the crucial habitat distribution statewide (6.8% vs. 15.3% respectively, Figure 3). This is consistent with the general hypothesis that the EIA process would promote wind energy development in areas having lower priority habitat conservation concerns.

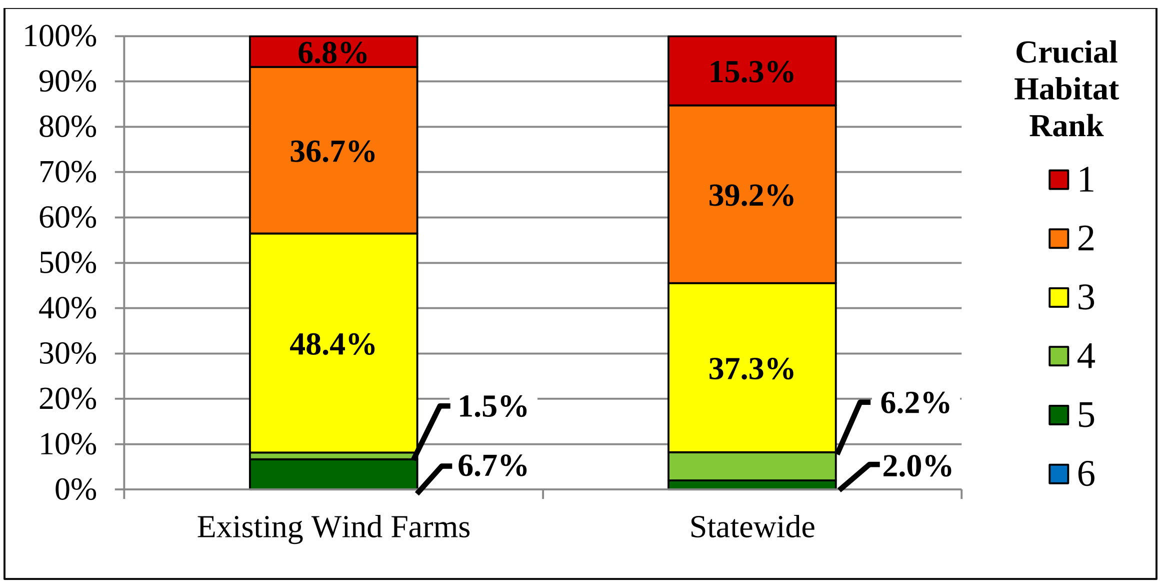


Figure 3. Crucial habitat on existing Washington wind farms and statewide

Despite the overall reduction in existing wind farm development on the most crucial habitat lands, the assessment of crucial habitat at an individual or zoned wind farm level is much more varied. For ease of visual comparison, the 20 Washington wind farms were placed into eight wind farm zones (Zones A – H) across the landscape to assess the crucial habitat distribution in different geographic locations (Figure 4a and 4b). Many of the zones show crucial habitat distributions that are consistent with the overall crucial habitat distribution of all 20 existing wind farms. However, some wind farm zones show notable differences. For example, zone G contains the Palouse wind farm, spanning 11,330 acres of land, which has been sited entirely on less crucial habitat lands with a rank of 5. This is the best-sited wind farm in the entire state with respect to landscape conservation priorities, and it is the only wind farm located in an area where crucial habitat is at a level 5. In contrast, zone F, including the Wild Horse and Vantage wind farms, spanning 14,988 acres, were sited in areas containing the most crucial habitat, with 39.2% of the lands having a crucial habitat rank of 1 and 52.5% with a rank of 2. These wind farms are the most poorly sited wind farms out of all the existing wind farms concerning landscape level habitat conservation priorities.

Figure 4. Crucial Habitat Assessments of Wind Farm Zones

Figure 4a shows the crucial habitat assessment for the existing and operating wind farms in zones A–C. Most of the wind farms in these zones have been developed in landscapes with crucial habitat rankings of 1–3.

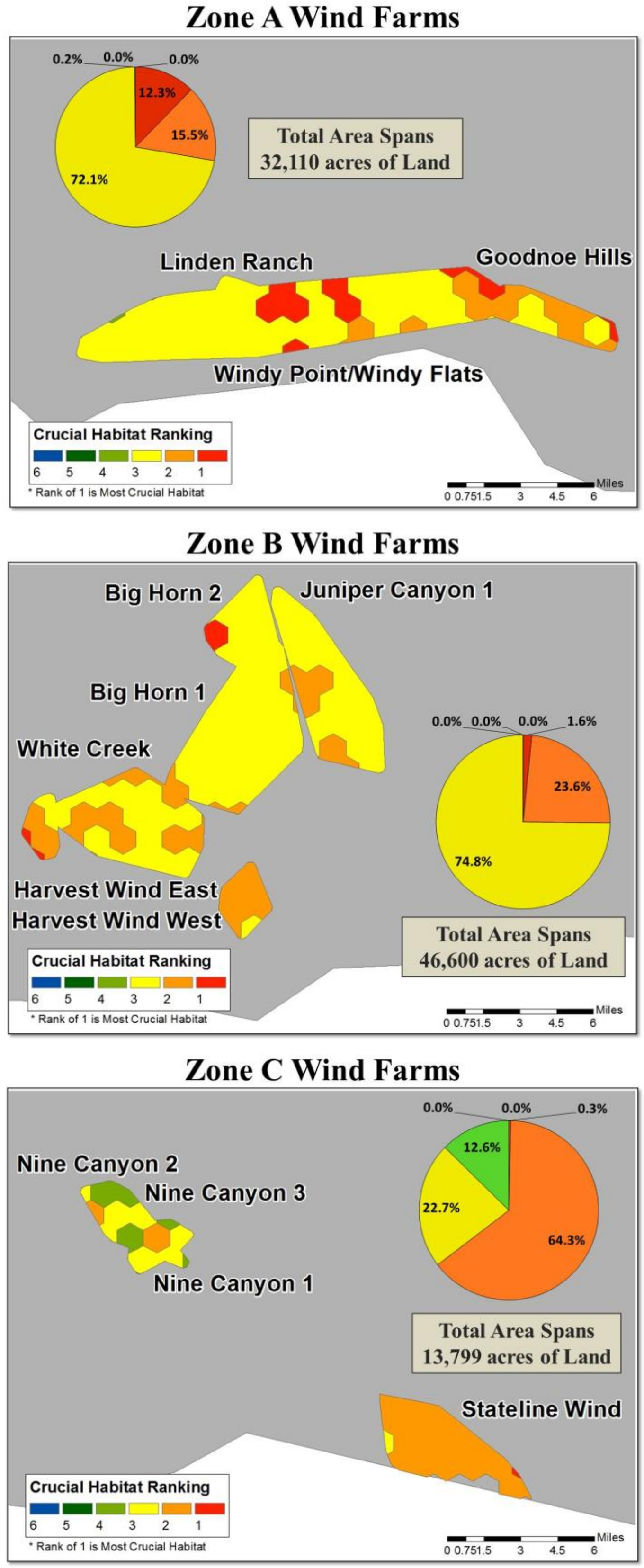
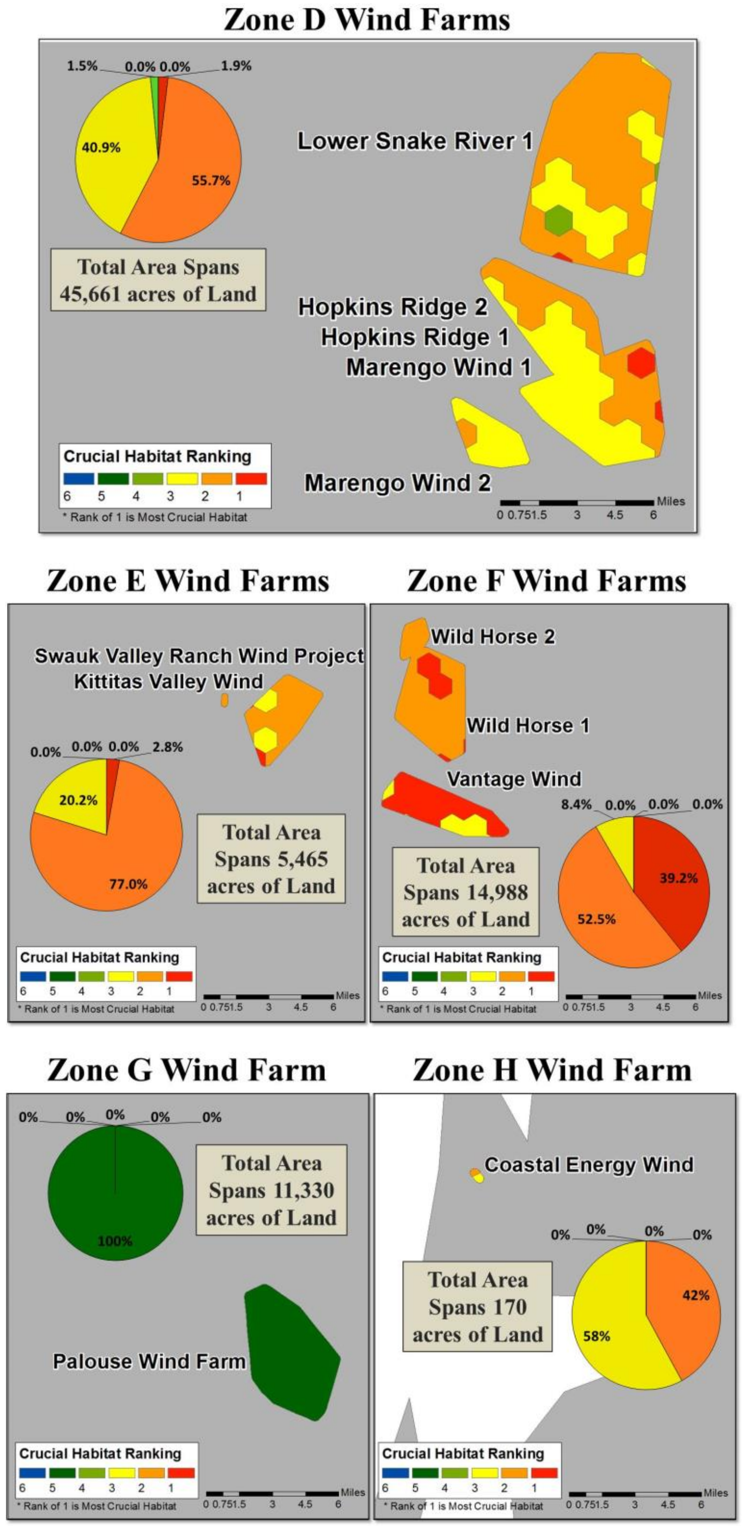


Figure 4. Crucial Habitat Assessments of Wind Farm Zones

Figure 4b shows the crucial habitat assessment for the existing and operating wind farms in zones D–G. The Palouse wind farm in zone G was developed on lands with a crucial habitat rank of 5 for the entire wind farm operation, making it the best-sited wind farm with respect to landscape level habitat conservation priorities. The Vantage and Wild Horse wind farms in zone F is the worst sited wind farm, with most development occurring on the most crucial habitat lands with a rank of 1.



NOTE: Crucial habitat distributions within individual wind farms appear in appendix, Figure 19.

4.2 Wind and Solar Energy Development Landscapes

Wind Energy Assessment

The crucial habitat assessment of suitable wind energy development landscapes shows that a majority of these lands is of moderate concern for landscape-level habitat conservation. Of the lands suitable for wind energy development, 8% have a crucial habitat ranking of 1, 30% have a crucial habitat ranking of 2, and 50% have a crucial habitat ranking of 3 (Figure 5). Combined, this occupies just over 1 million acres of the total 1.2 million acres of land suitable for wind energy development as defined by this study. Also, it is interesting to note that there are no least-crucial habitat lands with a rank of 6 in the lands suitable for wind energy development.

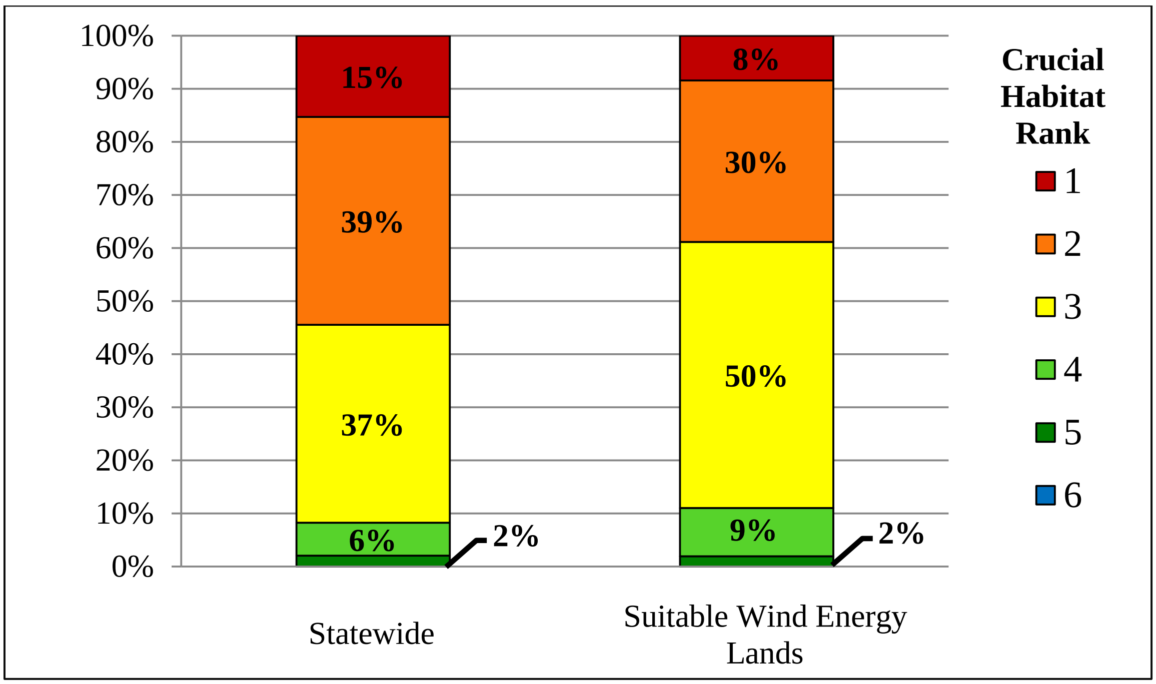


Figure 5. Crucial habitat on suitable wind energy lands and statewide

This distribution of crucial habitat was mostly expected as identified by the general hypothesis, since it follows similar patterns to the crucial habitat distribution across the entire state of Washington. Both have roughly 80% of the landscape with a crucial habitat ranking of 2 or 3 and less than 1% with a crucial habitat rank of 6. However, suitable wind energy development landscapes have slightly lower portions of most-crucial habitat lands with a rank of 1 compared to those across the entire state of Washington (8% vs. 15%, as shown in Figure 5). This is 46% less most-crucial habitat lands proportionally, and shows that wind energy development poses a slightly lower risk of conflict with the most crucial habitat conservation areas than might be supposed.

Closer investigation of the distribution of crucial habitat across the landscape shows that a few locations in southeastern and central Washington State have large contiguous areas suitable for wind energy development (Figure 6). Within these areas there are about four locations along the southern border of Washington that have groupings of lands with lower crucial habitat rankings. These are identified by the shades of green in Figure 6. If landscape-level habitat conservation efforts were a high concern in relation to wind energy development, these areas of land with lower crucial habitat rankings should be investigated first to determine the feasibility of wind energy development at a local scale.

