A SPATIAL ANALYSIS FOR ECOLOGICALLY CONSCIOUS WIND FARM SITING IN THE PACIFIC NORTHWEST

by

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ABSTRACT

A Spatial Analysis for Ecologically Conscious Wind Farm Siting in the Pacific Northwest

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As renewable energy resources are increasing availability, there is evidence to suggest that the renewable alternatives have numerous ecological impacts that should be addressed before developers proceed to mass produce energy. Birds are particularly vulnerable to experiencing population decline as a result of mortality from collision with wind turbines and displacement from habitat in which the wind farms are developed. The presently used mortality rate is based on rates at individual wind farms rather than on a collective rate for wind farms along flyways. Additionally, the present mortality rate does not account for population declines related to loss of viable habitat or habitat connectivity during and after construction of wind farms, so the overall population declines are grossly underestimated. The goal of this study is to locate sites for new wind farms that will aid in the reduction of bird mortality resulting from wind farm development in the United States. To accomplish this goal I will perform a spatial analysis of the United States using Geographic Information Systems (GIS) as an analysis platform. My analysis resulted in a preliminary siting tool that will address the conservation of birds by avoiding the important bird areas and protected areas while encouraging a multipurpose landscape. This tool can be used by the public, politicians and developers to make informed decisions about wind farm siting to reduce the overall ecological impacts birds while increasing the availability of renewable energy resources.

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Introduction

Renewable energy technologies represent an opportunity for the United States, as well as other countries, to reduce global impact on the environment. With early indications and knowledge development on the ecological impacts that these new technologies have, there is an additional opportunity to address these problems before they become crises. However in the United States, "government and industry decision making on energy questions tends to be event- or crisis-driven" (Heimann, 2004). For example, the North American Electric Reliability Council (NERC) was created as a result of the great Northeast blackout in 1965 despite a recognized need for a regulatory council prior to this energy disaster (Heimann, 2004), This crisis-driven behavior occurs in regards to climate change mitigation and ecological protection as well. For example, the Clean Air Act and Endangered Species Act emerged long after the recognition of a threat to human health and extreme losses of several species in the United States. However, there are encouraging global actions being taken to reduce the impacts of global climate change.

As climate change awareness and action increases, global efforts to reduce carbon emissions by establishing initiatives and policies to introduce an increasing amount of renewable energy for established and developing countries. The United Nations Framework Convention on Climate Change was developed in 1992 “as a framework for international cooperation to combat climate change by limiting average global temperature increases and the resulting climate change” (United Nations, Background on the UNFCCC). The Kyoto Protocol, adopted in 1997 as a legally binding contract for developed countries to meet a target for reducing carbon emissions, established a target for total reduction of greenhouse gases below the 1990 levels by 5 per cent (globally) between 2008 and 2012 (United Nations, A Summary of the Kyoto Protocol). The actual reduction targets for individual countries varied based on their present emissions rates. Since then, new climate change action reforms have been called for.

More recently for the Paris International Conference on Climate Change Action of 2015, nations developed non-binding agreements to reduce carbon emissions based on what they believe they are capable of achieving by 2020. This conference built upon the Convention on Climate Change’s goal in an effort to ambitiously combat climate change and adapt to its effects (United Nations, The Paris Agreement). The agreements will accelerate the global carbon emission reductions to maintain global temperatures below 2 degrees Celsius greater than the pre-industrial global temperatures (Center for Climate and Energy Solutions, 2015). While the Kyoto Protocol and the Paris Agreement are only two of the many actions taken, they have provided a basis for directing the existing and developing energy infrastructure toward renewable energy development across the world.

As the renewable energy sector expands, ideally this would mean that we would see an overall decrease in non-renewable energy use. However, the alternate scenario includes the expansion of fossil fuel based energy resources. As seen in Figure 1 below, through 2014, there has yet to be a decrease in the use of fossil fuels but there is evidence in the increased use of hydroelectric, biofuels, nuclear, and a category classified as “other” which consists of geothermal, wind, solar, etc. (International Energy Agency, 2016). The figure is evidence of what I just indicated; the demand for energy continues to rise. If the energy demand were to decrease or remain consistent, it would give renewable energy technology and opportunity to grow and command the market.

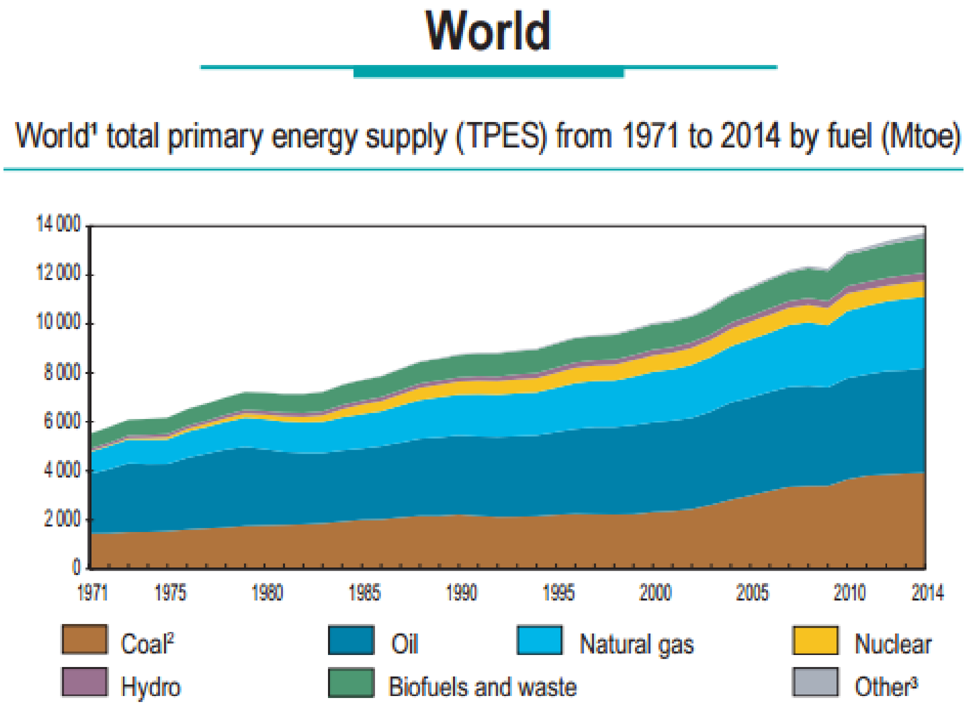


Figure 1: Total world energy supply by energy type. (IEA, 2016 p.7)

In the years following the 2015 United Nations Climate Change Conference (COP21) held in Paris, we should begin to see decreases in the demand for the non-renewable resources as commitments agreed upon during that conference come into play. Much of this decrease will have to occur with the cooperation of major polluters, such as heavily populated countries like China and the United States (the chart below shows each participating countries present contributions to greenhouse gas emissions), to reach and maintain significant drops in carbon emissions, with aid flowing to developing countries to avoid the coal and fossil fuel consumption and, instead, develop renewable alternatives. Moving directly to clean, renewable energy technology is often referred to as "leap frog" development.

Share of Greenhouse Gas Emissions by Countries with Climate Targets

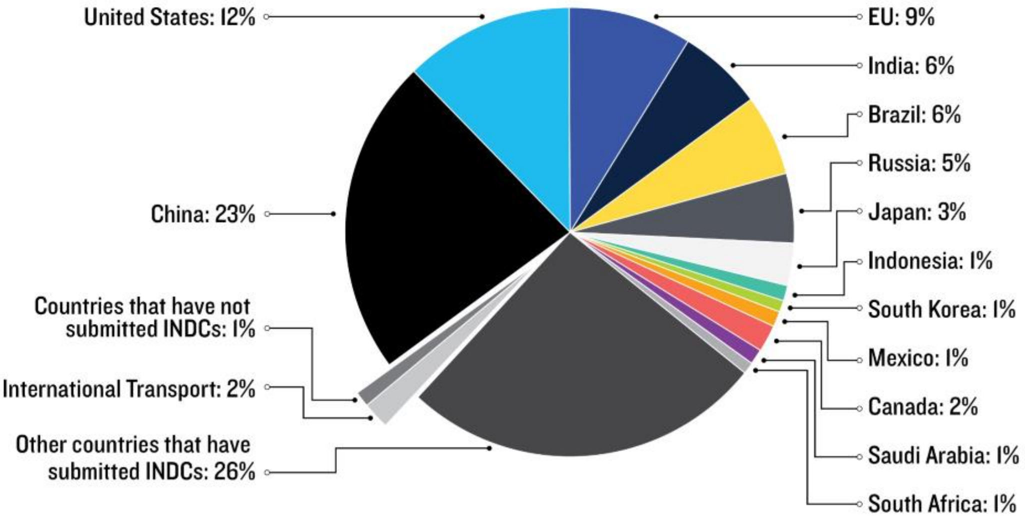


Figure 2: Countries' share of emissions as calculated by the Natural Resources Defense Council from the 2012 total GHG emissions. Does not include the countries that did not submit targets for 2012 (NRDC, Dec. 2015).