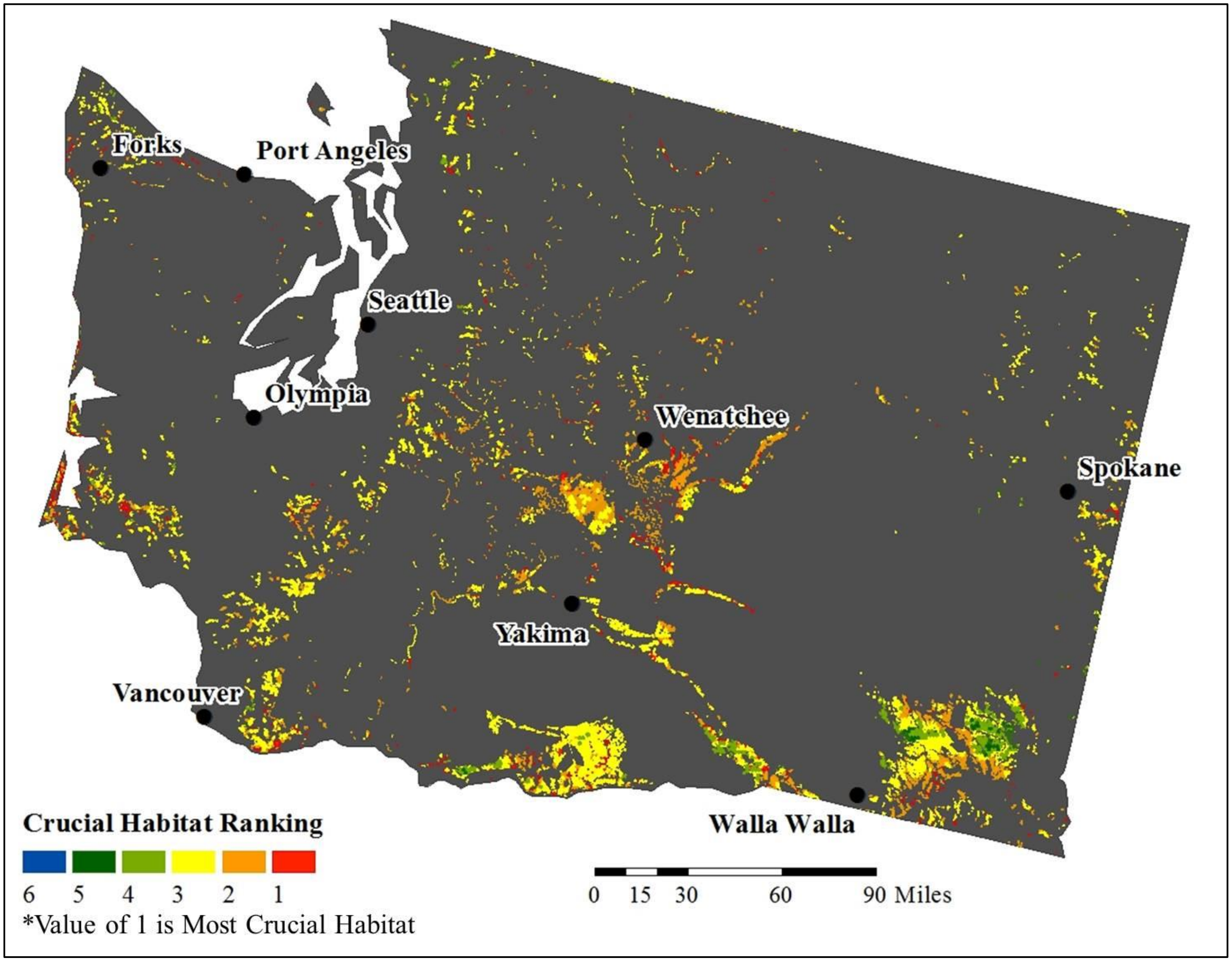


Figure 6. Crucial habitat on suitable wind energy development landscapes

To investigate the opportunity or challenge of optimizing the land use between habitat conservation and wind energy development, an assessment of the levels of crucial habitat that future wind energy development could be restricted in order to both protect habitat quality and contribute to future energy generation was conducted. To achieve this, an estimate of the average energy production (GWh) per year according to the total landscape area (acres) of suitable wind energy lands was calculated according to various crucial habitat levels. As discovered when investigating the first research question in this study, existing Washington wind farms span approximately 170,104 acres of land. These wind farms generated 5,830 GWh of energy in 2011, which made up 1.8% of all energy produced in the state of Washington (US Energy Information Administration 2012; Northwest Power and Conservation Council 2013). With this information it is estimated that, for every 1 GWh of wind energy produced over the course of one year, approximately 29.2 acres of land would be required. When applied to the total area of the landscapes ranked at each crucial habitat level, we may examine the impact on potential future wind energy production that would result from the exclusion of areas with specific crucial habitat levels.

According to the analysis, lands with the most crucial habitat ranking of 1 or 2 could be excluded from future wind energy development and still allow the generation of an estimated 25,640 GWh annually from wind energy production on less crucial habitat lands (Table 3). This represents a 440% increase in existing wind energy generation in Washington State. This means that there is enough land suitable for wind energy development that also has a lesser crucial habitat ranking of 3 and above to quadruple the existing wind energy production across the state if all of these lands were developed.

Obviously, it is very unlikely that the total area would be developed; however, it is important to know there is a healthy growth potential within these landscapes.

If wind energy development were to be restricted further, to crucial habitat lands of ranks 4–6 only, however, the potential for wind energy growth would be severely limited. Under this criterion for suitable wind energy development, the potential growth of wind energy would only be an about 4,636 GWh annually. This estimate is only an 80% increase in existing Washington wind energy production.

As can be seen in Figure 7, the majority of lands suitable for wind energy development have a crucial habitat rank of 3. Without these lands available for development consideration other siting issues, such as finding large, contiguous landscapes for development and working through social siting challenges, could further inhibit the already limited wind energy growth potential. From this assessment, it seems reasonable that if future policy or best practices in wind energy siting and development were to include landscape-level conservation priorities, absolute exclusions could only include crucial habitat levels 1 and 2. This does not mean the remaining lands rated as crucial habitat 3–6 are always fit for development, or that local environmental assessments identifying site-specific environmental concerns can be disregarded in these lands. What is clear from these findings, however, is that the most crucial habitat lands of ranks 1 and 2 could be preserved and protected, supporting high-level state conservation priorities, while still leaving ample room for future wind energy growth across the state of Washington.

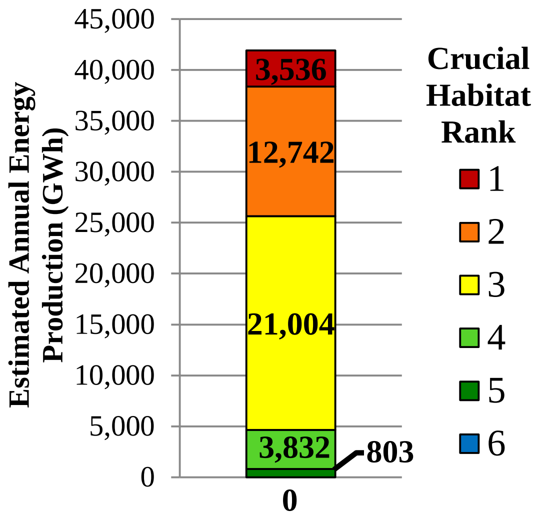


Figure 7. Estimated annual average energy production (GWh) of suitable wind energy development landscapes by crucial habitat rank

Table 3. Wind energy potential by crucial habitat levels

Crucial Habitat Levels	Est. Annual Average Energy Production (GWh)
1–6	41,918
2–6	38,382
3–6	25,640
4–6	4,636
5–6	803
6	0

Solar Energy Assessment

The crucial habitat assessment of suitable solar energy development landscapes shows a majority of these landscapes are of moderate to high concern for landscape level habitat conservation. Of the lands suitable for solar energy development, 50% have a crucial habitat ranking of 1 or 2 and another 37% have a crucial habitat ranking of 3 (Figure 8). Combined, this occupies approximately 11.8 million acres of the total 14 million acres of land suitable for solar energy development as defined by this study. As observed in the wind energy analysis, there are no least-crucial habitat lands with a rank of 6 in the lands suitable for solar energy development.

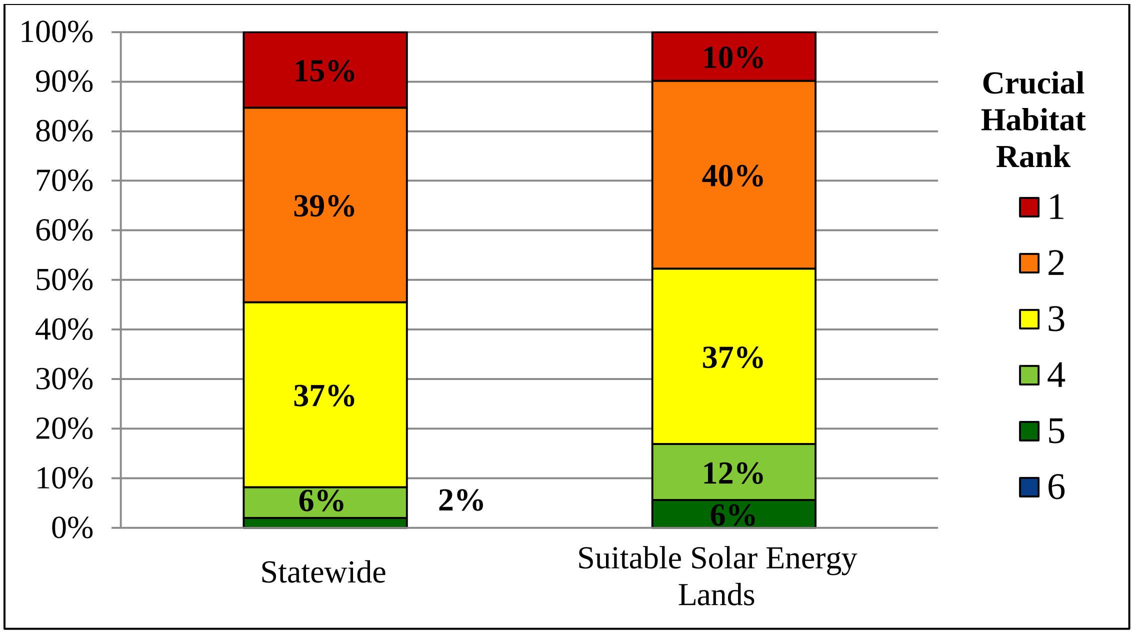


Figure 8. Crucial habitat on suitable solar energy development lands and statewide

This distribution of crucial habitat was mostly expected, as identified by the general hypothesis, since it follows a pattern similar to the crucial habitat distribution statewide; having roughly 90% of the landscape with a crucial habitat ranking of 1, 2, or 3 and less than 1% with a crucial habitat rank of 6. However, there are two notable differences between the crucial habitat distributions of these two landscapes. Like the suitable wind energy development landscapes, the suitable solar energy development landscapes have slightly lower most-crucial habitat lands with a rank of 1, as compared to those statewide (10% vs. 15%, as shown in Figure 8). This is 33% less most-crucial habitat land area within the suitable solar energy development landscapes proportionally. In addition, suitable solar development lands have 125% more crucial habitat lands of lower conservation value (ranks 4–5) than those observed across the entire state of Washington (18% vs. 8%, Figure 8). While the general distribution of crucial habitat is similar within the two landscapes, suitable solar energy development landscapes do have a slightly lower impact on the most-crucial habitat conservation priorities. Moreover, solar energy development also presents a greater opportunity to develop in areas of lower conservation value.

When looking at the distribution of crucial habitat across the landscape, nearly the entire eastern portion of the state of Washington is suitable for solar energy development (Figure 9). Within this area there are several locations that have large segments of the landscape with less-crucial habitat rankings. These are identified by the shades of green in Figure 9 and are generally located in the east-central and southeastern parts of the State. If landscape-level habitat conservation efforts were taken to be a high concern in relation to solar energy development, these areas of land with less-crucial habitat rankings should be investigated first to determine the feasibility of solar energy development at a local scale.

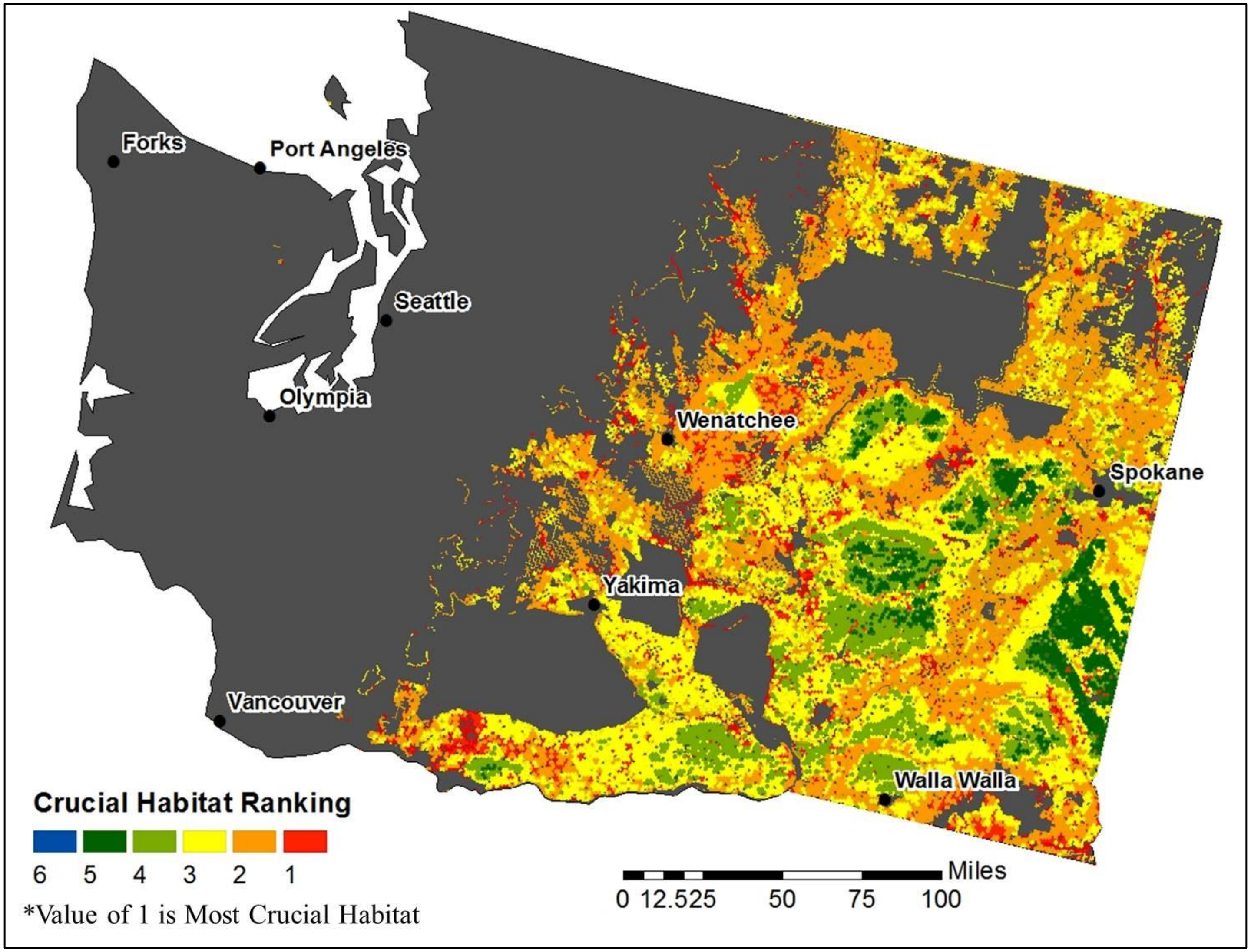


Figure 9. Crucial habitat on suitable solar energy development landscapes

To investigate the opportunity or challenge of optimizing the land use between habitat conservation and solar energy development, an assessment of the levels of crucial habitat that future solar energy development could be restricted in order to both protect habitat quality and contribute to future energy generation was conducted. To achieve this, an estimate of the average energy production (GWh) per year according to the total landscape area (acres) of suitable solar energy lands was calculated according to various crucial habitat levels. Since commercial solar facilities have a minimal presence in Washington State, the average number of acres required for solar PV technologies to produce one gigawatt hour (GWh) of energy in one year was taken from the Ong et al. study (2013), which showed that, for every 1 GWh of solar energy produced over the course of one year, approximately 3.8 acres of land is required. When applied to the total area of the landscapes ranked at each crucial habitat level in Washington State, we may examine the impact on potential future solar energy production that would result from the exclusion of areas with specific crucial habitat levels.

According to the analysis, future solar development could be restricted to crucial habitat lands with a rank of 5 only, and still allow for the generation of an estimated 209,540 GWh annually (Table 4). This is 65% of the total 2011 energy production (GWh) for the entire state of Washington. This means that there is enough land suitable for solar energy development on the less-crucial habitat lands (with a rank of 5) to increase Washington's annual energy production over 50%. This is a huge amount of energy potential but not entirely unexpected, since the total land use requirements per GWh of energy production in one year is only 3.8 acres. Again, it is extremely unlikely that the entire crucial habitat area of level 5 will be developed for solar energy generation. There are many economic, social, and technical aspects that further determine the suitability and feasibility for development at particular locations that must also be considered. These will be discussed in detail within the "Solar Energy Resource Analysis Limitations" section of the next chapter, beginning on page 110. However, this initial analysis does show that there is much solar energy generating potential in the least-crucial habitat areas wherever economic and other practical challenges permit.

As can be seen in Figure 10, there is a large potential for solar energy generation across the various crucial habitat levels. However, from this assessment it seems reasonable that if future policy or best practices in solar energy siting and development were to include landscape-level conservation priorities, future solar growth could initially be targeted in areas with a crucial habitat ranking of 5 alone. Not only are these landscapes sufficiently sized for ample solar energy growth, but they happen to also be located in the same general area of the southeastern corner of Washington State (Figure 9 above). This would be conducive to establishing larger solar facilities, further expanding renewable energy production in Washington, while also working toward protecting high-level state conservation priorities.

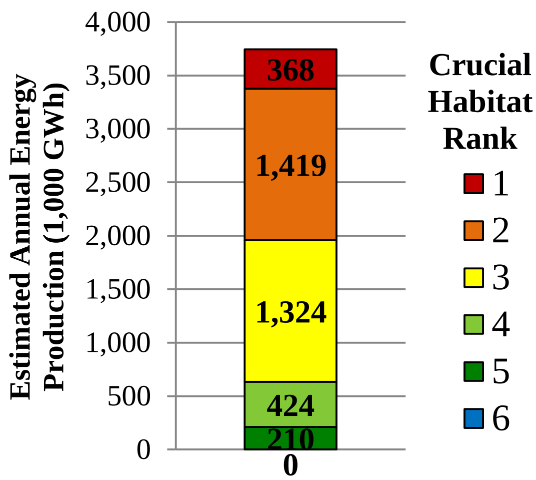


Figure 10. Estimated annual average energy generation (GWh) of suitable solar energy development lands by crucial habitat ranking

Table 4. Solar energy potential by crucial habitat level

Crucial Habitat Levels	Est. Annual Average Energy Production (GWh)
1–6	3,745,146
2–6	3,377,146
3–6	1,957,879
4–6	633,498
5–6	209,540
6	0

4.3 Washington Habitats

In the assessment of the interaction between crucial habitat and wind or solar energy resources, it is important to understand if there are positive or negative interactions between the variables within the different habitat types of Washington State. Gaining an understanding of these interactions will help habitat conservation efforts be more aware of the risks and opportunities of wind or solar development within certain Washington habitats. As mentioned in the data preparation section of this study, the 20 specific onshore habitat types present in the state of Washington have been combined to form five general habitat types according to habitat similarity. Figure 11 shows the distribution of these general habitat types across the Washington landscape.