Leap frog technology development requires money. Prior to implementation of the Kyoto Protocol "countries agreed to establish the multilateral Green Climate Fund (GCF) to help mobilize funding in development countries to reduce emissions and adapt to the impacts of climate change" in Copenhagen, Denmark (NRDC, 2015). The United States alone pledged three billion dollars of about 11 billion dollars to support the GCF (NRDC, 2015). Such donations will be extremely important for the maintaining and/or reducing the existing carbon dioxide emission levels in those countries as other countries reduce their pre-existing levels.

A variety of renewable energy options exist for the participating COP countries to select from as they pursue their individual commitments to reduce per capita emissions resulting from the Paris Agreement. Technologies related to energy production include wind turbines, solar panels, and hydroelectric dams used in many innovative ways across the globe. For example, in Chile, a small fishing village, named Caleta San Marcos, is developing a renewable energy plant that uses solar and hydroelectric methods to provide 24 hour access to electricity to the community. During the day the solar panels will provide energy to the community and to a pump that transport ocean water to a storage area, so that at night the water can be released to spin turbine generators to generate up to 300 Megawatts (MW) daily (Jarroud, 2016). This project creatively takes advantage of the seaside cliffs found in abundance along the Chilean coast and suggests the potential for innovation and efficient use of renewable resources as the renewable energy industry expands.

There is an advantage to developing innovative renewable energy projects, such as the one in Chile, but many of the ecological damages tend to be overlooked by the developers and the associated energy companies. Hydropower has been used heavily around the world, but the damming process often creates reservoirs, which disrupts the preexisting ecology of the location, permanently altering the habitat. Dams prevent fish from traveling up or down stream, and allow for silt accumulation that eventually clogs the water intakes and may contain toxic material. Additionally, the reservoirs cover the original vegetation, causing it to decay and release methane, a potent greenhouse gas. In fact new studies show that dams may significantly contribute to greenhouse gas emissions due to this reason (Magill, 2014). Environmental impacts are not limited to dams, but they occur in all renewable energy projects.

The United States has been exploring wind energy as one of the options for decreasing carbon emissions. Presently the United States is second in wind energy production at 17.2% of the shared capacity, following China’s 33.6%, shown below in Figure 3.

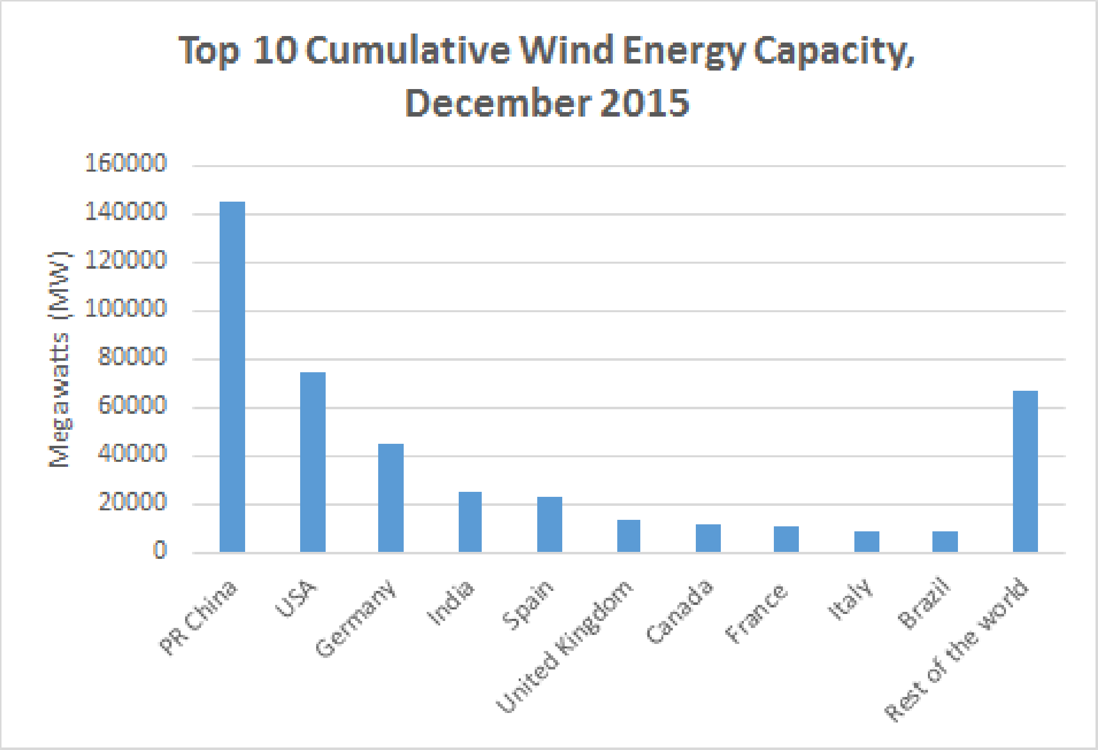


Figure 3: Cumulative capacity of the top ten wind energy producers compared to the rest of the world. Sourced from the Global Wind Energy Council, Global Wind Statistics 2016 (GWEC, 2016).

The United States likely will continue to develop wind energy due to the commitment made at the Paris Conference to cut greenhouse gas emission by 28% of the 2005 levels [44,153 metric tons (World Resources Institute, July 2009)] by 2025 (NRDC, December 2015). Wind energy may be a significant actor in achieving this goal based on “the Department of Energy estimates that if wind energy provides 20% of American Energy needs by 2030, it can reduce annual emission of carbon dioxide by approximately 825 million metric tons” (Evans, 2014). This achievement would result in a 1.8% cut from 2005 emissions, enlarging the total cut so far from 12% (EIA, May 2016) to nearly 14%.

Although wind farms represent an opportunity for the United States to reduce carbon emissions from the electricity generation sector, they do have known ecological impacts that must be addressed. For example, wind turbine siting puts birds at a particularly high risk of mortality and displacement, and prevents a species from remaining in a location due to the loss of essential resources and/or necessary habitat qualities. As a result, it is important to mitigate the negative impacts on birds prior to the expansion of the wind energy industry in the United States. This research outlines one approach to do just that.

In this study, I will perform a spatial analysis of the Pacific Northwest (Washington, Oregon, Idaho, and Montana) to develop a map series and web application tool using ArcGIS (Geographic information systems) and ArcMap Online to find potential locations for new wind farms that will account for:

1. The exclusion of protected areas and other important bird habitat, such as nesting sites,
2. The exclusion of open water such as rivers and lakes,

3. The encouragement of maximum use of agricultural and pasture land to promote a multipurpose landscape, and
4. The avoidance of existing wind farms sites.

By accounting for all of these restrictions, the potential mortality rates and effects of displacement on local and migratory bird populations as a result of wind farm development will be minimized. The result will be the creation of a preliminary tool that can, and should, be improved upon through additional research to include the other alternative energy options and account for other species that are experiencing negative impacts from similar development projects.

In the chapters that follow I will introduce the history of wind powered technology to put its development into perspective alongside the impacts that the turbines have on bird communities. The present bird mortality estimates as a result of wind farm development are very low (0.01% based on Stevens, et al., 2013 and Lucas, et al., 2008), but that number fails to include other factors that may significantly increase the total mortality rate. I will describe several of these additional factors in detail and how mortality may result. Furthermore, I will explain the purpose of using GIS analysis tools as an alternative to other modeling programs.

Literature Review

Development and Problem Recognition

Wind Energy Technology Development

The use of wind as an energy resource has been around for thousands of years, but it was only in the mid 1800's that wind turbines were optimized for electricity production and to use as water pumps in the United States. Between 1850 and 1970, over six million machines were developed for pumping water (Kaldellis & Zafirakis, 2011).The U.S. Wind Energy Company opened its doors and designed a windmill for the Midwest known as the Halladay Windmill in 1850, named for Daniel Halladay, one of the company's owners (Office of Energy Efficiency & Renewable Energy). In 1890 that metal blades were introduced to the design for their durability as the structures grew taller to catch more wind and create more energy. After that, the development of wind turbine technology took off.

In the mid 1900's wind farms started to be developed across the United States at utility scale. Following the oil crisis in 1973, and until 1986, the commercial wind turbine market evolved primarily from domestic and agricultural applications to encompass utility interconnected wind farms (Kaldellis & Zafirakis, 2011). It was an option explored with vigor, because it offered a way for the United States to maintain electricity resources in the midst of oil shortages (Wind Energy Foundation). The first large-scale wind energy project occurred in California (1981-1990) with over 16,000 installed turbines. Figure 4 below depicts the rapid increase in wind produced energy following 1990, and the projections for wind energy production, as well as other renewable sources, through 2035.