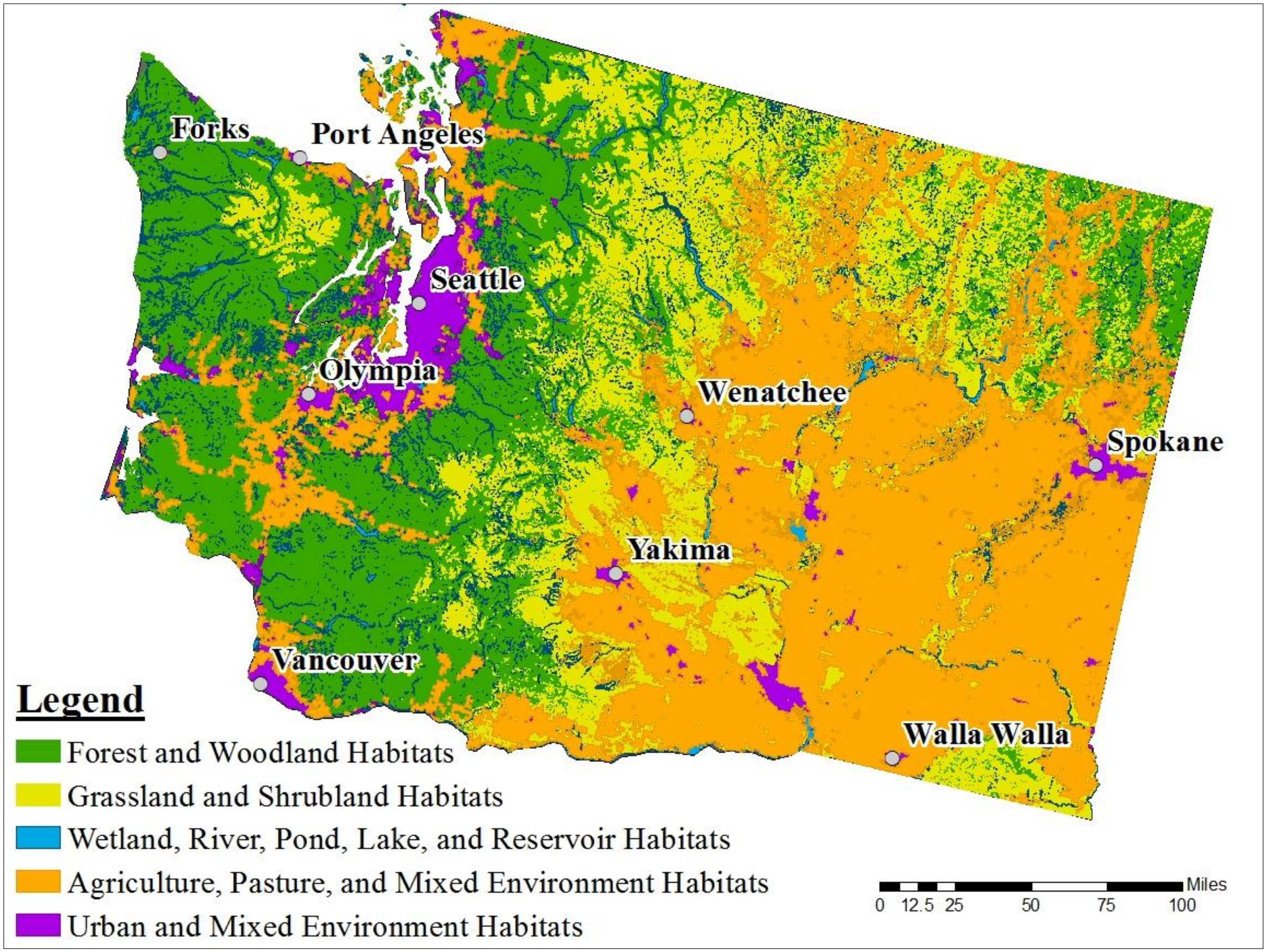


Figure 11. General Habitats in Washington State

The forest and woodland habitats are located in the western and northern parts of the state and most of the agriculture and pasture habitats are in the southeastern corner of the state. These two habitat types cover the most land, representing 78% of the landscape and about 33 million acres (Figure 12). The grassland and shrubland habitats are the third largest habitat type, covering about 16% of the landscape (approximately 7 million acres) and tend to border both the agriculture/pasture and forest/woodlands habitats. The wetland and other hydrologic habitats as well as the urban habitat are dispersed throughout the entire state and are the smallest habitat types, covering only 2% and 4% of the landscape, respectively.

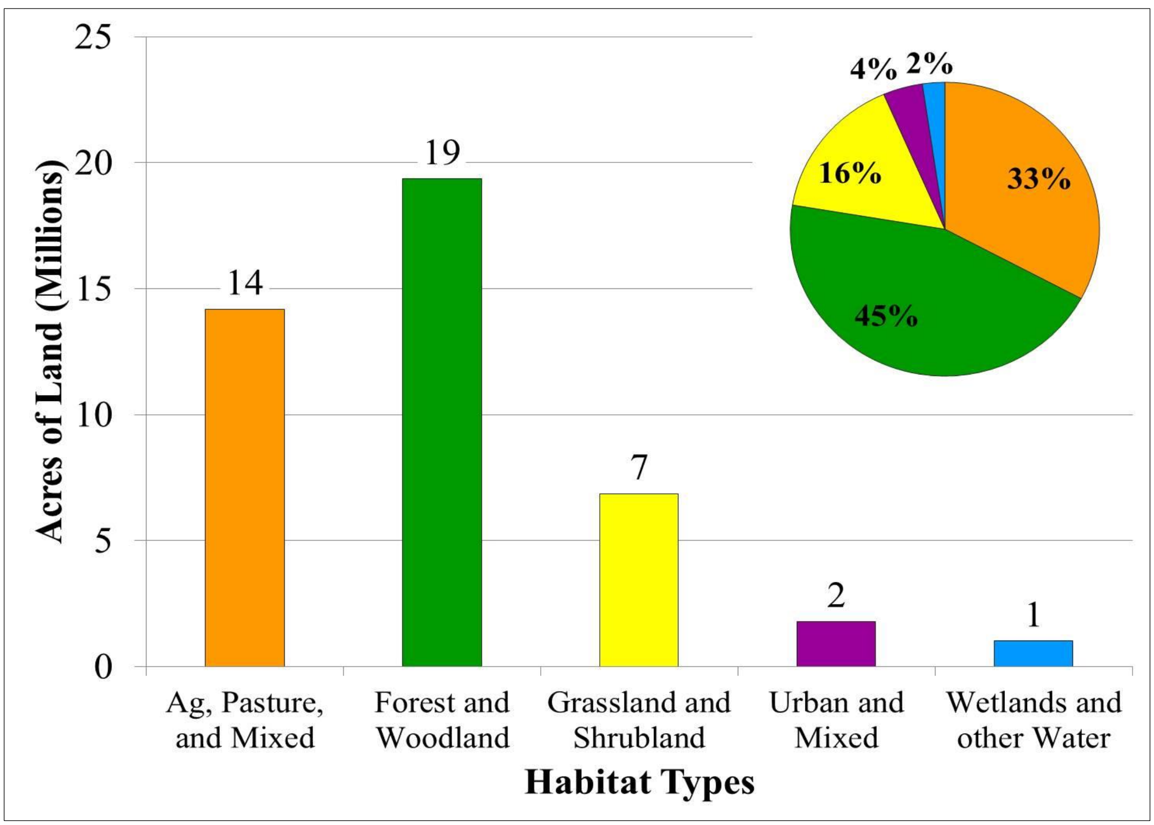


Figure 12. Habitat distribution in Washington

To understand the interaction between crucial habitat and wind or solar energy resources within the five general Washington habitats, a local autocorrelation analysis was completed for each of the three variables. This analysis identified significant clustering of high values and low values across the landscape for each of the variables. For the purposes of this study, there are four significant clustering outcomes or interactions that are important for understanding the impacts within the general Washington habitat. First, significant clustering of high wind or solar energy resources identifies areas with high energy generating potential. Second, significant clustering of most-crucial habitat lands represents areas with the highest conservation value. Third, significant high conflict areas are locations where the significant most-crucial habitat areas are also significant high wind or solar energy areas. Lastly, significant areas of low conflict are areas where significant high wind or solar energy are also areas of significant least-crucial habitat and have a low conservation value.

Wind Energy Resource Analysis

The outcome of this analysis with regards to wind energy resources shows greatly dispersed areas of significant clustering across the entire state of Washington (Figure 13). This is not surprising, since the wind power varies greatly as it moves across the landscape, resulting in many small areas of significant clustering. Since the areas of significant high wind energy resources are so small, it is also no surprise that only a very few areas of high or low conflict were detected across the landscape. These are indicated by the green and red colors in Figure 13.

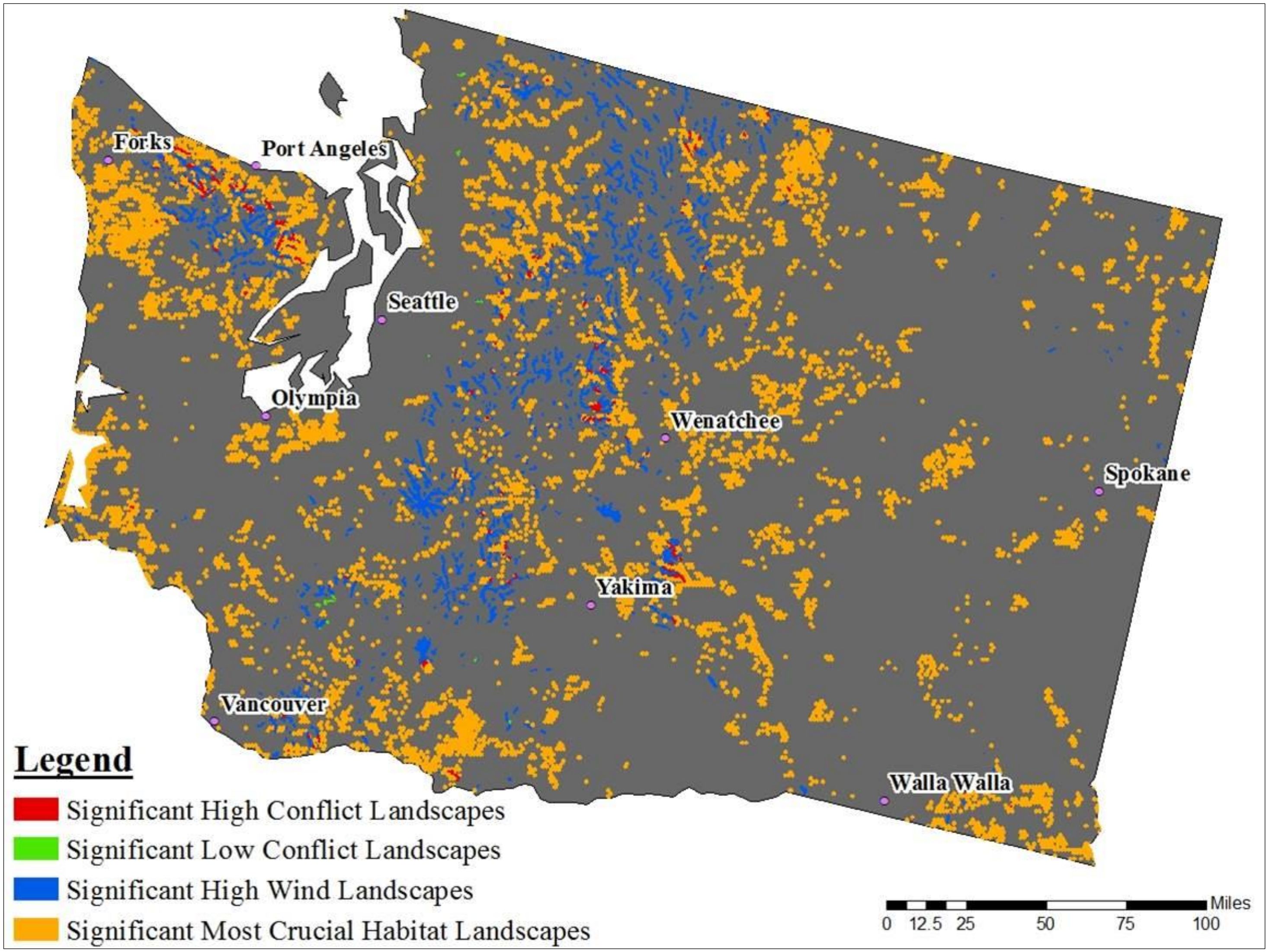


Figure 13. Spatial interaction of wind energy resources and crucial habitat statewide

When assessing these results according to general Washington habitats, a better picture of how these significant clusters are located across the landscape emerges, and related risks and opportunities within each habitat can be studied. According to this assessment, the grassland and shrubland habitat contains the highest portion of all significant high wind resources (61.7%) and high conflict (64.74%) landscape clusters (Table 5). This means that, while there are more preferred development locations for wind energy in the grassland and shrubland habitat, there is also a high risk of encountering high conflict areas in the landscape as well. However, when looking at these opportunities for development and risks of high landscape conflict, the footprints of these significant landscape clusters are quite small. The term footprint in this context is defined as the portion of total habitat area that exhibits a particular significant landscape cluster.

Table 5. Significant wind resource landscapes in each habitat as a percentage of total significant landscape areas

General Habitat Type	High Conflict	Low Conflict	High Wind	Most Crucial Habitat
Total Significant Area (acres)	47,619	3,262	532,439	4,545,264
Wetland, River, Lake, and Reservoir Habitats	0.48%	0.25%	0.26%	4.85%
Urban and Mixed-Environments	0.00%	0.00%	0.52%	2.17%
Agriculture, Pasture, and Mixed-Environments	0.63%	0.00%	2.19%	17.70%
Forest and Woodland Habitats	34.15%	99.75%	35.32%	57.16%
Grassland and Shrubland Habitats	64.74%	0.00%	61.70%	18.05%

Table 5 shows which general habitat types have a higher or lower risk of encountering each significant landscape cluster type.

Table 6. Significant wind resource landscapes as a percentage of total habitat area

General Habitat Type	Total Habitat Area (acres)	High Conflict	Low Conflict	High Wind	Most Crucial Habitat
All of Washington State	43,197,857	0.11%	0.01%	1.23%	10.52%
Wetland, River, Lake, and Reservoir Habitats	1,010,784	0.02%	0.00%	0.14%	21.83%
Urban and Mixed-Environments	1,788,156	0.00%	0.00%	0.16%	5.52%
Agriculture, Pasture, and Mixed-Environments	14,182,252	0.00%	0.00%	0.08%	5.67%
Forest and Woodland Habitats	19,353,822	0.08%	0.02%	0.97%	13.42%
Grassland and Shrubland Habitats	6,862,843	0.45%	0.00%	4.79%	11.96%

Table 6 shows the footprint of significant clustering within each general habitat type.

Only 4.79% of the total grassland and shrubland habitat lands are significant high wind areas and less than 1% of the habitat lands are significant high conflict areas (Table 6). In addition, the grassland and shrubland habitat also has a fairly high presence of most crucial habitat clustering, with 18.05% of this landscape cluster type occurring in this habitat, and a footprint of 11.96% in the total grassland and shrubland habitat area. This means that there is some risk of encountering significant most-crucial habitat areas when interacting within this habitat type. While these opportunities and risks do marginally exist within the grassland and shrubland habitat landscape, the only meaningful impact in relation to wind energy development are the areas of significant high wind energy resource clusters. For a visual representation of the grassland and shrubland general habitat type and the significant landscape clustering within this habitat, see Figure 14.

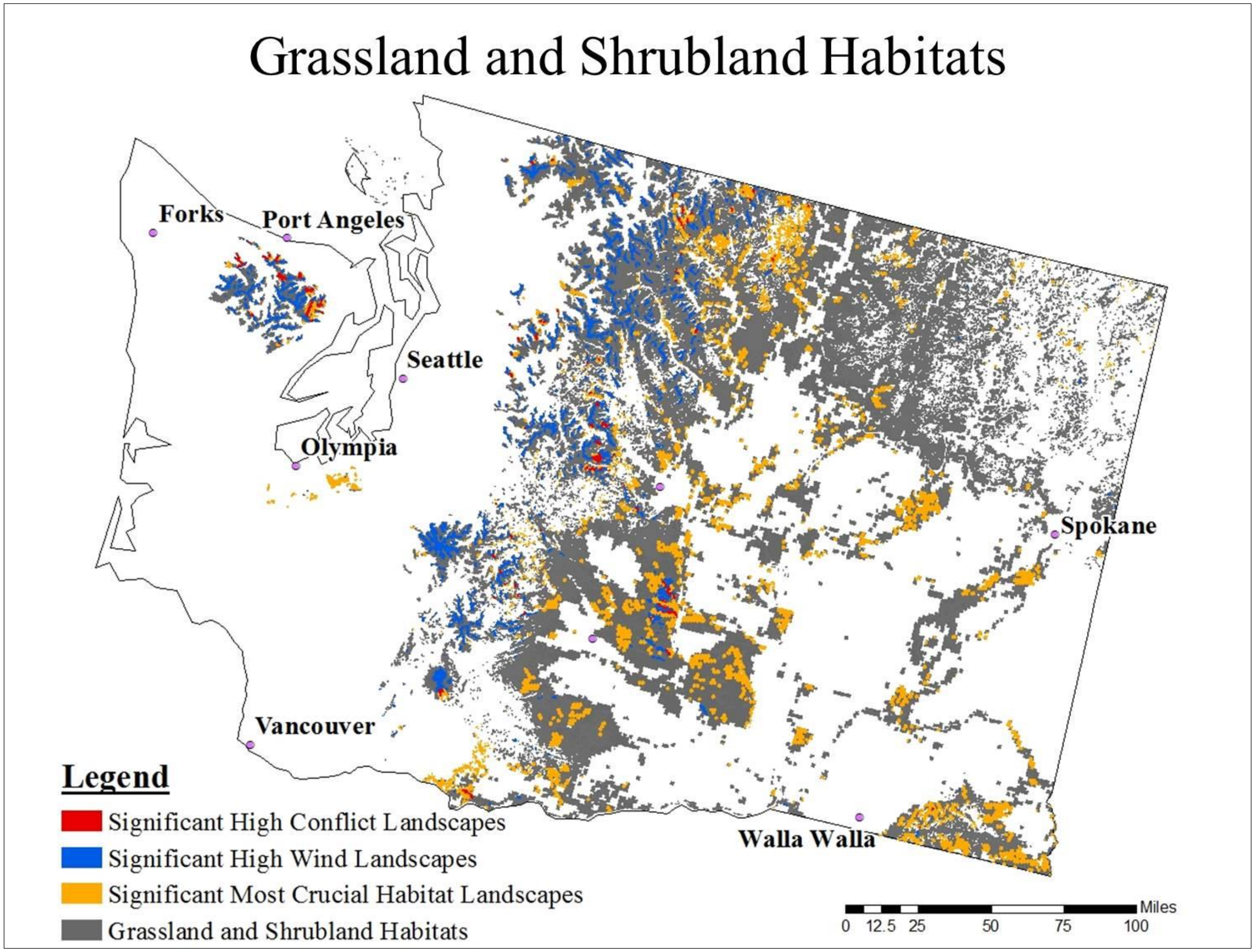


Figure 14. Spatial interaction between wind energy resources and crucial habitat in the Washington grassland and shrubland habitats

The forest and woodland general habitat has the highest portion of significant most-crucial habitat clusters (57.16%) and has a habitat footprint of 13.42% (Table 5 and 6). Although significant clusters of most-crucial habitat alone have no implication for wind energy development, knowing there are areas of most-crucial habitat could inform other industries working within the forest and woodland habitat of the environmental risks of some areas. Regarding low conflict areas, the forest and woodland general habitat also contains the highest portion of this significant landscape cluster type (Table 5). At first glance having 99.75% of all significant low conflict landscape clustering in a single habitat type seems like it would be an important discovery. This means the greatest opportunity for identifying areas of high wind energy potential in concert with lesser crucial habitat landscapes are within a single habitat type and would represent the most favorable wind energy development locations. However, when considering the total footprint of this significant landscape cluster type it becomes a moot point since this only represents 0.02% of the total forest and woodland habitat (Table 6). For a visual representation of the grassland and shrubland general habitat type and the significant landscape clustering within this habitat, see Figure 15.

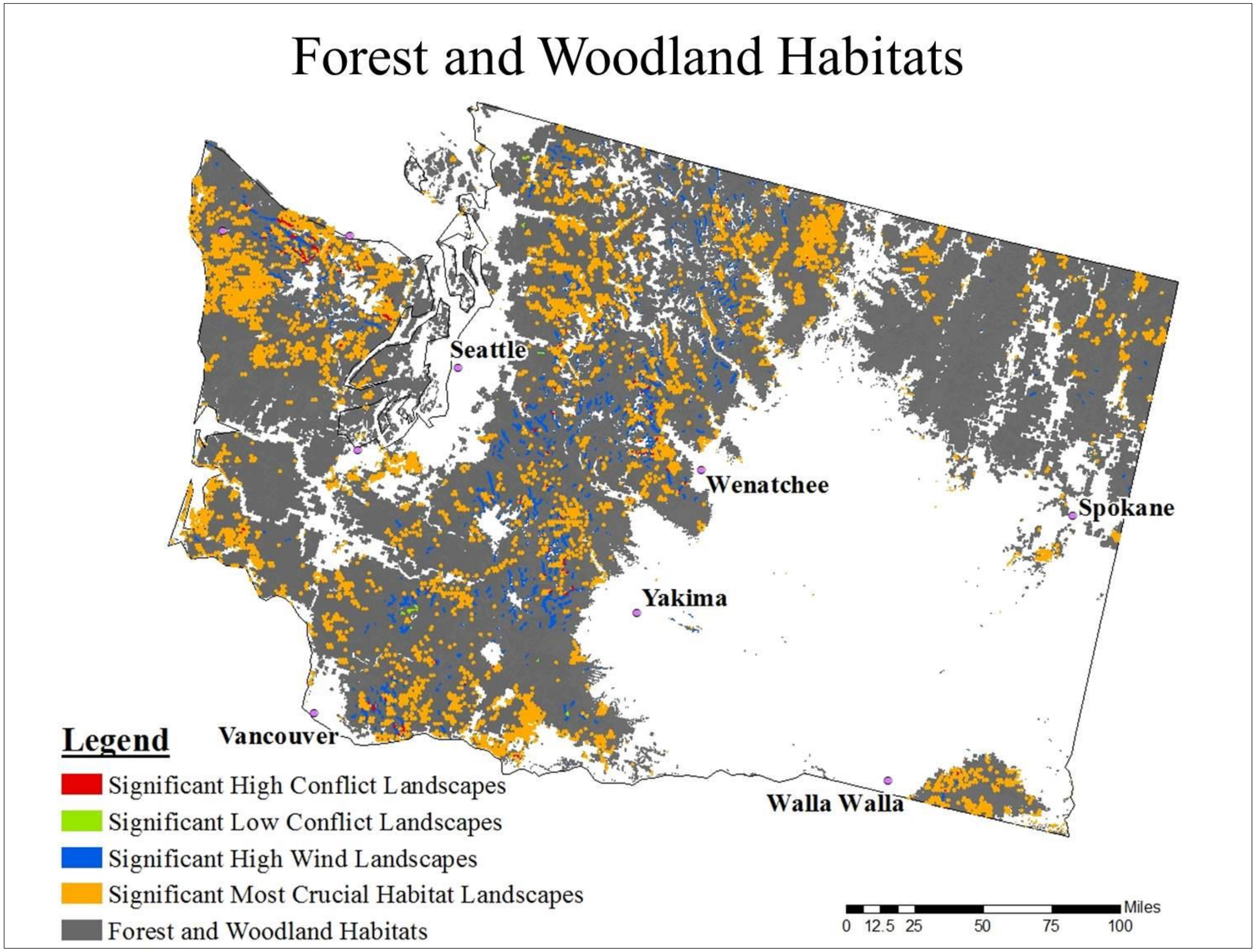


Figure 15. Spatial interaction of wind energy resources and crucial habitat in Washington forest and woodland habitats

The wetland, river, lake, and reservoir habitat type is also impacted by significant most-crucial habitat clusters. Despite this habitat only containing a small portion of all significant most-crucial habitat clusters, a large habitat footprint of 21.83% is observed (Table 6). This is likely due to the fact that this habitat type spans the smallest area across the landscape and, for Washington, represents a sensitive ecosystem with many threatened or endangered species present (Cowardin et al. 1979; Washington Department of Fish and Wildlife 2005). Despite crucial habitat clusters having a higher impact in this habitat, it is not unexpected and there are already many policies in place to monitor and regulate wetland and other riparian ecosystems across the state of Washington. For a visual representation of the additional habitat types and the significant landscape clustering not presented in this chapter, see Figure 20–22 in the appendix.

Overall, the interaction between crucial habitat and wind energy resources does not have a very large impact on most of the five general habitat types in Washington State. The footprints of significant landscape cluster types are in most cases very small or non-existent. However, the grassland and shrubland habitat is impacted most, out of all other habitat types, with the most significant high wind resources.

Solar Energy Resource Analysis

The outcome of this assessment with regard to solar energy resources is quite different from that of the wind energy resources analysis. Solar energy resources are concentrated, rather than dispersed, forming one large cluster of significant high solar energy resources in the southeastern corner of Washington State (Figure 16). Within this area, there are large significant clusters of both low conflict and high conflict landscapes, as indicated by the green and red areas in Figure 16. These large, significant clusters could have important impacts on the five general habitat types in Washington.

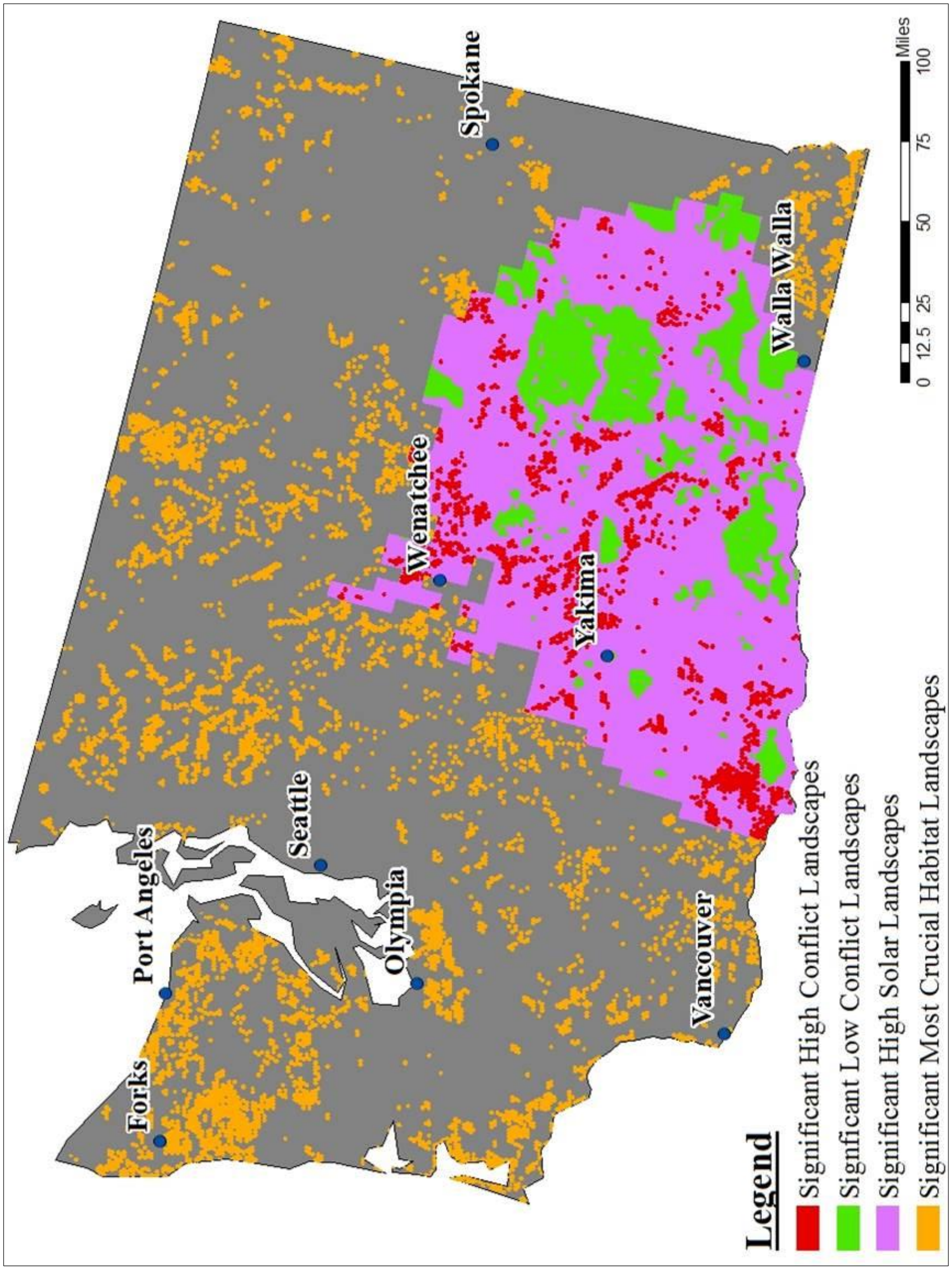


Figure 16. Spatial interaction of solar energy resources and crucial habitat statewide

Looking at these significant landscape clusters in relation to general habitat types in Washington State, there are certain habitat types that are impacted more than others. Most notable is the agriculture, pasture, and mixed-environment habitat. This habitat contains the highest portions of the high solar and low conflict landscape cluster types being 58.02% and 97.31% respectively (Table 7). The footprints for these landscape cluster types are also notable, with 35.51% of the agriculture and pasture habitat area being significant high solar resource areas, and 13.16% being areas of low conflict (Table 8). This means that the agriculture and pasture habitat type is most suited to development of solar energy, given that 48.67% of this habitat area has high solar energy resources and in some of those areas there are significant clusters of less-crucial habitat with a low conservation value. The areas of low conflict would be areas to investigate the feasibility of solar development first, followed by the remaining areas of significant high solar density. For a visual representation of the agriculture, pasture, and mixed-environment general habitat type and the significant landscape clustering within this habitat, see Figure 17.

Table 7. Significant solar resource landscapes in each habitat as a percentage of total significant landscape areas

General Habitat Type	High Conflict	Low Conflict	High Solar	Most Crucial Habitat
Total Significant Area (acres)	963,154	1,917,413	8,680,259	3,810,422
Wetland, River, Lake, and Reservoir Habitats	3.72%	0.10%	1.66%	4.77%
Urban and Mixed-Environments	2.54%	1.57%	2.54%	1.86%
Agriculture, Pasture, and Mixed-Environments	33.72%	97.31%	58.02%	12.31%
Forest and Woodland Habitats	15.78%	0.30%	11.15%	63.94%
Grassland and Shrubland Habitats	44.13%	0.72%	26.37%	11.10%

Table 7 shows which habitat types have a higher or lower risk of encountering each significant landscape cluster type.

Table 8. Significant solar resource landscapes as a percentage of total habitat area

General Habitat Type	Total Habitat Area (acres)	High Conflict	Low Conflict	High Solar	Most Crucial Habitat
All of Washington State	43,197,857	2.23%	4.44%	20.09%	8.82%
Wetland, River, Lake, and Reservoir Habitats	1,010,784	3.55%	0.19%	14.27%	17.98%
Urban and Mixed-Environments	1,788,156	1.37%	1.68%	12.34%	3.96%
Agriculture, Pasture, and Mixed-Environments	14,182,252	2.29%	13.16%	35.51%	3.31%
Forest and Woodland Habitats	19,353,822	0.79%	0.03%	5.00%	12.59%
Grassland and Shrubland Habitats	6,862,843	6.19%	0.20%	33.36%	6.16%

Table 8 shows the footprint of significant clustering within each general habitat type.

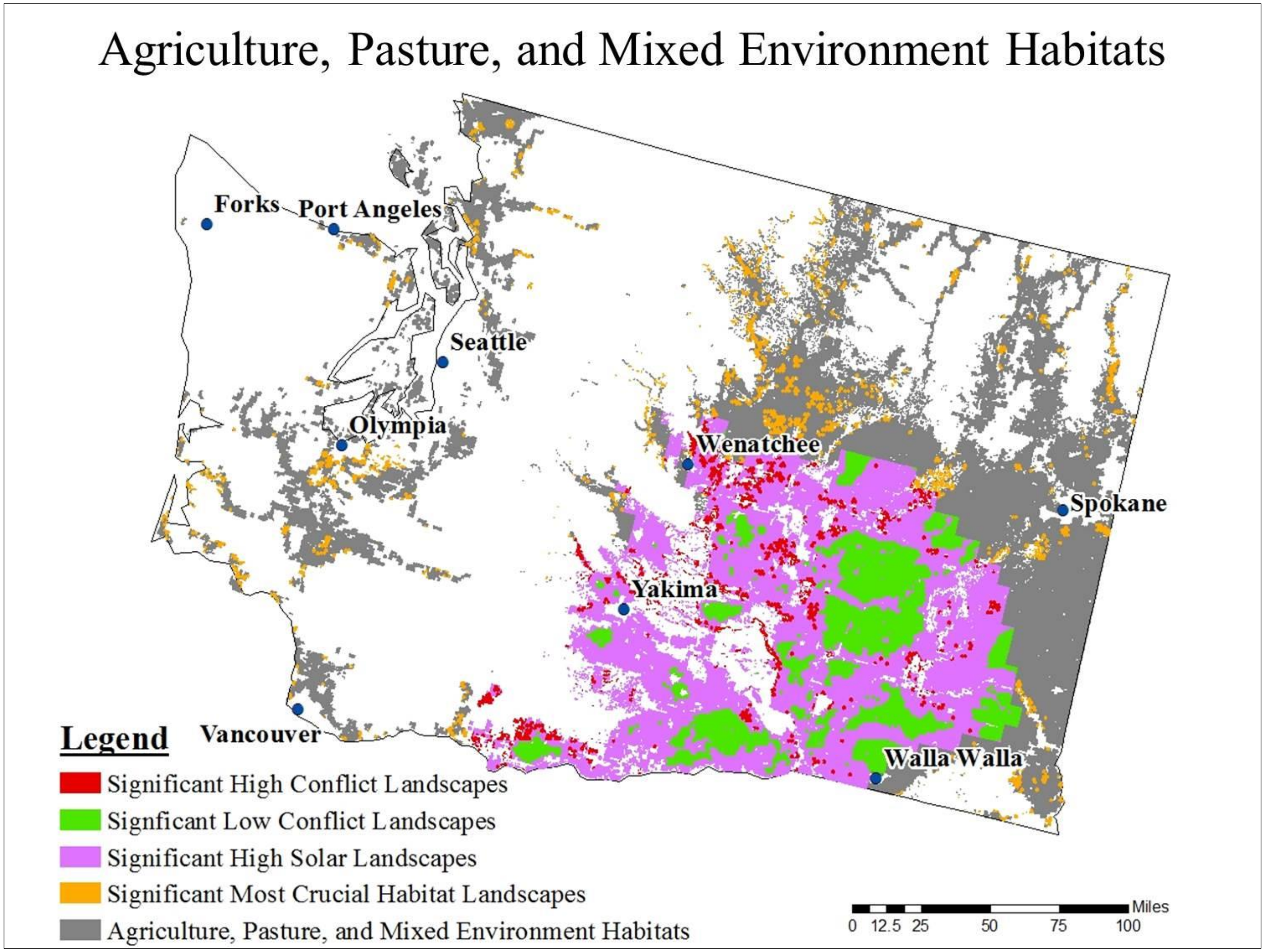


Figure 17. Spatial interaction of solar energy resources and crucial habitat in Washington agriculture, pasture, and mixed-environment habitats

Within the agriculture and pasture habitat there is also the smallest footprint of significant most-crucial habitat clusters, with only 3.31% of the total agriculture and pasture area (Table 7 and 8). This means that among the favorable amount of high solar energy resources there is also the smallest risk of encountering large significant areas of most-crucial habitat. In contrast, the wetland, river, lake, and reservoir habitat, again, has the highest risk of encountering significant most-crucial habitat, with a footprint of 17.98% of the total habitat area being significant most-crucial habitat areas. As explained above, this is not unexpected.