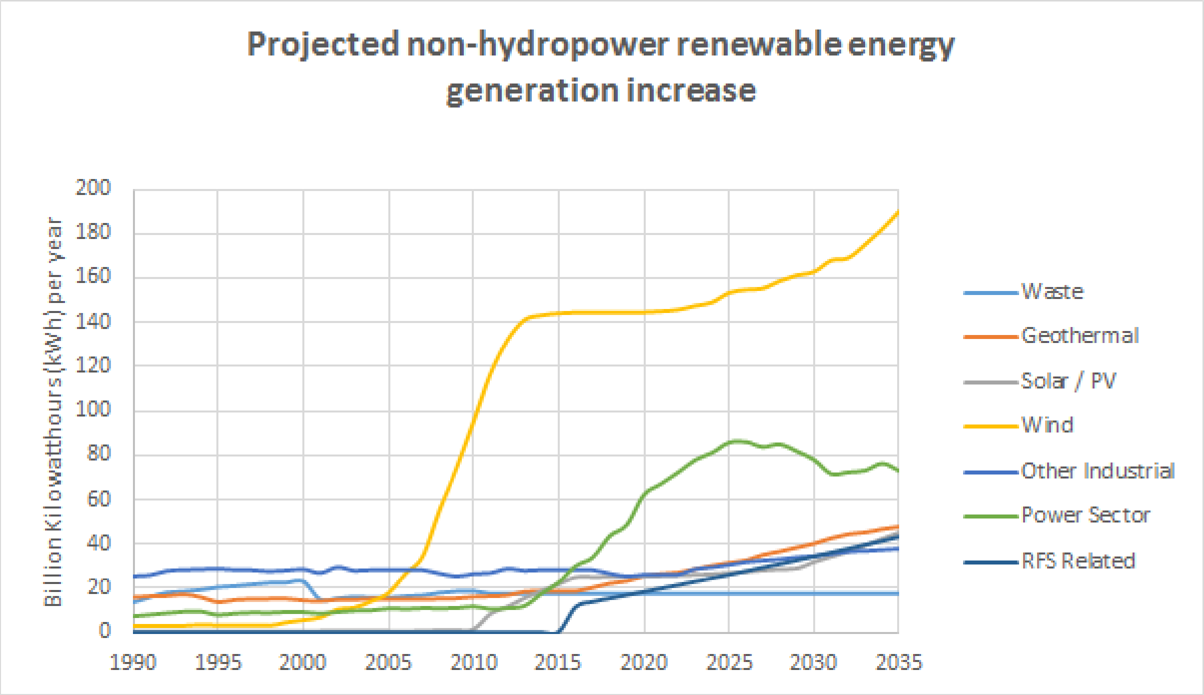


Figure 4: Projected increase in renewable energy generation (excluding hydropower) from 1990 to 2035. Sourced from the U.S. Energy Administration, Annual Energy Outlook 2012 Early Release (EIA, Today in Energy, February, 2012).

The current installed capacity of wind energy in the United States resulted from developing wind energy technology at the utility scale. However, the understanding of how renewable energy is classified at the utility scale has been under debate since the transition to interconnected utility scale wind farms. John Kaldellis and D. Zafirakis (2011), defined agricultural and domestic applications as 1-25 kilowatts and utility scale wind farms as 50-600 kilowatts. The California Energy Commission (2016) and Greentech Media (2013) both define a utility scale renewable energy resource as producing 10 megawatts or more. However, when the first “utility-scale” wind farm was developed it supported a local community near Grandpa’s Knob, Vermont for several months during World War II, year 1941, producing only 1.25 megawatts (Office of Energy Efficiency & Renewable Energy). For the sake of simplification in the case of this study, a utility-scale wind farm serves a community through a public utility service, regardless of its kilowatt capacity.

Ecological Impact Research Exploration

As the development of the turbine technology took off and wind farms started to spring up, investigation of bird mortality began. “The high number of bird takes each year is largely a result of the design of the wind turbines" (Andrews, 1999). Wind turbine designs dating back to 5000 B.C.E. were typically wooden structures with fabric or wood blades used to propel boats, pump water, or (later) grind grain (Wind Energy Foundation). American colonists used wind turbines for many of the same purposes, but the development of electrical power brought new applications for turbines (Wind Energy Foundation).

Engineers have designed modern turbines to be more efficient. The modern turbines require a greater amount of vertical space than the older ones, and, in the case of horizontal axis turbines (turbines with long, outward blades), placement to catch higher wind speeds (Evans, 2014). To support these designs, wood and fabric have been replaced with sturdier materials including metal and carbon fiber. The height and materials combined make it harder for birds to avoid turbines in a utility scale setting where there are many structures in one area and mortality is more likely to result when the birds collide with the stronger materials. Additionally, because computers assist in moving the blades to best catch the headwinds, and because the tips of the blades can move up to 180 mph, it can be difficult for birds to navigate through the farm without collision (Evans, 2014).

Part of the efficiency improvements during siting is that they are placed in areas with higher wind speeds. “Wind turbines are often arranged in rows, along coasts or mountain ridges,” which is, typically, where soaring and migrating birds use the air currents to travel and hunt (Barrios & Rodriguez, 2004). Mortality increases when turbines are placed in the path of birds which are hunting, gliding or flying using the wind. For this reason that it is not recommended for wind farms to be built along important migratory routes or in important areas, such as breeding or hunting grounds (Everaert, et al, 2014).

The ecological impacts largely went unnoticed until about 30 years ago (Smallwood, Bell, Snyder, & Didonato, 2010). Around that time, more intensive studies on wind turbine bird collision mortality were conducted. Ultimately this led to the realization of the negative impacts of wind turbines on birds, more so among some species groups than others. Many of these early studies focus on the short-term effects of individual wind farms on mortality, and concluded that wind turbine collision mortality contributes to 0.01% of all bird death cases (Lucas, et al., 2008). In later years, other researchers challenged the technique of the study as insufficient for determining the overall threat on bird posed by wind farms in general and based on species restrictions. This revelation will be discussed in the following section.

Impacts of Wind Turbines

Numerous impacts associated with wind farm development negatively affect the conservation of the bird community health. These impacts include displacement resulting from human disturbance (the presence and activity of humans within or near habitat areas), collision mortality, barrier effects that disrupt habitat connectivity, habitat loss or change, and the associated effects on available resources, such as prey (Langston, 2013). Each of these variables will be discussed in the following below.

Understanding the impacts in detail and considering ways to mitigate these impacts as the wind energy industry grows will help align the industry with the goals of conservation groups, environmental advocates, and the public. For example, Europe has a binding agreement (outlined in Directive 2009/28/EC) to produce 20% of the energy consumed from renewable energy sources by 2020, but some projects have been cancelled or postponed due to the potential impacts on wildlife (Johnston, et al., 2014). For countries in Europe, as well as other countries expected to experience an increase in wind energy (United States and Canada in particular), improving the evidence base reducing the uncertainty surrounding the impacts on wildlife will benefit the renewable energy industry and the European national conservation advisors and regulators by preventing cancellations or delays at a high financial cost (Johnston, et al., 2014). Increasing access to knowledge on the ecological impacts will ultimately lead to more insight and research efforts on how to effectively mitigate the problems to promote development of the wind energy industry.

Displacement

Many species of birds exhibit avoidance behaviors when interacting with tall man-made, or anthropogenic, structures and will ultimately leave that area completely (Kuvlesky, et al., 2007). Grassland species for example, demonstrate avoidance behaviors near anthropogenic structures during and after construction, suggesting that the presence of a utility-scale wind farm “could degrade habitat to such an extent that it would be avoided or abandoned by sensitive species” (Stevens, Hale, Karsten, & Bennett, 2013). This is known as displacement and is “often considered to be a greater threat to bird populations than collision fatalities" (Stevens, et al., 2013) because it reduces the amount of habitat available for sensitive species and/or reduces the amount of habitat connectivity. Avoidance behavior may be viewed as positive "in terms of reducing collision risk and associated direct mortality," but the consequences of making usable habitat unavailable tend to be unclear (Langston, 2013). Although displacement is an issue for most bird species, it is more significant for species that have low human disturbance tolerance thresholds, such as the Marbled Murrelet or the Northern Spotted Owl.

Many of the displaced species are listed as endangered or threatened and the scope of their available habitat tends to be considered critically low. Siting a new wind farm within an undisturbed area (or an area not used for human purposes, such as grasslands) poses a risk to birds by reducing the amount of habitat available for the sensitive species, fragmenting suitable habitat, and making it more dangerous for the birds to travel between suitable habitat parcels. For example, a bird may avoid the immediate vicinity of a wind farm, since it may be viewed as an obstacle or barrier (Madden, et al., 2009). By exhibiting avoidance behavior the bird cannot use potential feeding habitat and necessitates "additional flight to avoid the obstacle" resulting in excess energy expenditure, which could affect breeding success and survival (Langston, 2013; Madsen, et al., 2009; Kuvlesky, et. Al., 2007).

The amount of displacement due to wind farm construction varies and is considered species specific, ranging between 100 to 500 meters in displacement from a single wind farm (Steven, et al., 2013; Langston, 2013; Kuvlesky, et al., 2007). However, T.K. Stevens et al. (2013) discovered that certain bird behaviors may be indicative of the amount of displacement that occurred. The presence of wind turbines did not impact three of the four grassland species studied as heavily, but these species were not limited to the resources available in undisturbed landscapes and did use those found in altered habitats, such as agricultural and grazing fields. The single species more severely displaced didn’t frequent disturbed areas and was limited to locations with low human disturbance, dominated by native vegetation.