Finally, the highest portion of high conflict landscape clusters falls within the grassland and shrubland habitat (44.13%). This habitat also has the highest footprint of significant high conflict lands, being 6.19% of the habitat area (Table 8). This is interesting because the grassland and shrubland habitat type has the second largest portion of significant high solar energy resources (26.37%) and a total footprint that is 33.36% of the total habitat area. This footprint is almost as large as the footprint for the agriculture and pasture habitat type. However, these results suggest that, despite having an ample amount of significant high solar energy resources across the habitat, there is also the highest risk of also encountering most-crucial habitat clusters within those high solar areas. For a visual representation of the grassland and shrubland habitat and the significant landscape clustering within this habitat, see Figure 18. For a visual representation of the additional habitat types and the significant landscape clustering not presented in this chapter, see Figure 23–25 in the appendix.

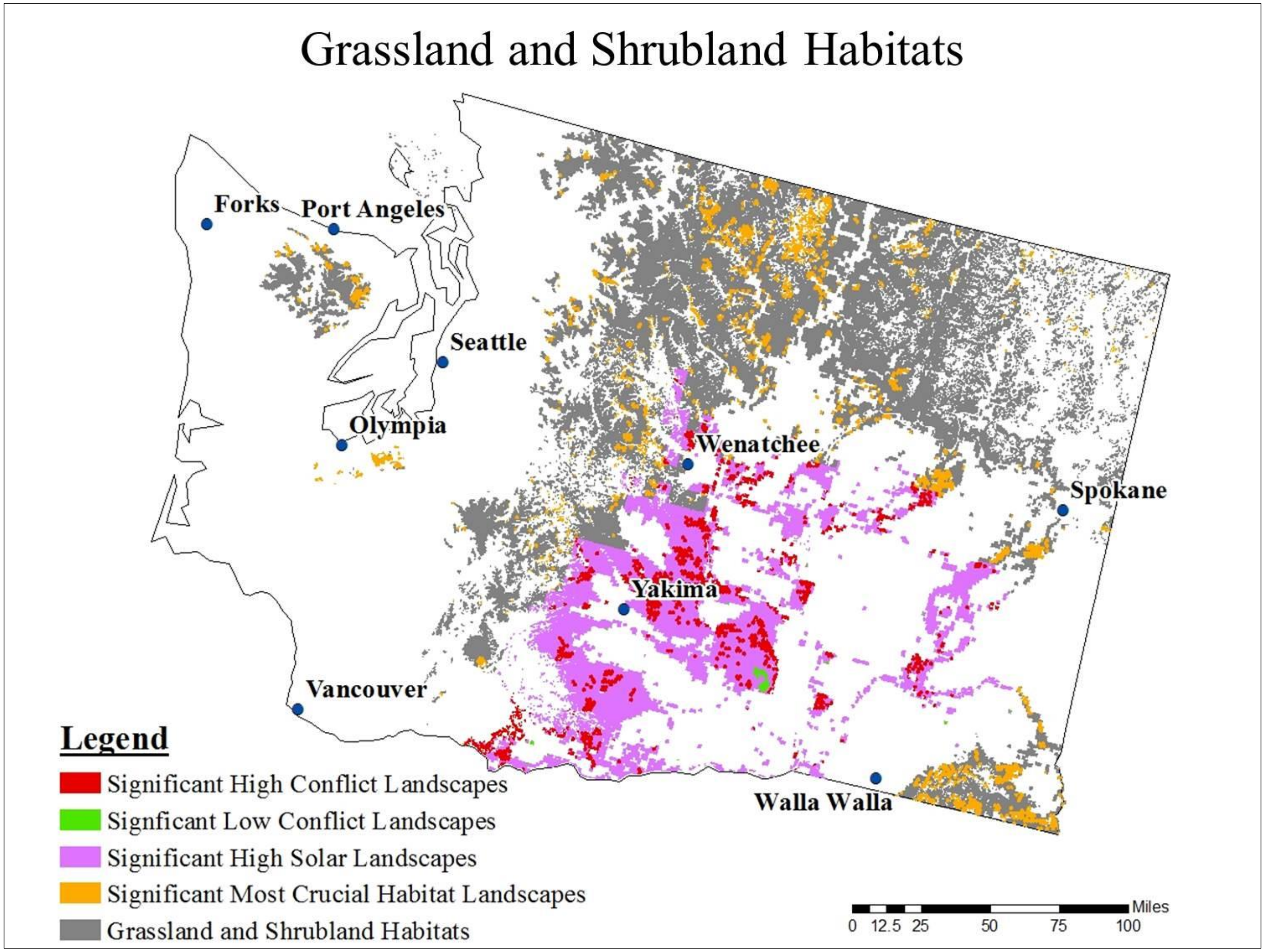


Figure 18. Spatial interaction of solar energy resources and crucial habitat in Washington grassland and shrubland habitats

Overall, the interaction between crucial habitat and solar energy resources has a moderate impact on two of the five Washington habitats. The agriculture, pasture, and mixed-environment habitat type has the highest potential for solar energy development as well as the lowest risk of infringing upon landscapes with a high conservation value. These areas would be preferred development locations to investigate for future development. In contrast, the grassland and shrubland habitat type also has a high potential for solar energy development, but there is also a high risk of encountering lands that have high conservation value. In this habitat, development proposals should be scrutinized more thoroughly to balance the needs of renewable energy development and habitat conservation priorities.

Knowing where the significant landscape clusters are and how much of a particular habitat is impacted by the significant landscape clusters will help land use managers balance renewable energy development and habitat conservation goals. It is important to recognize that the grassland and shrubland habitat is impacted by significant landscape clustering for both wind and solar energy resources. While the impact may be small-to-moderate, proposals for wind or solar energy development in this habitat should be reviewed closely to ensure the best balance between development and conservation efforts.

Chapter 5: Discussion

Understanding the interactions between wind and solar energy development potential and crucial habitat across the landscape provides a first glimpse into how these two environmentally important initiatives can synergize and minimize landscape-level conflicts. This study's five research questions addressed how these two initiatives interact and potentially conflict across Washington State, within three different contexts—existing wind farm developments, suitable landscapes for future energy development, and areas of opportunity or conflict within Washington habitats. This provides many insights into how a landscape-level conservation indicator could be utilized to better optimize the priorities of both renewable energy development activities and statewide wildlife conservation priorities. The context of each research question addressed in this study will be discussed at length in the following sections, highlighting the opportunities for improved land use management and exploring how the concept of multifunctional landscapes could begin to be applied across the state of Washington.

5.1 Existing Washington Wind Farms

Knowledge of how existing Washington wind farms were developed in relation to crucial habitat sheds light on how well environmental impact assessments (EIA) at the local scale captured landscape-level habitat conservation priorities. While, overall, there is a smaller portion of rank 1, most-crucial habitat lands in existing wind farms than what was observed statewide, the results of the assessment also showed that the distribution of crucial habitat is varied from one wind facility to another. This indicates that some wind farms were sited in locations where renewable energy development activities and landscape impacts had minimal engagement with lands of high conservation value. Others, however, impose a direct conflict across the landscape. Of particular interest were the Vantage Wind and the Wild Horse Wind Power project, since they were the most poorly sited wind farms according to crucial habitat distribution. With the highest landscape percentage of most-crucial habitat rank 1 within these wind farm sites, questions arise regarding the capability of the EIA process to capture and manage landscape-level habitat conservation priorities.

Upon investigation of the EIA documentation for both of these wind farms, it is apparent that different levels of rigor were used in pre-development planning and environmental assessment. For the Wild Horse Wind Power project, a very thorough draft EIA was completed and released in August of 2004. In this assessment, Wind Ridge Power Partners, LLC, highlighted many development impacts across the proposed landscape and identified tangible and specific mitigation and remediation activities with an aim to minimize the negative effects of the project (Jones & Stokes et al. 2004). Nearly all the known negative impacts of wind energy development as discussed in the second chapter of this study were identified and addressed throughout the EIA. Impacts of greater concern included habitat disturbance and loss of shrub-steppe grasslands and sensitive lithosol habitat; sage grouse and big game animal avoidance of the area; presence of a few rivers and wetland areas; threats of exotic and invasive species dispersal; and the hedgehog cactus (*Pediocactus nigrispinus*—also known as snowball cactus)—a Washington State review listed species—was identified within the project area (Jones & Stokes et al. 2004).

Given the long list of potential environmental impacts, the facility planners in charge of the Wild Horse Wind Power project identified many mitigation strategies in acknowledgement of the dangers posed by development, to keep biodiversity and ecological health as intact as possible. Actions that were explicitly identified included fencing and avoiding wetlands, rivers, and known locations of the hedgehog cactus; washing construction vehicles before entering the premises to reduce the risk of exotic and invasive species dispersal; minimizing new road construction to reduce landscape fragmentation; replanting disturbed landscapes with native species; using underground transmission lines to reduce risks to avian species; and on-going monitoring of animal behavior within the project site. In addition, 600 of the 8,600 acres within the project area was partitioned to be fenced and left as native shrub-steppe and grassland habitat, serving as a large corridor to connect with adjoining state lands (Jones & Stokes et al. 2004). This land serves as a protected reserve with no risk of future development, is inaccessible to livestock grazing and other ranching activities, and serves to protect biodiversity and natural habitats in the area. Overall, the Wild Horse Wind Power project EIA shows a great concern for environmental impacts, incorporating significant measures to minimize the potential impacts of wind energy development.

In contrast, the Vantage Wind project—built after the Wild Horse Wind Power project in 2008 and only 6 miles away—did not even complete a full EIA prior to development. Rather than an EIA, a determination of non-significance (signifying the project location is not likely to have significant adverse environmental impacts and including a less rigorous environmental checklist) was completed and submitted as part of the permitting process. The environmental checklist did state that several wildlife and ecological surveys were completed, but the mitigation proposals identified within the plan only addressed the most common concerns of wind energy development (White et al. 2003; Kittias County Community Development Services 2008). Given that the crucial habitat rating for a majority of the Vantage Wind project site is of the most-crucial habitat rank 1, a determination of non-significance was probably not appropriate for this site. A more thorough environmental investigation should have been completed to understand what environmental factors caused the landscape to be rated as crucial habitat rank 1, and specific avoidance and mitigation tactics should have been employed.

Comparing the environmental assessments of these two wind power projects, it is clear that, despite being closely located and in similar ecological regions, the local EIA process does not always capture landscape-level conservation concerns. On the one hand, the Vantage Wind project seems to have been completed with minimal effort related to environmental permitting, and has evidently established the primary purpose of the landscape to be energy production, regardless of high priority conservation values in the area. On the other hand, the Wild Horse Wind Power project did complete a rigorous environmental study of the project landscape and carefully crafted mitigation strategies to minimize negative environmental impacts. This project demonstrates how the EIA process can facilitate the optimization of renewable energy development and habitat conservation efforts, to work toward establishing a multifunctional landscape as explored by Howard et al. (2013) and Reyers et al. (2012). Here, land use planning seems to have been balanced between energy, ecological, economic, and social priorities. This plan promotes energy production along with the protection and preservation of biodiversity and ecological health, enabling ranching activities in some areas, and allowing hunting and other recreational activities within the same landscape.

For future renewable energy developments, crucial habitat assessments could enhance environmental impact assessments across different landscapes, informing of potential landscape conflicts. Even if future renewable energy development is proposed in more crucial habitat lands, the Wild Horse Wind Power project is an example of how careful planning and landscape design can attempt to optimize such landscapes. However, knowing the level of landscape conservation value can also function as guide to initial project planning and siting. This indicator could inform the rigor of environmental assessment that should be undertaken across different landscapes as well as additional costs that may be associated with environmental mitigation activities on more crucial habitat lands (Western Governors' Wildlife Council 2013a). This new measure of landscape-level conservation priorities will be essential to improving the existing renewable energy development practices, to move toward the successful design and management of multifunctional landscapes in the future.

5.2 Wind and Solar Energy Development Landscapes

Having an understanding of the interaction between landscape-level habitat conservation priorities and suitable renewable energy development locations provides insight into the levels of landscape conflict between these two initiatives. As shown in the outcome of the analysis for Washington State, suitable wind energy development locations display a crucial habitat distribution that is similar to what is observed across the entire state. Despite having a lower impact on high conservation value lands than what is observed statewide, there is still a moderate conflict between these two initiatives on the landscape. This is observed when considering the portions of land rated as crucial habitat values 1–3, given that nearly 90% of suitable wind energy landscapes fall within these crucial habitat values. These would be lands with observed or presumed threatened or endangered species; federal and state candidate and sensitive species; priority ecological systems of concern; confirmed heritage vegetation; important estuary and wetland habitats; large, high quality natural areas; or most-important habitats for species of recreational and economic importance.

Applying estimated annual energy generation per acre to suitable wind energy development lands according to various crucial habitat levels further reveals that future wind energy development could exclude the most crucial habitat lands of ranks 1 and 2, and still expand existing levels of annual wind energy production by 440%. This means it is likely that a moderate level of environmental mitigation will still be required for future wind energy development, but that wind energy growth could be better balanced with habitat conservation priorities. Under this landscape management strategy, habitats with observed threatened and endangered species, some federal and state candidate and sensitive species, priority ecological systems of concern, confirmed heritage vegetation communities, important estuaries, and spawning ground for aquatic species of recreational importance, will be protected from disturbance. The remaining landscape conflicts in areas with lower conservation value (crucial habitat rank 3–6) can then be identified, assessed, and managed at the local level. Overall, this landscape management strategy will work toward optimizing the requirements for both the habitat conservation and wind energy development initiatives.

For solar energy resources, a crucial habitat distribution signifying a moderate to high conflict is observed across the landscape, with 50% of the suitable solar development landscape having a crucial habitat rank of 1 or 2. However, given that suitable solar energy development locations span a large geographic area and the land required for energy generation is small, there is a great opportunity to target less-crucial habitat lands with low conservation value for future solar energy development. According to this assessment, suitable solar energy development locations in the least-crucial habitat lands of rank 5 can be exclusively targeted and still have the potential to generate an additional 65% of the total annual Washington State energy production. This energy generation potential is huge, and the conflict between habitat conservation priorities and solar energy development can be reduced to the absolute minimum. In addition, the spatial locations of these landscapes are clustered in the southeastern portion of Washington State, providing large contiguous areas to investigate the feasibility of future solar energy development in a local context. This is an example of how landscape-level planning can be utilized to truly optimize the land use requirements of multiple initiatives to achieve the most desired outcome.

Solar Energy Resource Analysis Limitations

The initial assessment of suitable solar energy development locations in relation to crucial habitat alludes to major solar resources in eastern Washington State. There are, however, some limitations to this estimate that may have caused the results of this analysis to overestimate the potential energy generation per acre across the landscape. Unlike wind energy, commercial solar energy production has not largely been established in the state of Washington. Due to the lack of state-specific energy information, this study used a national average landscape footprint per annual gigawatt hour (GWh) of energy production figure to estimate the potential energy generation of suitable solar resources in Washington State. The national average figure was calculated from 166 existing or under construction U.S. solar facilities in locations with a large range of solar irradiance resource levels (Ong et al. 2013). This means solar facilities in areas with the highest solar irradiance levels would require less land to generate solar electricity, while areas with the lowest solar irradiance levels would require more land than what is represented by the national average.

Washington is located at a northern longitude and has some of the lowest levels of solar irradiance suitable for commercial solar energy production—Washington annual average solar irradiance levels range from 3.11–5.3 kWh/m2/day, with a mean of 4.44 kWh/m2/day. In contrast, the annual average solar irradiance levels across the United States range from 3.11–7.03 kWh/m2/day, with a mean of 5.22 kWh/m2/day (National Renewable Energy Laboratory 2013a). This difference in solar resource levels is not precisely reflected in the landscape footprint requirements for Washington solar energy production. As indicated above, it is likely that a larger landscape footprint per GWh of annual energy production would be required in Washington State. This would result in a lower annual solar energy production estimate. Future assessments of how crucial habitat relates to suitable solar energy resources should attempt to account for the lower solar irradiance levels in Washington State.

Opportunity for Future Research

Suitable wind and solar development locations as defined in this study only account for lands available for development and appropriate wind and solar energy resource levels required for commercial energy production. In reality, there are many more factors that influence suitability for development. To take this assessment further, a feasibility study should be conducted to more precisely identify preferred renewable wind and solar energy development locations in Washington State. This research opportunity would build upon the existing analysis conducted in this study and further restrict suitable development locations to reflect additional economic, social, and additional technological conditions that impact renewable energy development at local scales.

To reflect economic conditions associated with renewable energy development locations, proximity to existing electrical transmission lines and substations should be included. The associated cost to connect to or create new electrical transmission lines would begin to more realistically pinpoint the most preferred renewable energy development locations. Further, the social perspectives of support or opposition for specific renewable energy technologies could be modeled to reflect the economic implications of local acceptance or resistance to development. This could be done at a county level with the general assumption that areas of high opposition would either prevent development or require more time and investment in the siting and permitting phases to negotiate an acceptable development location and plan with the local public. Finally, the topography of a landscape is a major consideration in determining feasibility and least-cost options for renewable energy development. There should at least be modeling of slope gradients according to the requirements of the specific technologies, using a weighting system that associates cost with the level of landscape preparation required for development.

This more advanced model of suitable energy development lands would present the opportunity to conduct a more detailed analysis of how landscape-level conservation priorities relate to the most preferred renewable energy development locations across Washington State. This analysis would provide a more realistic indication of the landscape-level conflicts between renewable energy development and crucial habitat than what is presented in this study. With this information, the appropriate energy and wildlife stakeholders could identify more precise opportunities to approach land use management from a multifunctional perspective, to optimize land uses for both purposes.

5.3 Washington Habitats

As explored in the first three research questions, the interaction between crucial habitat and existing as well as suitable renewable energy development locations reveals the general landscape-level conflict between the two initiatives. These analyses are important to frame the high-level landscape interactions, but do not identify specific risks or opportunities that could aid in optimizing the land use between crucial habitat and renewable energy development. By investigating how significant spatial clustering of crucial habitat interacts with significant spatial clustering of wind and solar energy resources within Washington habitats, risks and opportunities of future development begin to appear.

Of particular interest are the areas of significant high-conflict and low-conflict clusters and how they are placed on the landscape. These areas specifically define the positive and negative interactions between significant clustering of high renewable energy resources and significant clustering of both high- and low-crucial habitat areas. Looking closer at all areas of significant clustering and interactions within the context of general Washington habitats further define the risks and opportunities for future wind and solar energy development. This information helps explore how renewable energy development will impact the landscape according to the ecology and conservation priorities unique to the various habitat types.

It is important to remember that the 5 general habitat types defined in this study are a combination of several, more specific, habitat types identified by researchers at the Northwest Habitat Institute (NWHI). The Washington Department of Fish and Wildlife (WDFW) has taken these same specific habitats and prioritized them according to conservation importance as part of the Washington Comprehensive Wildlife Conservation Strategy (CWCS). Within the Washington CWCS, each specific habitat type is identified as priority 1, priority 2, or "other," according to the number of species of greatest conservation need (SGCN) that occur within each habitat. This information, in conjunction with specific, known land use threats to the habitat types, enables a thorough assessment of how renewable energy development is likely to impact the general habitats as defined in this study. This is discussed in the following sections.

Wind Energy Resource and Crucial Habitat Analysis

In the analysis of significant landscape clustering and interactions between wind energy resources and crucial habitat, results show that the grassland and shrubland habitats, forest and woodland habitats, as well as the wetland, river, lake, and reservoir habitats will be impacted the most. However, there were not meaningful impacts related to significant high- or low-conflict areas on the landscape. Nevertheless, there are still important risks and opportunities that can be perceived from the landscape clustering of high wind resource areas and most-crucial habitat areas independently.

Significant High-Wind Clustering

The grassland and shrubland habitats contained the highest portion of significant high wind clustering and had a landscape footprint of 4.79% within the habitat. This means future wind energy development is most likely to occur in the grassland and shrubland habitats because this is where spatial clustering of high wind energy resources occur the most. However, there are a number of challenges that will need to be managed, due to the history and ecology of this habitat type.

Since 1889, the grassland and shrubland habitats have suffered the highest landscape conversion rates of all habitat types. Approximately 50% of historic shrub-steppe habitats and 70% of historic grassland habitats have been converted to agricultural landscapes (Washington Department of Fish and Wildlife 2005). This history of land use conversion has resulted in much native habitat loss, habitat fragmentation, and the introduction of invasive species, which all continue to be the largest threats to the remaining natural lands. These habitat threats, in addition to a large number of SGCN present in these landscapes, has resulted in much of this habitat being categorized as priority 1 conservation habitat.

In relation to wind energy development, the land use threats most impacting the grassland and shrubland habitats will be encountered as a consequence of the wind facility development process to some extent. A large network of roads is required to access and maintain the wind turbines, effectively fragmenting the landscape. Additionally, an increased presence of construction equipment and maintenance vehicles increases the potential for invasive species to establish in new areas (Washington Department of Fish and Wildlife 2005). Finally, during the construction phase of wind farm development, large areas of the landscape are often modified as staging locations for turbine parts and equipment (McDonald et al. 2009). Although these areas are remediated after construction, habitat loss does occur and natural lands are altered. Given the importance of this habitat type to the Washington CWCS and the many potential negative impacts from wind energy development, careful environmental planning and mitigation should be conducted for all wind energy development projects occurring within grassland and shrubland habitats.

Significant Most-Crucial Habitat Clustering

Regarding significant clustering of most-crucial habitat, wetland, river, lake, and reservoir habitats, forest and woodland habitats, as well as grassland and shrubland habitats all had notable landscape footprints. Within wetland, river, lake, and reservoir habitats 23.83% of the habitat area contained significant most-crucial habitat clusters. For forest and woodland habitat, 13.42% of the landscape contained significant most-crucial habitat clustering. Finally, within the grassland and shrubland habitats, 11.96% of the habitat area contained significant most-crucial habitat clustering. This means that, when interacting within these habitat types, there is a fair chance that large areas of most-crucial habitat will be encountered. While these significant most-crucial habitat clusters do not have any relation to wind energy development, they could be important to other natural resource related industries interacting within these habitat types, such as forestry or mining. Such industries should complete a more thorough investigation of how, exactly, industry practices would be impacted by the significant areas of most-crucial habitat. However, this is out of scope of this study.

Solar Energy Resource and Crucial Habitat Analysis

In the analysis of significant landscape clustering and interactions between solar energy resources and crucial habitat, the results are quite different than the outcome of the wind energy resource analysis. Regarding solar energy resources, a single, large significant, high solar energy cluster was identified in the southeastern part of Washington State. Within this large, significant cluster, several significant clusters of high-conflict and low-conflict areas were also identified. The habitat types most impacted by these results are the agriculture, pasture, and mixed environment habitats as well as the grassland and shrubland habitats, as discussed in detail below. The wetland, river, lake, and reservoir habitat, as well as the forest and woodland habitat, were again impacted by significant most-crucial habitat clusters. However, since the impact is the same as was described in the wind energy resource and crucial habitat analysis section above, it will not be discussed again in this section.

Agriculture, Pasture, and Mixed-Environments Habitat

The agriculture, pasture, and mixed-environments habitat contained the highest portions of significant high solar energy resource areas and significant low landscape conflict areas out of all other habitat types. In addition, these significant landscape clusters had large landscape footprints of 35.52% and 13.6% of the total agricultural, pasture, and mixed-environments habitat respectively. This means that there are more high solar energy resources as well as low-conflict areas in this habitat than any other habitat type. This outcome represents a potential opportunity to plan and design low-impact, multifunctional energyscapes for solar energy in the agriculture, pasture, and mixed environment habitats in the state of Washington.

With regard to the Washington CWCS conservation priority, the agriculture, pasture, and mixed environments habitat has been categorized as an "other" priority habitat. This means conservation of this habitat type is not of high importance compared to other habitat types in the state. This makes agriculture, pasture, and mixed environment habitats a good place to consider developing solar energy facilities from a habitat conservation perspective, since land use in this habitat does not have many SGCN and development impacts are less likely to negatively affect Washington conservation goals.

As identified in the second chapter of this study, solar energy development does have negative environmental impacts as a result of facility construction. One of the primary negative environmental impacts is the near-full conversion of the landscape required for energy production, which for natural lands results in habitat loss (McDonald et al. 2009). However, in agriculture, pasture, and mixed-environment habitats the impact of habitat loss is likely to be much smaller because this habitat type is already a product of landscape conversion (Washington Department of Fish and Wildlife 2005). Additionally, the road construction that is often associated with renewable energy development, and which results in habitat fragmentation, is also likely to be minimal. Agricultural landscapes generally have extensive road networks already in place which, if utilized in the construction and operation of solar facilities, would greatly reduce or mitigate the need for new roads. Furthermore, if development were targeted in the significant low landscape conflict areas of this habitat type, environmental impacts would again be reduced, since these areas represent landscape clusters of low conservation value. This means that if negative environmental impacts were incurred in the development of solar facilities, those impacts would only minimally conflict with landscape level conservation priorities, if at all.

While the agriculture, pasture, and mixed-environment habitat clearly presents an opportunity to create multifunctional landscapes benefiting energy production and habitat conservation priorities on the landscape, there are challenges that are likely to surface that are unique to this habitat type. To develop solar energy facilities, existing functional agricultural lands would likely be replaced with solar energy technologies. This would result in a reduction of existing agricultural and pasture lands. If solar energy development in this habitat were not strategically designed to fit a multifunctional landscape model, the landscape conversion would simply transition from one land use type to another without improving the overall function of the land. This is more of a concern with solar technologies, since solar panels can be constructed close together, utilizing the entire landscape footprint of the facility for energy production alone.

In the design of multifunctional landscapes in agriculture, pasture, and mixed-environment lands, creative construction and placement of solar technologies would be required. Ideally solar development would strategically minimize the reduction of existing agricultural production while enabling the additional landscape function of energy production. For example, rather than converting an entire agricultural field to a solar facility, solar technologies could stretch along the edges of the field and along existing roads. With this type of landscape design, most of the existing agricultural production could continue, while adding the production of solar energy to the overall functionality of the landscape.

In addition to the challenge of strategic, multifunctional landscape design, multiple stakeholders such as farmers, landowners, and energy companies would all need to be involved in the design and operation of the facilities. With multiple stakeholders involved, conflicts over landscape needs and potential influences on neighboring lands would need to be identified and managed for the least possible impact to all parties (Harden et al. 2013). As identified in the ecosystem approach to landscape design management as discussed in Chapter 2 (beginning on page 29), an interdisciplinary collaboration and partnership would be required to successfully adjust the existing landscape functions and design in order to introduce permanent solar facilities to the landscape. However, despite these additional challenges, the opportunity to create multifunctional solar landscapes should still be explored and, if successful, could contribute greatly to the growing literature on landscape ecology and planning (Reyers et al. 2012).

Grassland and Shrubland Habitats

The grassland and shrubland habitats also contained high portions of significant, high solar energy resource clusters as well as the highest portion of high-conflict landscape clusters with landscape footprints of 33.36% and 6.19% of the total habitat area, respectively. This means that over one-third of the total grassland and shrubland habitat is suitable for solar energy development, and some of that land is also significant most-crucial habitat cluster areas. However, unlike the agriculture, pasture, and mixed environment habitat, the grassland and shrubland habitats include several CWCS priority 1 habitats, making this habitat type more important to statewide conservation goals. Solar energy development on this landscape will likely pose higher environmental risks to the habitat than what would be seen in the agriculture, pasture, and mixed-environment habitats.

With regard to solar energy development in the grassland and shrubland habitat, this habitat is again likely to be impacted by habitat loss, habitat fragmentation, and the threat of invasive species as a consequence of development. However, in this case, the threat of habitat loss is likely to be the largest threat of solar development. As mentioned above, solar energy development often requires landscape modification and full landscape development of the energy facility site. Since over half of the native habitat has already been lost over the past 125 years and much of the habitat is a CWCS conservation priority 1 habitat, habitat loss poses a higher environmental risk in this landscape than in some other habitat types. In addition, if road construction were required, some impact from habitat fragmentation and threat of invasive species could also be incurred.

All in all, the grassland and shrubland habitats as well as the agriculture, pasture, and mixed-environment habitats will be impacted the most according to significant landscape clustering and the interaction between wind and solar energy resources and crucial habitat in the state of Washington. While the agriculture, pasture, and mixed-environment habitat presents an opportunity to explore multifunctional solar landscapes, there are substantial risks associated with energy development in the grassland and shrubland habitats. Given that there are significant, high energy resource clusters for both wind and solar energy in the grassland and shrubland habitat, it is highly likely that some renewable energy development will occur. However, knowing there is a significant interaction within this habitat type should better enable energy developers and conservation biologist to work together to identify the best mitigation processes and environmental safeguards for developing in this important habitat. Through this process, the interests of both initiatives can be optimized by balancing the priorities and trade-offs for each.

5.4 Policy Implications

Renewable energy development and habitat conservation initiatives are largely supported and enforced by state and federal policy for successful implementation of state and national targets and goals. Regarding the land use interactions of wind and solar energy development and habitat conservation initiatives, there are two policy areas that relate to the results and discussion sections of this thesis. These are the Washington State Energy Independence Act, also referred to as the Washington Renewable Portfolio Standard (RPS), and the Washington State Environmental Protection Act.

Washington State Energy Independence Act

In 2006, Washington State passed the Energy Independence Act, which states that, by January of 2020, large utility companies will be required to obtain 15% of the electrical load they supply from new, renewable energy technologies in Washington

State. These renewable energy facilities could produce energy from water (but not large hydroelectric facilities), wind, solar, geothermal, wave, ocean, tidal, landfill and sewage treatment gas, and biodiesel (not from crops grown on cleared old-growth or first-growth forests) (*Chapter 19.285 RCW: ENERGY INDEPENDENCE ACT* 2006). However, to constitute a "new" renewable energy facility, operation must have begun after March of 1999 and be operating in Washington State to count toward the 15% target. There are two incremental targets leading up to the 15% target in year 2020, to encourage a smooth transition to a more renewable energy platform. These are (1) by January of 2012 3% of electrical load, and (2) by January of 2016 9% of the electrical load should be supplied by new renewable energy resources (*Chapter 19.285 RCW: ENERGY INDEPENDENCE ACT* 2006). Further, to enforce this legislation, utility companies are required to pay to the state of Washington a penalty of $50 per megawatt hour (MWh) of energy that fails to meet the renewable energy targets.

This legislation is one of the primary drivers for the growth of renewable energy technologies such as wind and non-commercial solar in the state of Washington. Further, since the final renewable energy target is not until the year 2020, this policy will continue to encourage the growth of renewable energy technologies across the state. While the Energy Independence Act does support climate mitigation through the offsetting of greenhouse gas emissions, it does not consider any potential for other negative environmental impacts. Given the financial penalty incurred for non-compliance, this policy effectively spurs development regardless of other landscape concerns such as habitat conservation.

Fortunately, through the analyses conducted in this study, it seems as though renewable energy development for commercial wind and solar energies could contribute substantially to this energy target with only moderate to low impact to habitat conservation initiatives. With a current contribution of 1.8% of Washington's energy generation (Northwest Power and Conservation Council 2013), wind energy could expand to contribute an additional 7.9% of state energy generation within less crucial habitat lands ranked 3–6. Solar energy could potentially target the least crucial habitat lands with a rank of 5 and contribute enough energy to meet or exceed the entire 15% state renewable energy target. While, in this case, renewable energy development can occur with minimal negative impacts to the environment, future policies should assess land use impacts when establishing targets and penalties. This would promote land use management within a multifunctional landscape perspective without prioritizing a single land use function.

Washington State Environmental Protection Act (SEPA)

The State Environmental Protection Act (SEPA) is the most powerful legislative tool to protect the environment and aims to "Utilize a systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences and the environmental design arts in planning and in decision making which may have an impact on man's environment" (Washington State 1971; White et al. 2003). This policy defines the state regulations for making land use changes in the state of Washington. As a general regulation for compliance to SEPA, an environmental impact assessment (EIA) is required to identify probable, significant adverse environmental impacts and discuss mitigation strategies to minimize the final impact. Once identified, it is expected that development will occur only after all practical means and measures have been employed to "create and maintain conditions under which man and nature can exist in productive harmony" (Washington State 1971).

The Washington Energy Facility Site Evaluation Council (EFSEC) is the regulatory agency that manages and approves the permitting process to site and begin development for new energy facilities (Energy Facility Site Evaluation Council 2014). Compliance with SEPA regulations and EIA acceptance largely falls with the Washington EFSEC. This agency is highly effective in enforcing compliance with environmental policies, and maintains a strict procedure for obtaining required permits for energy facility development. However, the policies and EIAs associated with energy development are generally assessed and reviewed at a local scale unique to the project site. Industry best practices have been developed over the years to include the assessment of broader landscape-level impacts and mitigation strategies, but these practices are not entirely enforceable by law. In fact, the rigor and extent of EIA completion have been inconsistent, as discussed previously, when comparing the EIA assessments for the Vantage Wind and Wild Horse Wind Power projects.

Here lies an opportunity to improve the EIA process and include a broader investigation of land use impacts at the landscape level. Completing EIAs at a local scale will identify specific threatened species and sensitive habitats such as wetlands. However, landscape-level conservation priorities such as habitat connectivity are not often included in the local-level assessments. Using the crucial habitat assessment as an environmental indicator, the level of rigor and scope of assessment required for EIAs could be better defined. While assessment of crucial habitat is not meant to be a regulatory requirement, this indicator could be utilized as an industry best practice for the improvement of the EIA process. This best practice would highlight areas of most-crucial habitat, so that they receive more thorough environmental surveys and investigation of impact. Areas of less-crucial habitat could continue with the current requirements. In addition, landscape-level habitat conservation priorities, such as habitat connectivity, would also be captured in the EIA process, and mitigation strategies would further support the creation of multifunctional landscapes.