While the habitat preference of an individual species or groups of species may be an indicator of the species’ or group’s reaction to wind farm placement, Steven et al. discovered evidence to suggest that predator avoidance behaviors may better reflect responses to wind turbine development on a broader response spectrum. The displaced species adopts a cryptic evasion strategy, meaning that individuals hide and remain undetected while predators go by. “If cryptic species perceive wind turbines as a predation risk [as raptor perches for example] then [they] may be more likely to avoid areas with wind turbines” (Stevens, et al., 2013). Based on these findings, the researchers hypothesized that “species occupying natural or semi-natural habitat would be more sensitive to wind energy development than species occupying intensively produced landscapes” (Stevens, et al., 2013).

Using cryptic species as an indicator species may be an appropriate method for adjusting turbine siting practices, to avoid negatively impacting the disturbance sensitive species. This would mean including a suitable buffer zone around the wind turbines, to account for the amount of unsuitable habitat and the range of displacement post construction. Since species that already have a high tolerance for human disturbance did not experience high impacts from displacement, siting wind farms with in agricultural and grazing lands, or other disturbed landscapes, may not severely impact those communities.

Fatigue

As stated briefly above, another consideration when addressing the impacts of displacement is the fatigue experienced by birds confronted with an obstacle that leads them to expend excess energy flying around it, which could affect breeding and survival when they frequently have to avoid anthropogenic structures (Langston, 2013; Madson, et al, 2009; Kuvlesky, et al, 2007). This issue particularly affects species which have large ranges, such as raptors or migratory species, because fatigue can increase mortality events. (Citation) Placing wind farms within heavily used migratory corridors, forces species that utilize it to go around the obstruction in the airspace or avoid the location (Kuvlesky, et al, 2007). The impacted species are then likely to use more energy and potentially with less for resources to replenish their energy before the next stretch toward their goal. Unfortunately, this topic has been largely unexplored and the available evidence is anecdotal, at best.

Cumulative Mortality Impacts

Bird mortality presents another significant concern for wind farm development, but the implications suggest that the mortality rate per farm is fairly low compared to other causes for mortality. Newer studies reveal that while the impact of an individual wind farm impact may be low, the cumulative impact on bird populations may be detrimental to the overall population health of individual species (Brabant, et al., 2015). This factor is especially important for migratory species with varying densities in a single space over time and throughout a region.

As the number of wind farms increases in the United States, it will be essential understand the cumulative effects of wind farms within migratory corridors and along coastlines, because there may be indications of species health decline from increased loss of individuals. In an assessment of the cumulative risks of collisions among the North Sea offshore wind farms, researchers discovered that “up to 1,046 seabirds are expected to collide with the turbines” and an “estimated 297 thrushes to collide with offshore turbines in a single night [during migration]” along the North Sea wind farm structures alone (Brabant, et al, 2015). These results demonstrate that “the cumulative impact of large-scale wind farms development [has the potential to] cause significant increases in bird mortality levels” which would put the affected populations under pressure (Brabant, et al, 2015). The results of this study may be transferable, but there are few cumulative impact studies available and this type of research is necessary for appropriately modeling the distances needed between wind farms to reduce the cumulative impacts.

Raptors and Seabirds

The discussion of habitat displacement suggests a gap in the investigation of the contribution that wind farms have in total annual avian mortality. Even so, most of the mortality analyses “do not acknowledge that some bird species may be affected more by wind turbines that other anthropogenic sources” (Lucas, et al, 2008). Large bird species, such as raptors and seabirds, are more vulnerable to fatal collisions with wind turbines than with other structures. At the Altamont Pass in the United States and Tarifa in Spain, raptors show some of the highest levels of reported mortality due to their dependence on thermals to gain altitude for travel and foraging (Wang, et al, 2015). The tendency to fly lower for foraging and use of the thermals for travel makes it more likely for them to collide with wind turbines, because these behaviors place them right in their path (Evans, 2014). This behavior also has been observed with seabirds. Seabirds use the wind coming of the water or other thermals to glide while traveling and feeding, which makes offshore wind farms a threat for these species as well (Wang, et al, 2015).

Another characteristic of these species that may be of concern when siting wind farms is that many of them have longer life spans, lower fecundity rates, and smaller healthy population size compared to other species (Ballard & Bryant, 2007; Brabant, et al, 2015). By having a lower fecundity rate these species already have a lower reproductive potential than other species, meaning they may wait multiple years before mating and, once they select a mate, they do not produce many young. That being said, if too many members of a single population are lost due to collisions with wind turbines, the reproductive potential will be reduced even further (Evans, 2014; Kuvlesky, et. Al., 2007).

The potential effects of detrimental population impacts on raptors has been particularly evident on Somalia Island, Norway. Prior to the construction of a wind farm in XXXX, 13 White-tailed eagle pairs were present within a 500 meter territory (Zimmerling, et al, 2013; Nygard, et al, 2010). In the years following construction, only five pairs remained. Thirty-six white-tailed eagles carcasses were recovered by 2009, suggesting that the collisions directed impacted the health of the local eagle population (Zimmerling, et al, 2013; Nygard, et al, 2010). Similar, long-lived species in the United States with low reproductive rates are likely to experience similar impacts when turbines are poorly sited--placed in important nesting and hunting territories. Unfortunately, there is very little population level quantitative data to support these concerns (Zimmerling, et al, 2013).

As for Seabirds, offshore wind farms are far more difficult to monitor for collisions than onshore wind farms, because carcass searches are impractical in this particular setting. As a result there is very little collision data for offshore wind farms (Brabant, et al, 2015). Brabant, et al, (2015) did monitor collisions at multiple offshore wind farms along the North Sea using visual counts and radar observations to determine the number of birds flying through the location and the number of collisions each day. They determined that 98% of all the fatality victims to be seagulls along this stretch, with a small percentage being the migratory songbirds that utilized this corridor (Brabant, et al, 2015).

The distance of individual wind farms from the coast may play a significant role in the high percentage of seagull victims. “The Bligh Bank location compared to OWEZ, located respectively 46 versus 10 km from the coast, which is inevitably reflected in lower background densities of gulls” (Brabant, et al, 2015). This study provides some evidence that proper placement of wind turbines can reduce the number of fatalities of seabirds.

It might be possible to reduce the mortality of birds by turning the turbines off during migrations or peak breeding seasons if necessary, because mortality theoretically increases during periods of high population abundance. For some species this idea may be valid. However, in the case of raptors, this theory is not accurate. Lucas, et al, (2008) analyzed 10 years of bird mortality data for Tarifa in Cadiz, Spain, and compared those figures to bird abundance. They found no correlation between abundance and mortality (Lucas, et al, 2008). Griffon Vultures, for example, had higher collision rates during the winter even though the period of highest abundance was during pre-breeding season in the spring (Lucas, et al, 2008). This was the case for the majority of the studied raptors. This study provides evidence that higher abundance does not always mean higher instances of collision mortality. Deeper exploration of "the mechanisms involved in influencing collision risk," (Lucas, et al, 2008) will be necessary, but will also require the improvement of mortality estimations and development of consistent protocol for carcass searches (Wang, et al, 2015; Everaert, et al, 2014; Lucas, et al, 2008).

Scavenger Removal and Carcass Searches

Many other variables need to be considered when determining the collision influence on total annual bird mortality. Some carcasses get removed by mammalian and avian scavengers, or are not recovered because they fall outside of the search radius (Johnson, et al, 2016; Wulff, et al, 2016; Smallwood, et al, 2010). As a recognized problem for mortality estimation, some studies have adjusted for the relative collection biases. Johnson et al (2016) understood several of the inaccuracies that need to be accounted for when comparing avian fatalities at different wind farms. They stated that the number of carcasses found is a biased estimator of the actual number of fatalities due to spatial incompleteness, temporal incompleteness, incomplete availability, and imperfect perceptibility (Johnson, et al, 2016). In lay-man's terms, the entire expanse is not usually investigated for fatalities, the searches only occur for a part of the year, scavengers remove some of the carcasses, and some carcasses are missed by the observers (Johnson, et al, 2016, Wulff, et al, 2016, Smallwood, et al, 2010, Johnson, et al, 2002).

To account for these biases there are a few recommendations given by the authors of these studies. First of all, covering the entire area rather than preforming searches on a fraction of the area on occasion may give a more accurate adjustment in the estimators currently used (Johnson, et al, 2016). Additionally, Johnson et al (2016) mentioned that the searches are temporally incomplete, only occurring six to nine months of the year, so continuing the searches for the whole year will improvement mortality estimates as well. Some of the solutions already used are to customize adjustment factors for estimator method used, search interval, and classification for carcass removal (Johnson, et al, 2016; Erickson, et al, 2014).

While there are solutions for some of the biases, it is difficult to develop more precise estimates for the removal of carcasses by scavengers. A study using scavenger removal trials recognized that previous scavenger removal trial studies may have experienced “scavenger swamping,” which means that the researchers placed too many carcasses per the area to accurately estimate the rate at which scavengers take their meals (Smallwood, et al, 2010). The resulting mortality rate estimation tool underestimates the removal rate of birds killed by turbines.

Mortality Estimation Accuracy

"It is assumed that wind farms are less harmful to birds that other energy industries or other human-made structures" (Barrios & Rodriguez, 2004), but this is largely because of the limited available knowledge on the mechanisms driving bird collision mortality (Zimmerling, et al, 2013; Masden, et al, 2009; Barrios & Rodriguez, 2007). As mentioned above, the mortality rates of birds at individual wind farms cannot be determined simply based on the number of carcasses with characteristic impact injuries found present after a period of time, a common practice. Additionally, early estimates of bird mortality from collision with wind turbines may have been grossly underestimated. Some of the earliest estimates place total annual mortality from wind turbine collisions at less than 0.1% (Stevens, et al, 2013; Lucas, et al, 2008), but more recent studies reveal that it could be as high as 0.8% when factoring habitat loss associated with wind turbines (Zimmerling, et al, 2013). This suggests that the overall mortality estimation may increase as more factors are included and models more accurately depict the influences of collision mortality.

As discussed previously, scavenger removal is only one of many issues that may influence the low mortality rate estimates. Displacement and fatigue are often left out of the equation and are difficult, and nearly impossible, factors for wind farm operators to monitor effectively. However, developing a more accurate fatality rate estimate is necessary for assessing the effectiveness of impact reduction measures, but “remain imprecise and potentially biased by common field methods” (Smallwood, et al, 2010). This practice, combined with technological modeling ingenuity, may represent an opportunity to “balance technical requirements with environmental considerations,” and refine spatial planning techniques accordingly (Langston, 2013).

Science in Technology-Based Planning Approaches

One of the key components for completing this research to is develop a tool that is easily accessible to all community members, as well as to key players in wind farm development, a tool that will suitably describe the potential for minimizing ecological impacts of wind farms while encouraging sustainable infrastructure development. Using technology to reach a greater audience aligns with the goals of the National Science Foundation (NSF), according to Nalini Nadkarni and Amy Stasch in *How broad are our broader impacts? An analysis of the National Science Foundation's Ecosystem Studies Program and the Broader Impacts requirement (2013*). This goal appears under the

Broader Impacts Creterion (BIC) with the intention to broaden the use and understanding of science and technology for enhancement of research and education, while creating benefits to society and include the participation of underrepresented groups (Nadkarni, Stash, 2013).

As researchers develop the knowledge base on the broad scope of bird mortality risk, there lies potential to develop a tool that can semi-accurately calculate the impact of wind turbines on birds to find suitable wind farm locations based on flight patterns and population density models along a temporal scale. Spatial analysis is a useful tool for visualizing the potential for wind farm siting in the Pacific Northwest while considering the reduction of bird mortality. In order to make wind farm siting a more participatory process it is important to make the tools and models easy to understand, otherwise the model is essentially useless because people cannot understand what is being proposed (Al-Kodmany, 2000). For example, in a study in the UK and Europe, Alison Johnston et al (2014) modeled flight heights of 25 seabird species from 32 sites to estimate collision rates with wind turbines for proposed offshore wind farms (OWF's). Based on the flight height ranges and different turbine designs for hub height and rotor diameter, the resulting "distribution makes it possible to consider how different turbine designs and collision risk with the rotor-swept area may affect collision rate estimates” (Johnston et al, 2014). This is a great way to assess design options in sensitive areas, but is not readily available for public education and interpretation. The result of the Johnston et al study was a matrix of graphs for each species. Visually, it is complex and difficult to understand without prior explanation of the significance of the graph matrix and the modeling process.

In a similar study, Liechti et al (2013) created a model for Switzerland through a simulation and recognizes that birds have specific spatial and temporal patterns that they follow when migrating and assert that "the best way to mitigate conflicts between birds and wind turbines is to avoid their spatial concurrence." This is one way to account for impact on birds by predicting collision potential from this model, and it resulted in a product that was more user-friendly for people outside of the field of study. However a series of assumptions underlying the model could have influenced the collision rate estimates. These assumptions included uniform flight patterns year to year with account for variation (based on species or just general pattern changes, fixed bird concentration migrating along a route, and did not consider changes in flight patterns from other construction or proximity to nearby habitat. The sole focus on migratory pattern and exclusion of roosting sites exhibits endangerment risk for unknown population damages, based on this modeling technique.

Although the Liechti et al modeling example may provide a sufficient conflict mitigation solutions, the result is not readily accessible to the general population because it requires a deeper understanding of the modeling process and its limitations in order to understand the output. Al-Kodmany (2000) explains that GIS offers "a way to provide all participants with full access to a large amount of spatial data in the form of easily digestible, non-threatening graphics and maps." Using GIS provides the opportunity to create an interactive tool that will allow a broad audience to understand why some locations should be selected as potential wind farm sites, while others are not ideal, without requiring the viewer to understand the process of building the geodatabase and the resulting maps.

Methods

Goal/ Products

The overall goal of this study was to create an easy to understand tool that can be used by a broad audience to site/understand the siting of potential wind farms in the Pacific Northwest for new wind farms that do not interfere with open water areas and the Important Bird Areas (IBA's) that have been established by the National Audubon Society. To accomplish this, I prioritized agricultural lands to promote a multipurpose landscape, while avoiding the IBA's. The end product will include a preliminary map series created in ArcMap.

Data Collection & Resources

As indicated, the data used in this study came from existing resources, The United States Geographic Survey (USGS) which provides GIS point data for all of the existing turbines in the United States. Land use data tends to come in a variety of forms, but the most reliable is raster data. A raster file consists of a matrix of pixels that are organized in to a grid, where each pixel represents information (ESRI, 2008). In this case, the information represents land use types. The National Land Cover Land Use data for 2014 is the most recent raster data available. Accompanying the raster in a separate file is a table that contains the necessary metadata used during the manipulation process. Lastly, the bird habitat data came from the National Audubon Society's Important Bird Area polygon data. This data shows important nesting, feeding, and resting habitat for local and migratory bird species.

Data Manipulation: ArcGIS Desktop

Gathering together the various data sets acted as a starting point, but several steps were required before the desired result emerged. After downloading the data into a geodatabase I first reduced the data to the study area (Washington, Oregon, Montana, and Idaho or the Pacific Northwest) to make them more manageable. Following the reduction, I created wind farm polygons based on the wind turbine point data and added a buffer around the IBA's of 500 meters. This distance was selected based on a series of studies that found evidence suggesting bird displacement from habitat areas between 100 and 800 meters (Steven, et al., 2013; Langston, 2013; Kuvlesky, et al., 2007). The majority of these studies stated that the greatest distance for displacement is 500 meters, so I chose this number as the buffer distance; there was little support in the literature for the 800 meter distance.

The raster file required the greatest amount of manipulation to be used for my study. The initial raster file contained data for the entire United States, so the first step was to reduce the file to my study area to make it easier to manipulate. I used the Raster Clip analysis tool to limit it to the general area of the PNW. To read the raster file there is a key available on USGS website in the same location as the raster file download. I put the key into excel and turned it into a flat file so that I could use it to designate land use types. To connect to the two files I "joined" them by classification number.

Next, I created additional layers to narrow down possible wind farm locations. One of my goals was to suggest multipurpose landscapes. By selecting the agricultural and pasture/hay classifications I created a new layer that removed all other ineligible land types. To further reduce this file, I created a second new layer of all the open water and placed a second buffer around it to protect riparian corridors as a sensitive, protected area. Finally, I eliminated the polygons that intersected with the IBA buffer, the open water buffer, and the existing wind farm polygon set. The end result was several polygons considered eligible for wind farm placement by the standards I had set for this study.

With a file that could now be analyzed, I aggregated the polygons to reduce the number of borders present and performed a near analysis. A near analysis creates the final new layer file that had to be developed prior to creating the map series. In this final file, I reclassified the symbology to reflect the following site quality levels:

- High- agricultural lands, farthest from IBA's or greater than 4000 m (meters) away,
- Moderate- agricultural lands or minimally developed lands, Relatively far from IBA's or between 2000 m and 4000 m away, and
- Low- agricultural lands or minimally developed lands, close to IBA's less than 2000 m away.

Maps

This chapter displays some of the map products that may be available by using my completed geodatabase as a resources for finding and developing new wind farms with ecological consciousness. The legend given on this page is applicable to all of the maps in this section. There are two copies of all of the land classification maps, with and without the IBA's, followed by close up images of the intersections of existing wind farms with the IBA's. This map set includes full scale images of the Pacific Northwest Available Lands, followed by close up image of each state in this order: Washington, Oregon, Idaho, and Montana. The intersection maps follow the same order.

In the upper left corner of each map is a scale equation so that the viewer can develop a spatial understanding of the land classifications, IBA's, and Wind farm/IBA intersection points. The north end of the each map is oriented in the same direction of the title with the map description at the south end.