While both the Energy Independence Act and State Environmental Protection Act are effective policies encouraging better environmental stewardship, both can continue to be improved, in order to capture broader landscape-level impacts and perspectives. To further encourage this transition, other policies, such as incentives contributing to both energy and habitat conservation goals, could also be employed. For example, the permitting process could be expedited if proposed renewable energy facilities were sited on least-crucial habitat lands. This would still encourage renewable energy development working toward energy independence targets, while focusing on landscapes having the least conflict with habitat conservation priorities. While there are many creative ways that could encourage this shift in land use perspective, the idea of multifunctional landscapes should be greatly considered in the construction of policy incentives. This would instill a statewide focus on optimizing land use for both renewable energy development and habitat conservation initiatives.

5.5 Conclusions

This study was completed as a first attempt to understand the levels of landscape conflict between wind and solar renewable energy resources and habitat conservation priorities, according to a landscape-level perspective in Washington State. Previous studies have largely been restricted to more localized assessments of these topics. This study is unique in its use of the recently published crucial habitat assessment data, which have provided the unparalleled opportunity to employ a statewide, landscape-level analysis. While local levels of assessment are useful for understanding the particular characteristics of a specific area, a landscape-level assessment is necessary to provide important insight into the interactions, risks, and opportunities required to optimize land use planning among multiple landscape functions. With this information, land use managers, conservation biologists, and energy developers will have greater insight into the landscape opportunities and conflicts between these two initiatives. This will encourage future landscape design and management from a multifunctional landscape approach, in which the priorities of habitat conservation and renewable energy development are more balanced across the landscape.

Because of the specific scope and types of spatial analysis utilized, the results of these analyses can only be interpreted within the context of Washington State. However, this study does provide a methodology for future analysis in different study areas, and demonstrates an effective way in which areas of significant landscape conflict can be identified and explored. Regarding the analysis of Washington State, a number of important outcomes were identified, leading to a lengthy discussion around the opportunity to use crucial habitat as an indicator to optimize land use and move toward the creation of multifunctional landscapes.

In the context of existing Washington wind farms, the distribution of crucial habitat was found to vary from one wind farm to another. This provided an opportunity to analyze the approved environmental impact assessments for the worst sited wind farms according to crucial habitat distribution. It was found that the rigor of environmental assessment varied greatly between the two wind farms. However, despite being located in most-crucial habitat lands, if assessments are thoroughly completed and mitigation plans are carefully constructed, the environmental impacts of development can be minimized. Additionally, wind farm projects can contribute to high-level conservation goals by designating natural lands as preserves and establishing habitat corridors connecting multiple parcels of natural habitat. This analysis demonstrated the potential to use EIAs as a springboard for thinking about development within the context of multifunctional landscapes.

Analysis of suitable wind and solar development locations and the estimate of future energy contributions found that solar energy development could specifically target the least-crucial habitat lands. Within these landscapes, solar energy could provide over 50% of total existing state energy production if fully developed. On the other hand, wind energy development could only be restricted to crucial habitat lands 3–6 and still be able to quadruple in size, contributing another 7.9% of annual state energy needs. Since there were some limitations to the solar energy estimate, future analyses—including a more realistic feasibility study—should be conducted. Preferred renewable energy development locations could be identified for the assessment according to economic, social, and technological impacts to renewable energy development. This more realistic model for determining preferred renewable energy development locations would help land use planners better understand and anticipate land use conflicts between the two initiatives and optimize land use to the benefit of both.

Finally, the analysis of significant spatial clustering and landscape conflicts within general Washington habitats showed that the grassland and shrubland habitats, as well as the agricultural, pasture, and mixed-environment habitats, were impacted the most. Grassland and shrubland habitats had high energy resources for both wind and solar, which would make renewable energy development in this habitat highly likely. However, the solar analysis also showed a significant presence of high conflict clusters. Since many of the grassland and shrubland habitats are priority 1 conservation habitats and already threatened by habitat loss, habitat fragmentation, and invasive species, development should occur cautiously, with a thorough EIA of the proposed development locations.

The agriculture, pasture, and mixed-environment habitat also had high solar energy resources, as well as high low conflict areas. These results identified the best opportunity for solar development, since the agriculture, pasture, and mixed-environment habitat is not a priority conservation habitat. Additionally, many of the typical environmental impacts associated with renewable energy development could be minimized. Existing road networks could be utilized, reducing further habitat fragmentation and, since this habitat is already a product of landscape conversion, siting renewable energy development there would reduce the impact of habitat loss, especially when low conflict areas are targeted. However, since agricultural lands already have a dominant land use function, challenges of strategic multifunctional landscape design and stakeholder accommodation may be encountered. Despite the additional challenges, solar development in agriculture, pasture, and mixed-environments presents an outstanding interdisciplinary opportunity to pilot the construction and management of multifunctional energyscapes. In this case, land use would be balanced between the environment, energy, and agriculture.

Overall, the findings of this study have demonstrated the great potential that landscape-level assessments have in identifying how multiple land use interests can interact across the landscape. By specifically identifying the levels of conflict between renewable energy development and habitat conservation priorities at a landscape-level perspective, the first steps to initiating a multifunctional landscape approach to landscape design and management have been achieved. If applied to future landscape planning, lands that would generate energy while also having a low conservation value would be first identified at a landscape-level and targeted for future energy development. This would avoid lands having more severe landscape conflicts between renewable energy development and habitat conservation priorities. Then, the existing EIA process for development would identify any lesser land use conflicts at a local scale and propose specific mitigation plans to further optimize the landscape design between these two initiatives.

While there will be many challenges associated with the design and application of multifunctional landscapes, this approach to landscape management is becoming critical for the future. More studies should be conducted with a landscape-level perspective, so that land use planning can fully optimize the land use requirements of multiple functions across the landscape. This could include similar studies in other states, smaller regional studies within Washington, and studies that explore different landscape contexts. These future studies will identify more opportunities and challenges of optimizing the landscape design between habitat conservation and renewable energy development and further encourage a multifunctional landscape approach to landscape planning and management. These efforts will provide the foundation to better balance the needs of society and the environment for the future across all types of land uses and provide a healthier Earth for all inhabitants.

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Appendix

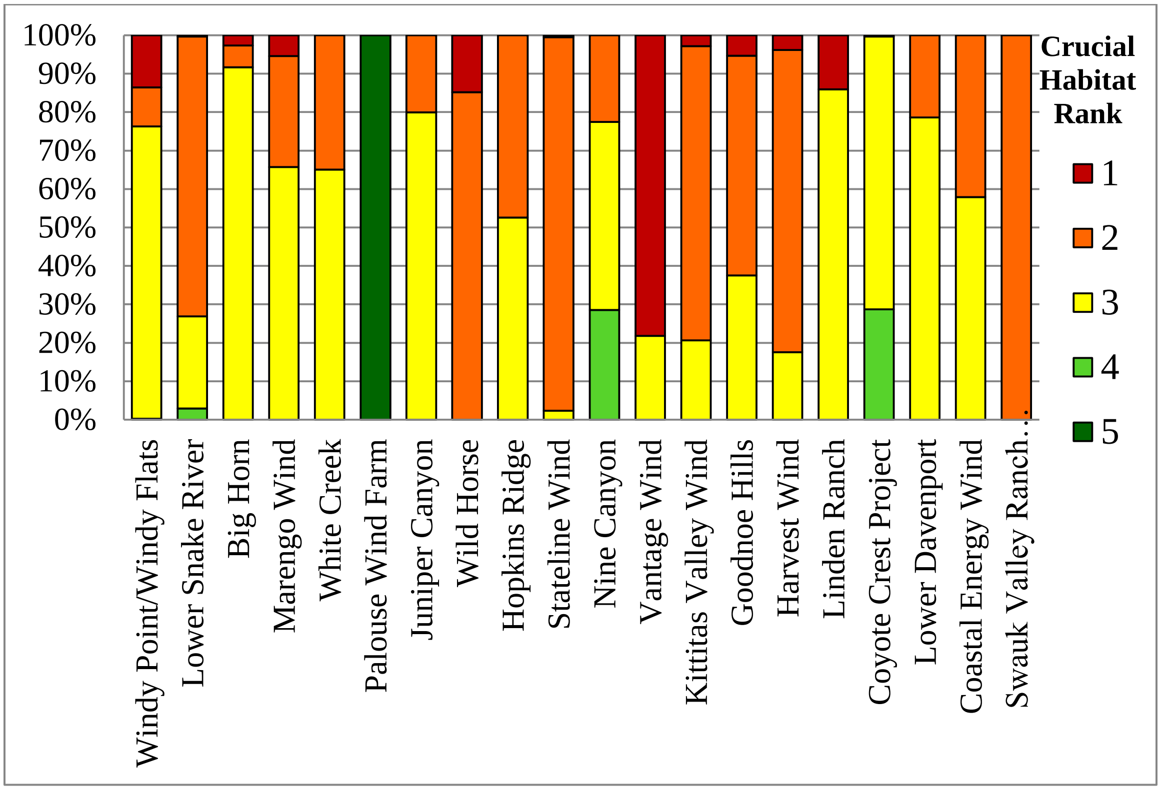

Figure 19. Crucial habitat on each existing Washington wind farm

Table 9. Crucial Habitat Ranking Factors

(Source: Crucial Habitat Assessment Tool metadata prioritization worksheet (Western Governors' Association 2013))

Ranking Factors	**Crucial Habitat Rank**					
	1	**2**	**3**	**4**	**5**	**6**
Aquatic Species of Concern	Endangered and threatened species spawning area (documented).	Endangered and threatened species documented, presumed, transported, or artificial presence.	Federal species of concern documented or presumed presence; state candidate species of concern documented or presumed presence.	Endangered and threatened species potential presence.	Endangered and threatened species potential presence.	None of the afore-mentioned factors applies.
Terrestrial Species of Concern	Confirmed locations for threatened and endangered plant and animal species; level 1 priority habitat species.	Confirmed locations for level 2 priority habitat species; federal and state candidate and sensitive species.	Confirmed locations for level 3 priority habitat species; level 2 modeled species of concern locations.	Level 3 modeled species of concern locations.	Level 4 modeled species of concern locations.	None of the afore-mentioned factors applies.
Natural Vegetation Communities	Ecological systems of concern with level 1 priority habitat and confirmed heritage vegetation locations.	Ecological systems of concern with level 2 priority habitat and confirmed heritage vegetation locations; federal and state candidate and sensitive species.	Presence of at least one global ranked G1 or G2 ecological systems of concern with level 3 priority habitat and confirmed heritage vegetation locations.		Presence of at least 1 global ranked G3 ecological systems of concern.	None of the afore-mentioned factors applies.

Ranking Factors	Crucial Habitat Rank 1	2	3	4	5	6
Wetland and Riparian Areas	High integrity estuaries.	Moderate integrity estuaries.	Low integrity estuaries; priority species wetland and riparian habitats; National Wetland Inventory; presence of excellent condition flood plain.	Presence of good condition flood plain.	Presence of fair condition flood plain.	None of the afore-mentioned factors applies.
Aquatic Species of Economic & Recreational Importance		Other salmonid spawning areas (documented).	Other salmonid documented or presumed presence; white sturgeon presence.	Non-native game fish presence.	Other salmonid potential presence.	None of the afore-mentioned factors applies.
Freshwater Integrity			Catchment in relatively excellent condition.	Catchment in relatively good condition.	Catchment in relatively fair condition.	None of the afore-mentioned factors applies.
Large Natural Areas			Large intact blocks greater than 1000Ha and with best (top 33%) integrity.	Large intact blocks less than 10,000Ha or greater than 50,000Ha and with integrity less than top 33% (best).	Large intact blocks greater than 10,000Ha or less than 50,000Ha and with integrity less than top 33% (best).	None of the afore-mentioned factors applies.
Terrestrial Species of Economic & Recreational Importance			Level 1 priority game habitats and concentration areas.	Level 2 priority game habitats and concentration areas.	Level 3 priority game habitats and concentration areas.	None of the afore-mentioned factors applies.

Ranking Factors	Crucial Habitat Rank					
	1	2	3	4	5	6
Landscape Connectivity				Connectivity zones with score of 1.	Connectivity zones with score of 2.	None of the afore-mentioned factors applies.
Wildlife Corridors				WA wildlife habitat connectivity modeled network with overlap of at least three focal species.		None of the afore-mentioned factors applies.

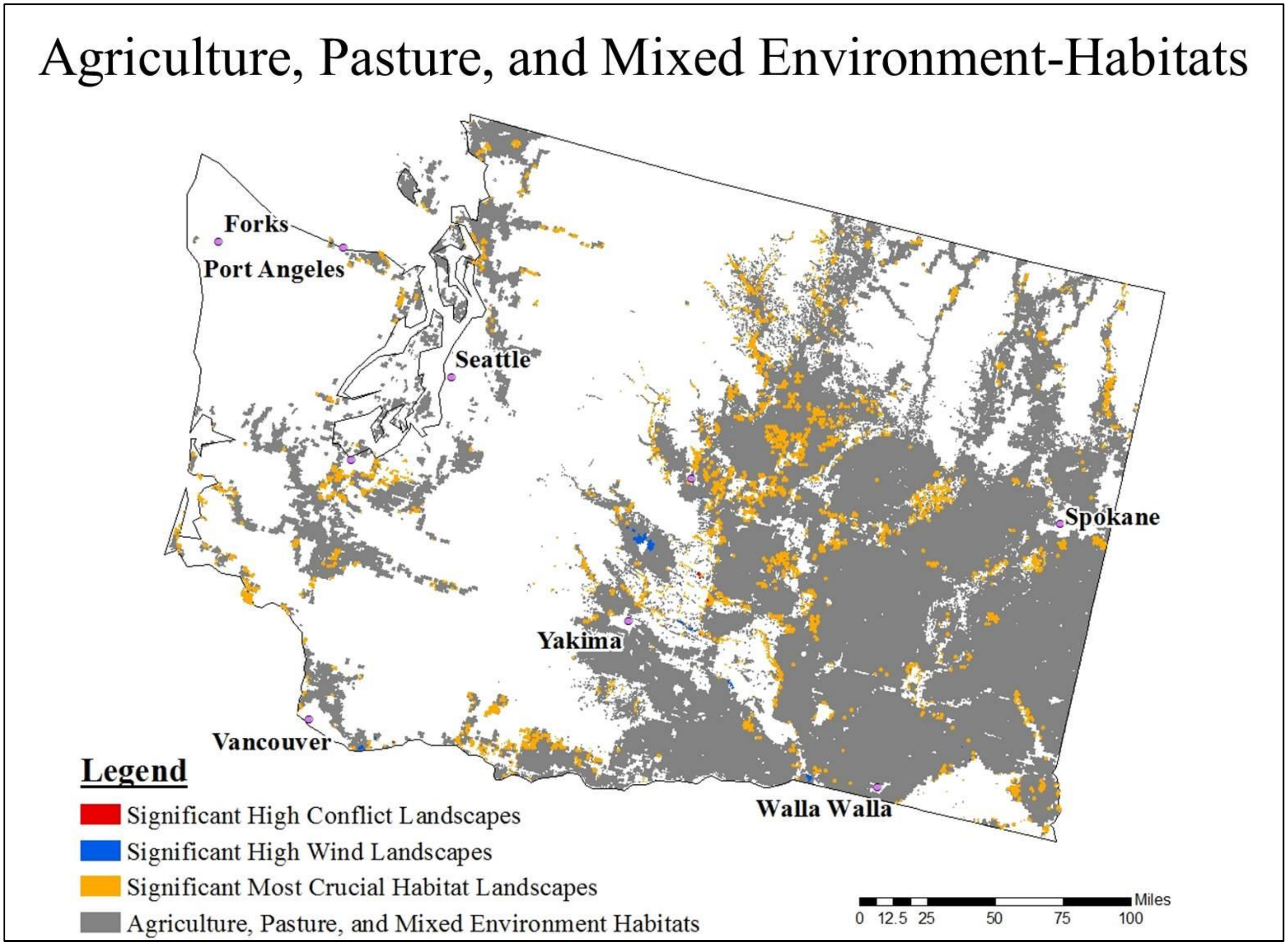

Figure 20. Spatial interaction of wind energy resources and crucial habitat in Washington agriculture, pasture, and mixed-environment habitats