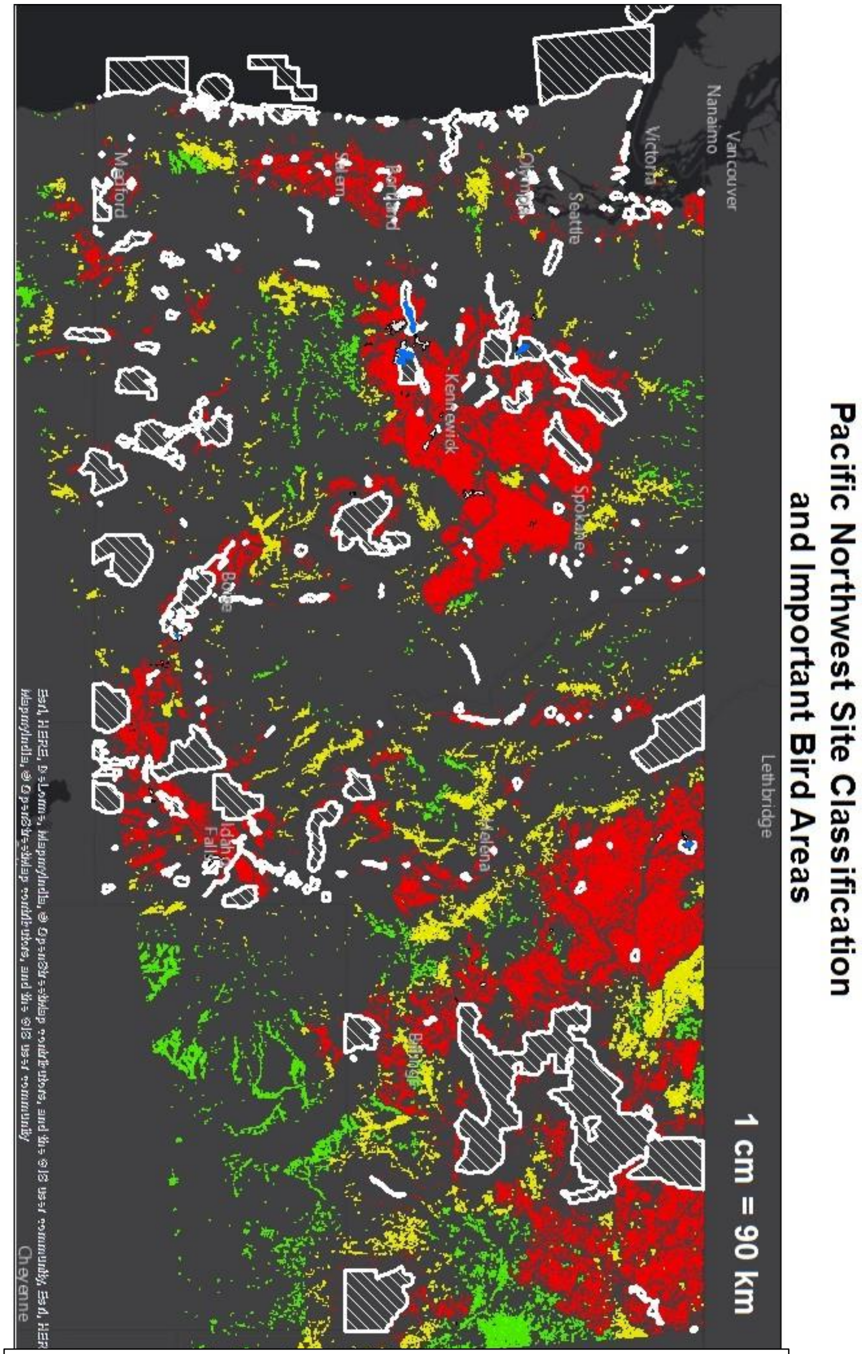


Figure 5: Available land for the entire study area for wind farm siting with classifications for poor, intermediate, and good locations with the Important Bird Areas for

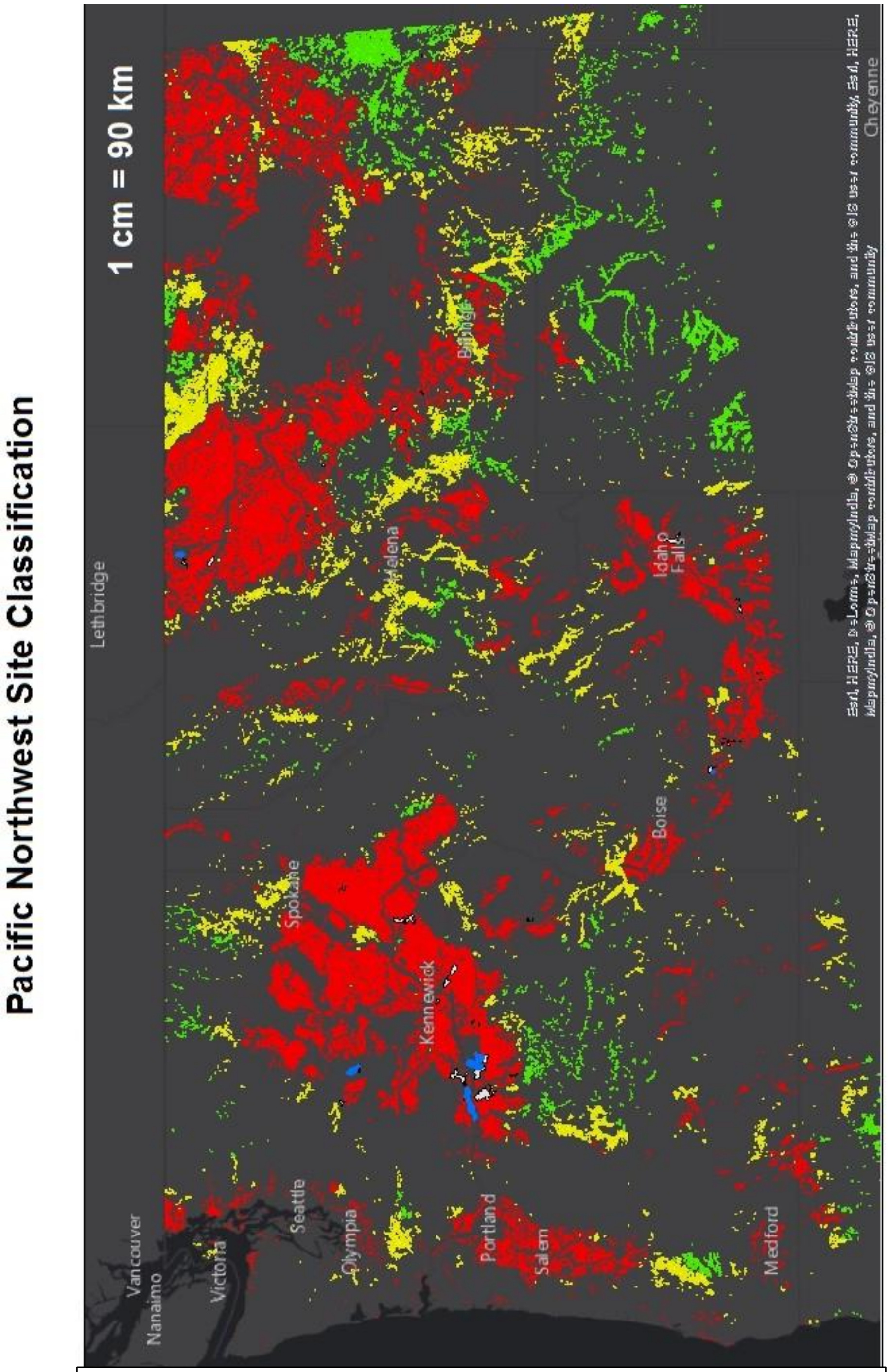


Figure 6: Available land for the entire study area for wind farm siting with classifications for poor, intermediate, and good location without Important Bird Areas.

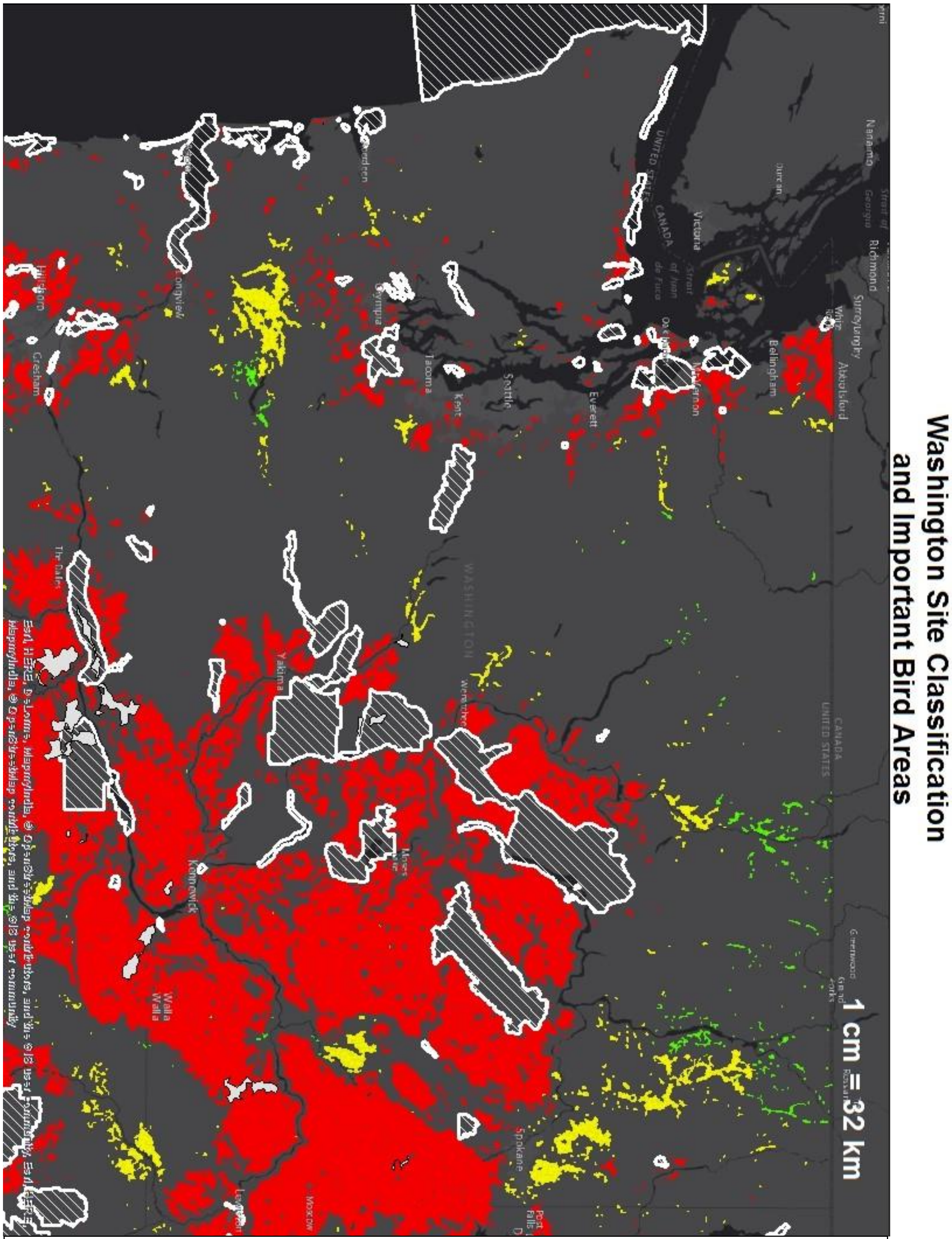


Figure 7: Available land classifications for Washington State with Important Bird Areas for comparison.

Washington Site Classification

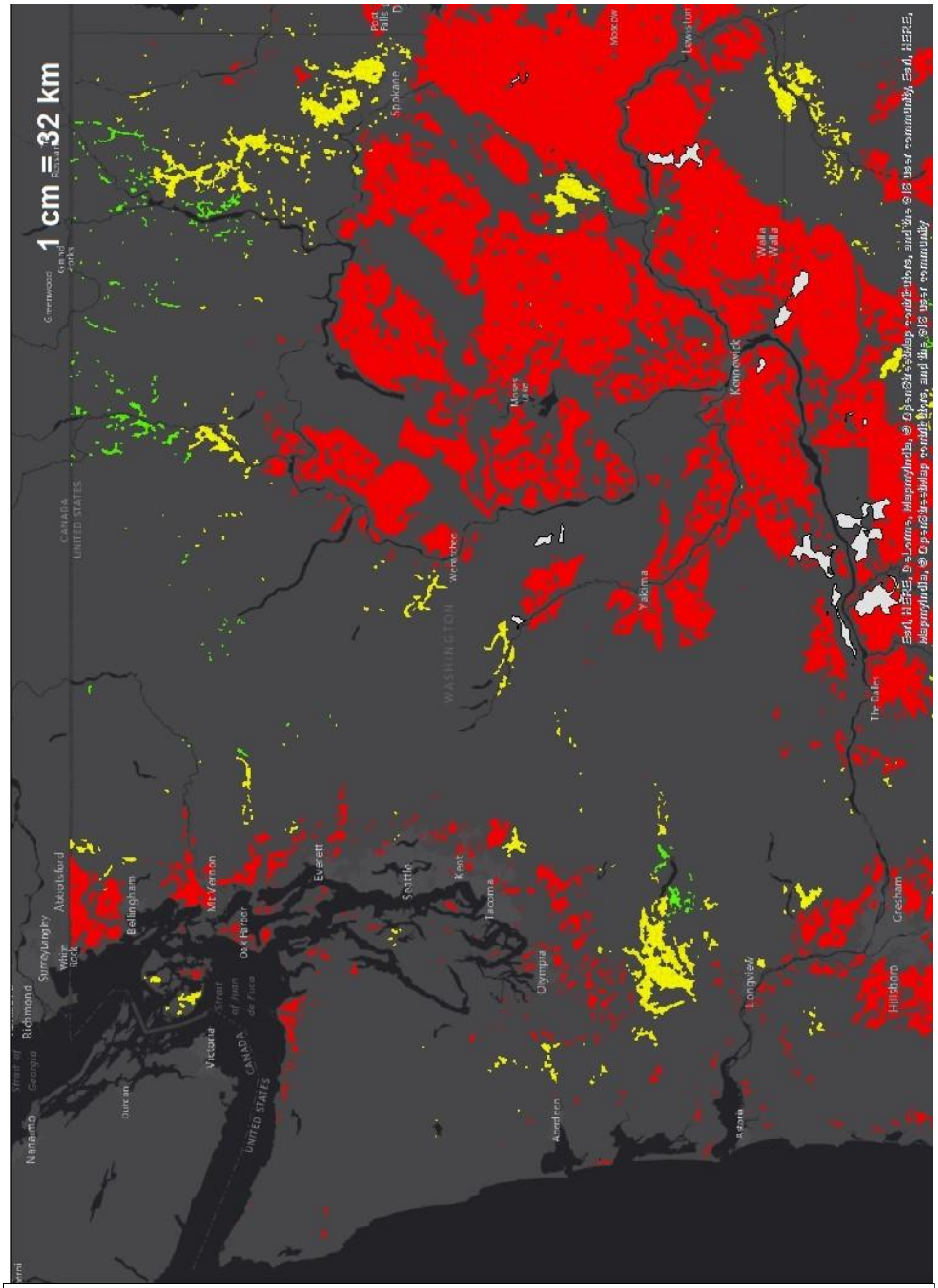


Figure 8: Available land classification for Washington State without Important Bird Areas.