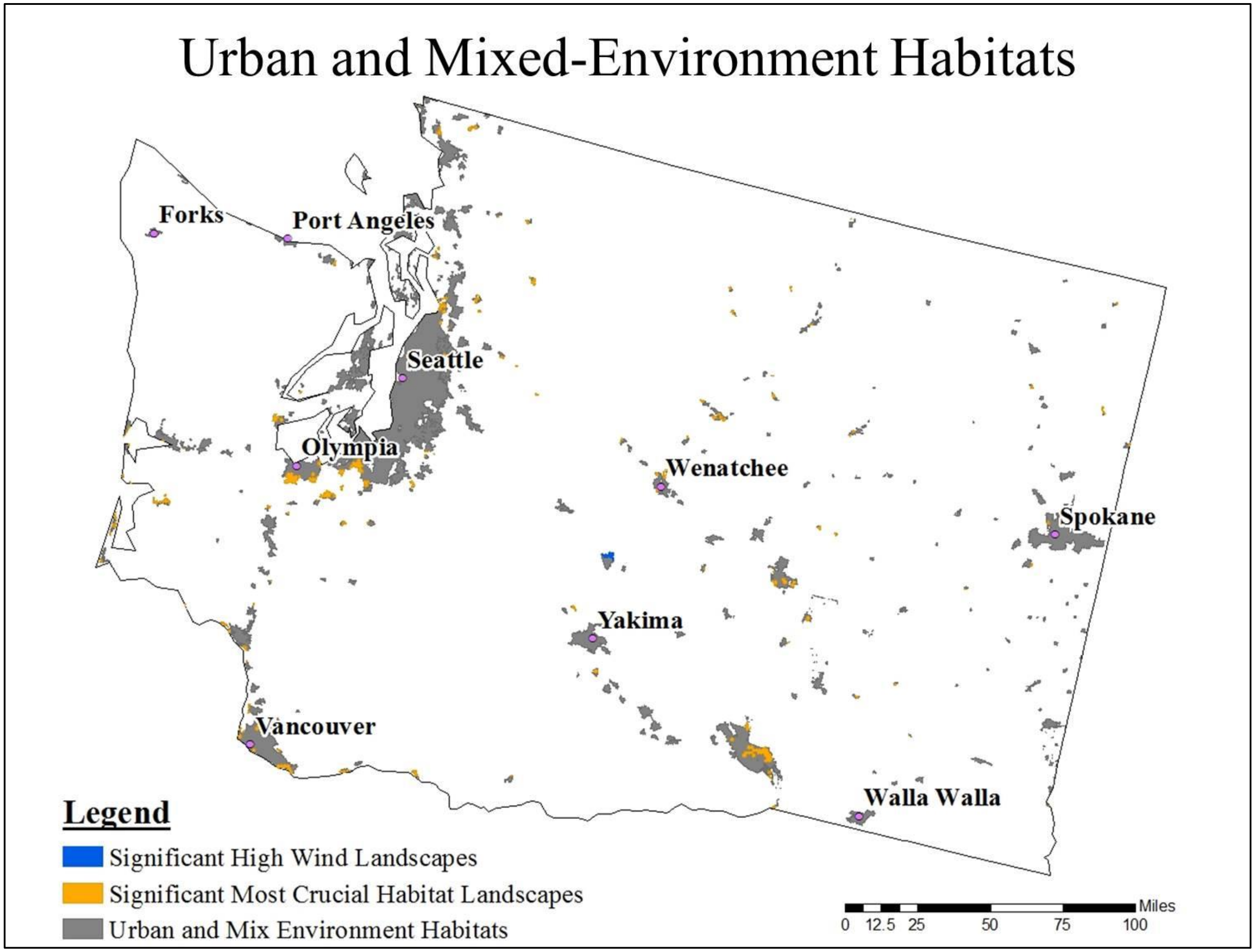

Figure 21. Spatial interaction of wind energy resources and crucial habitat in Washington urban and mixed-environment habitats

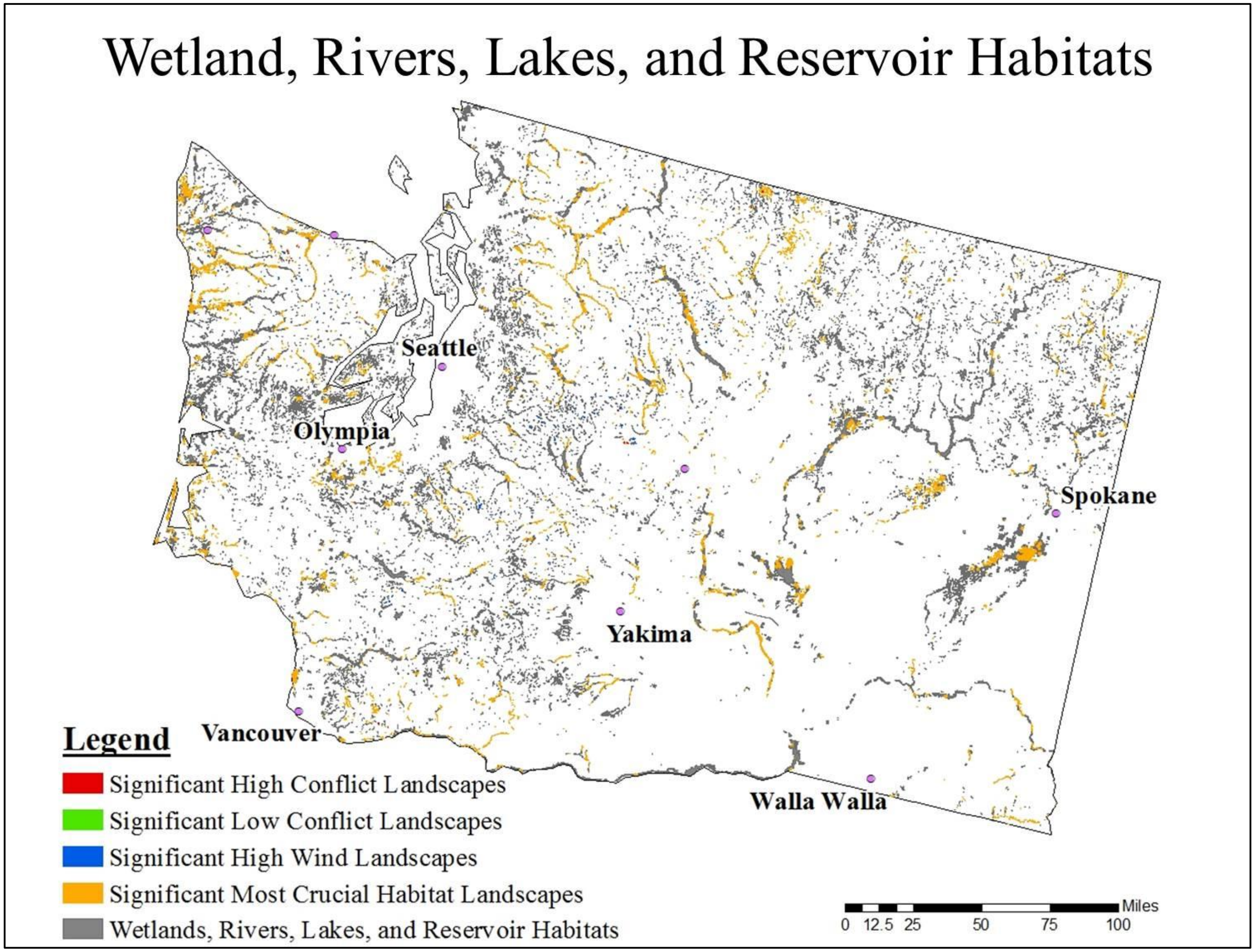

Figure 22. Spatial interaction of wind energy resources and crucial habitat in Washington wetland, rivers, lakes, and reservoir habitats

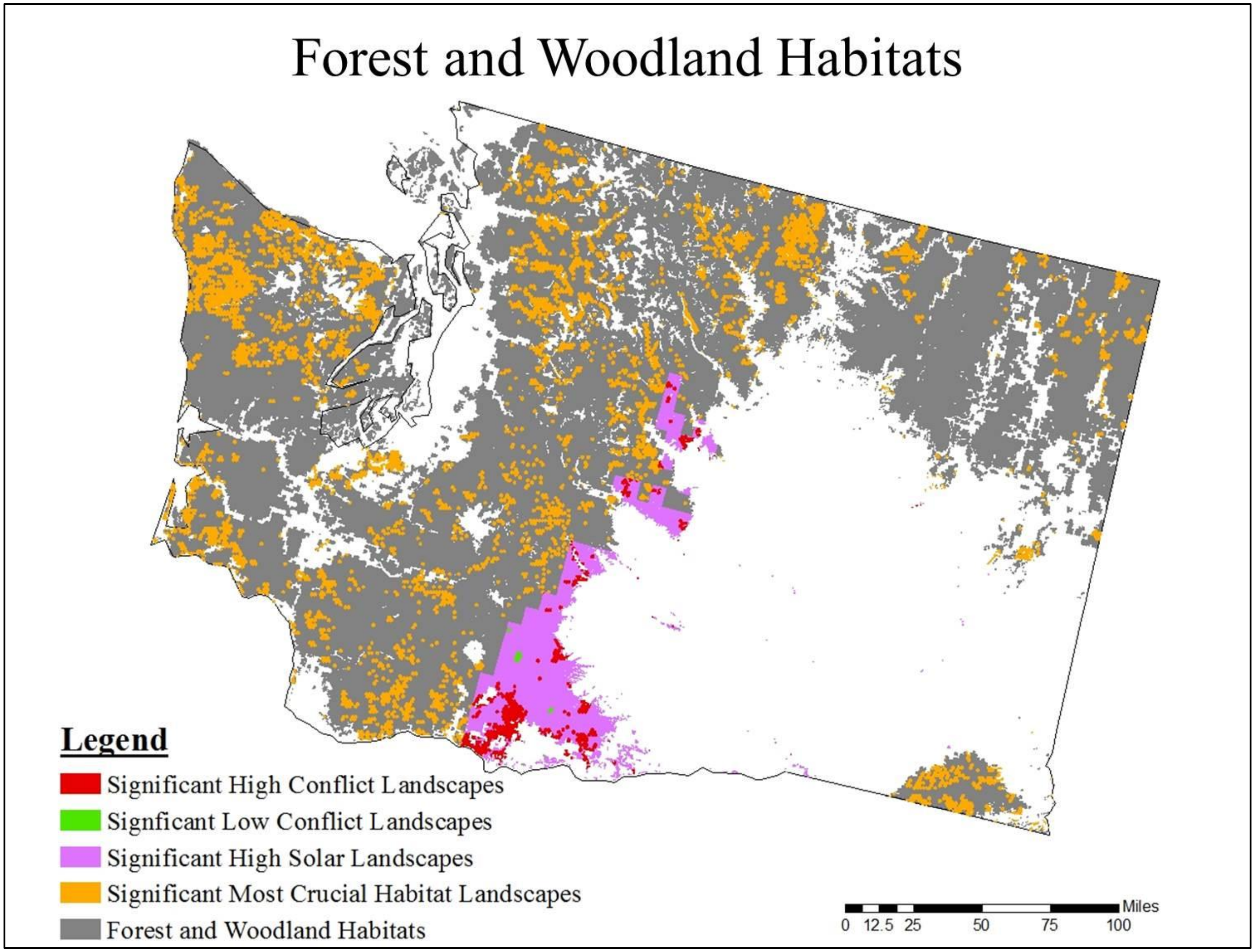

Figure 23. Spatial interaction of solar energy resources and crucial habitat in Washington forest and woodland habitats

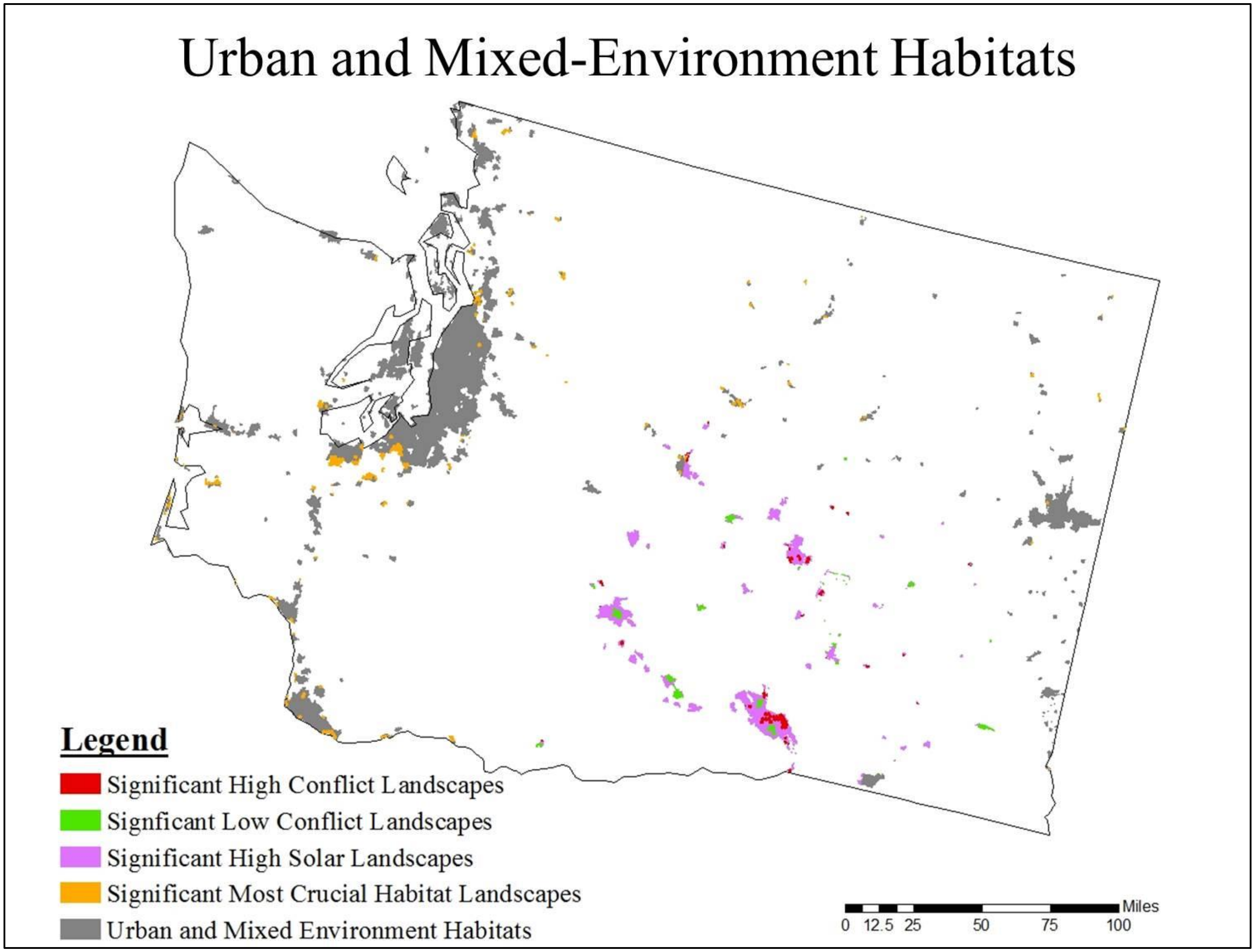

Figure 24. Spatial interaction of solar energy resources and crucial habitat in Washington urban and mixed-environment habitats

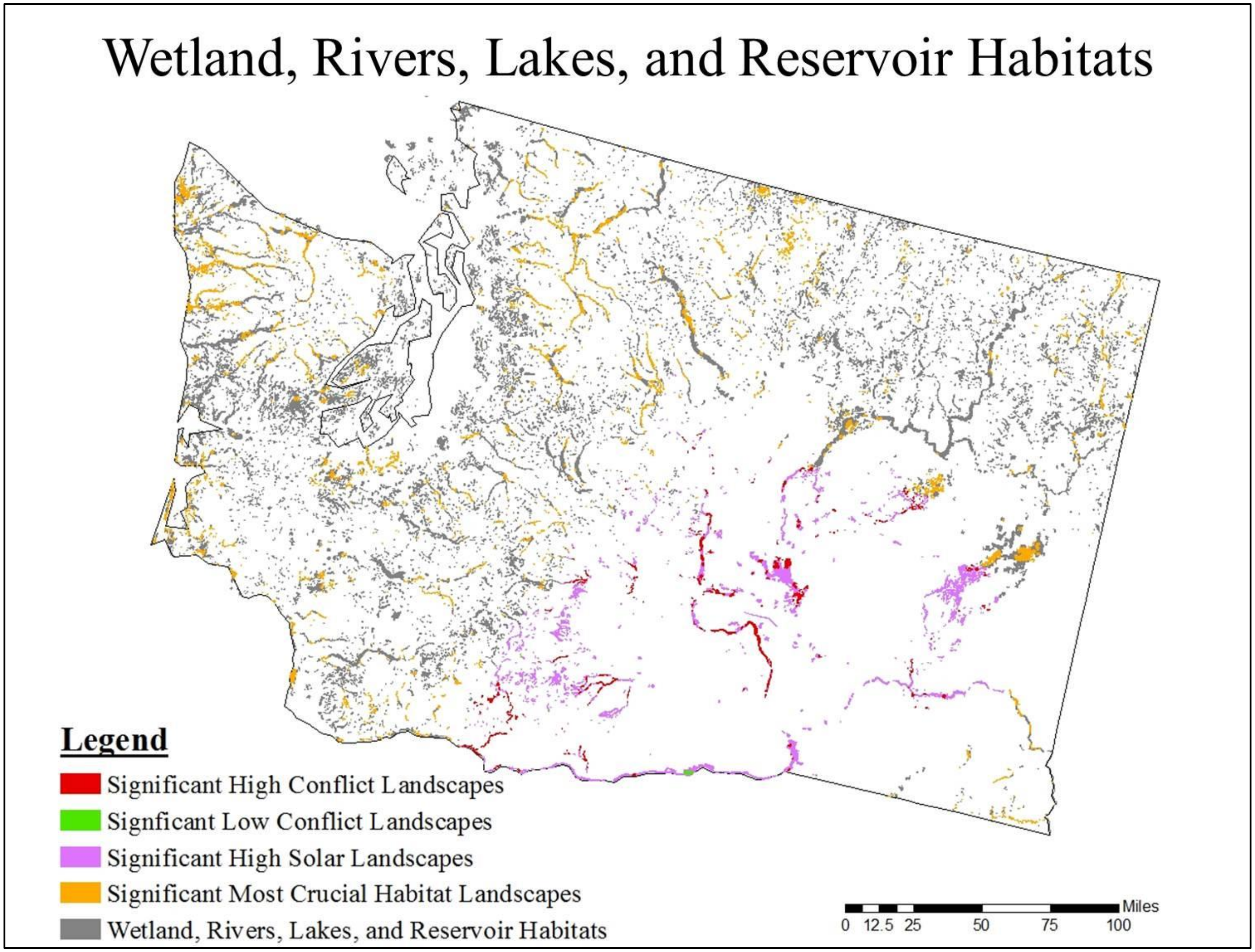

Figure 25. Spatial interaction of solar energy resources and crucial habitat in Washington wetland, rivers, lakes, and reservoir habitats