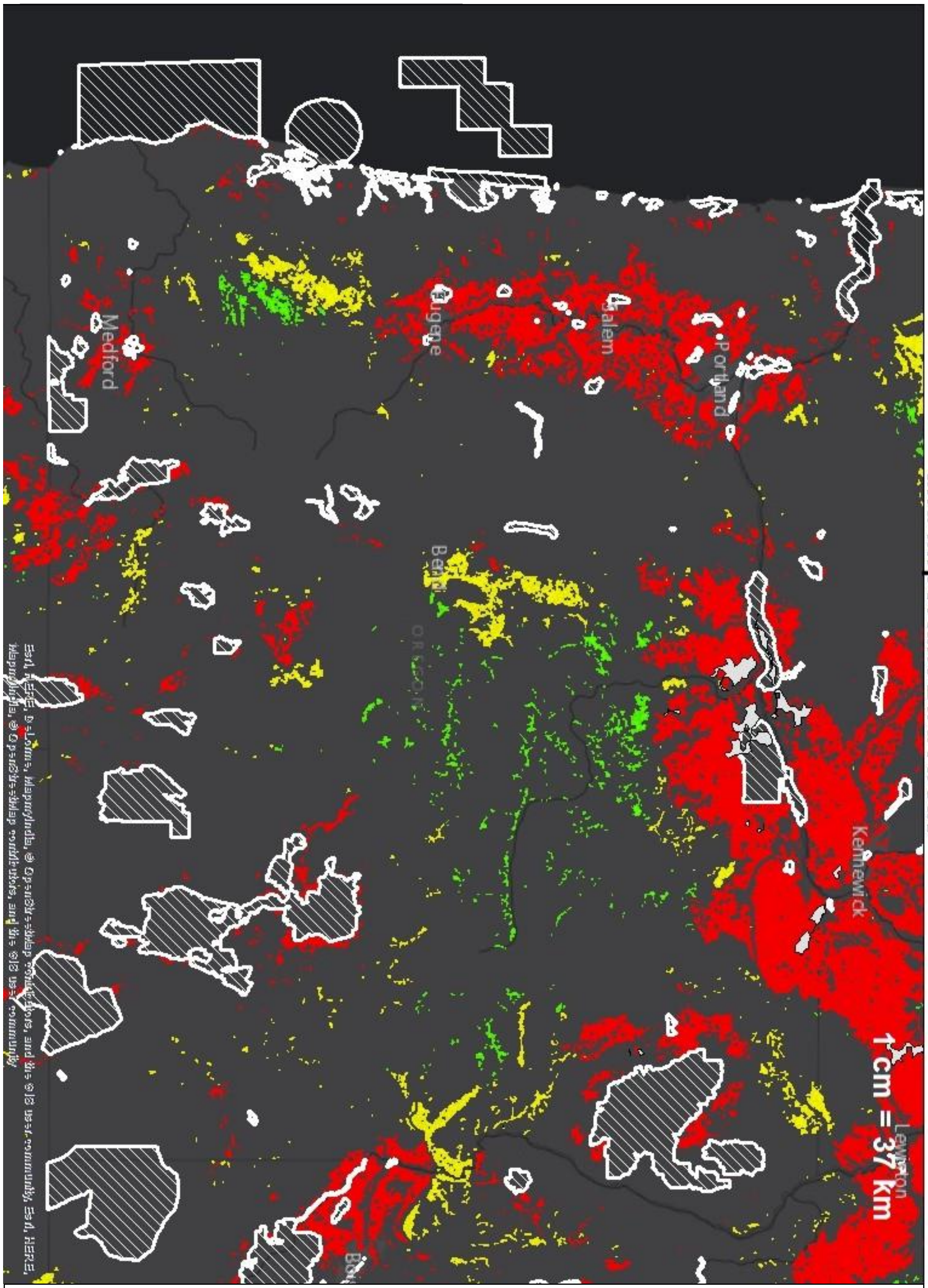
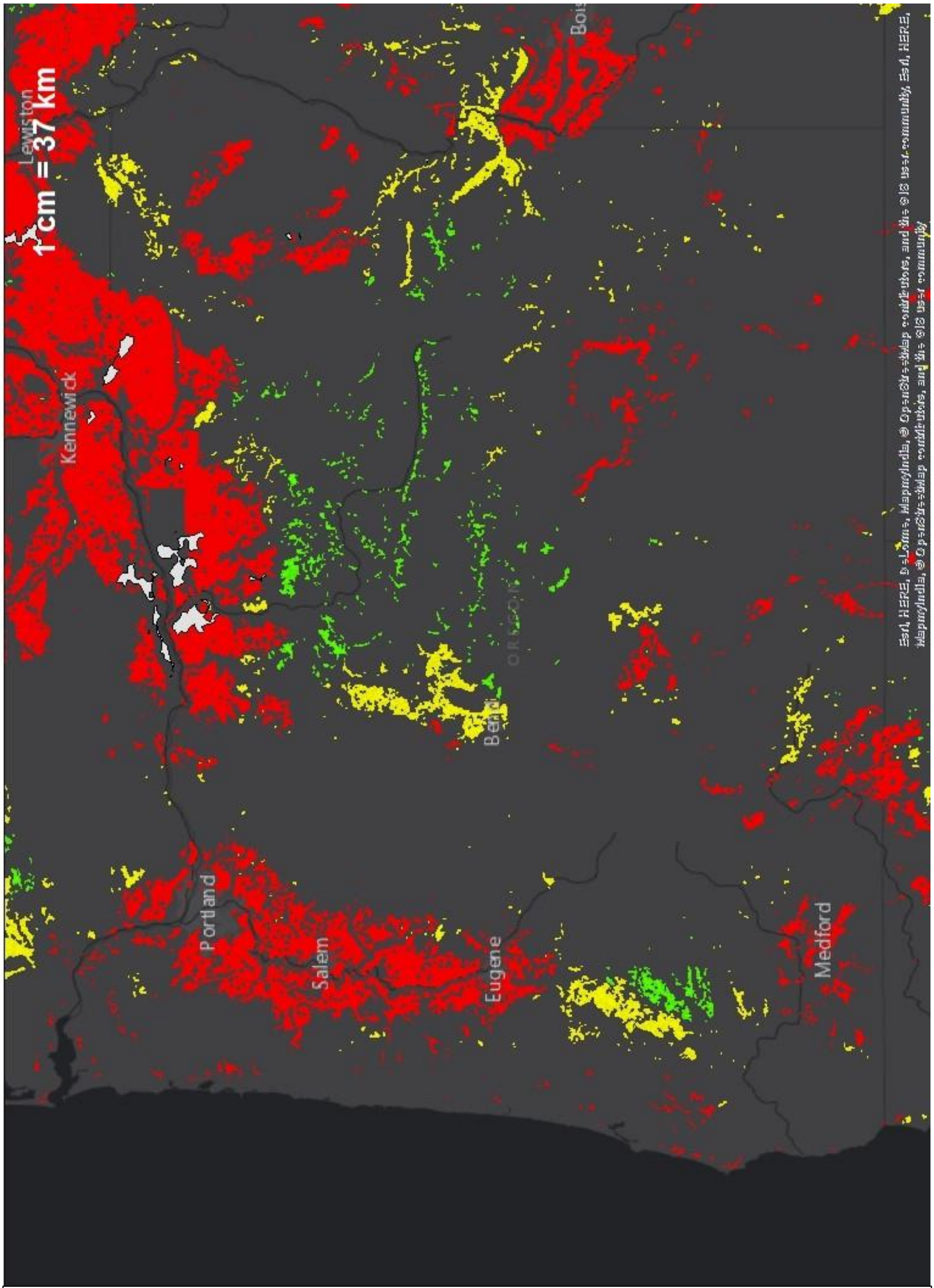


Figure 9: Available land classifications for Oregon States with Important Bird Areas for comparison.



Oregon Site Classification

Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community, Esri, HERE, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Figure 10: Available land classifications for Oregon State without Important Bird Areas.

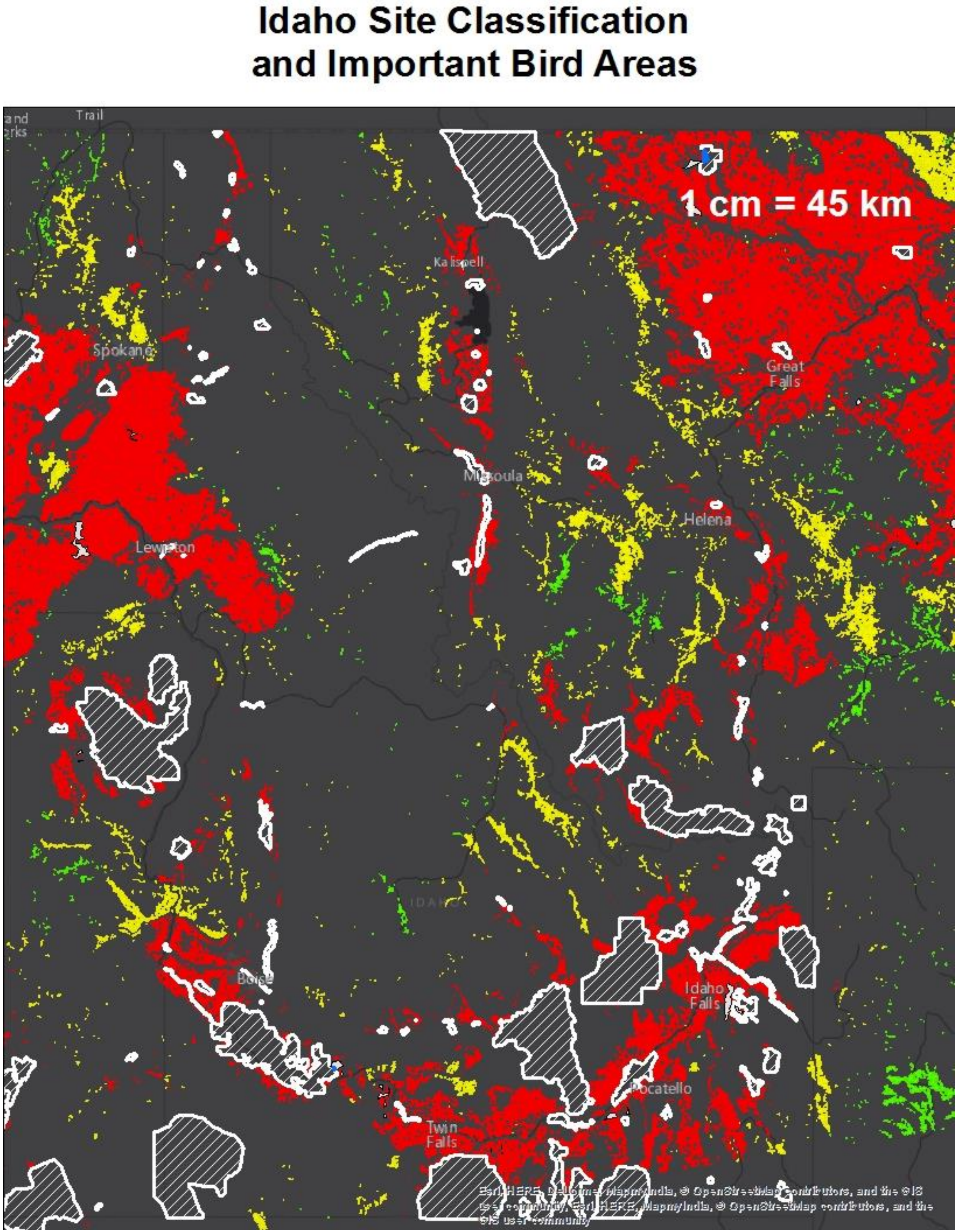
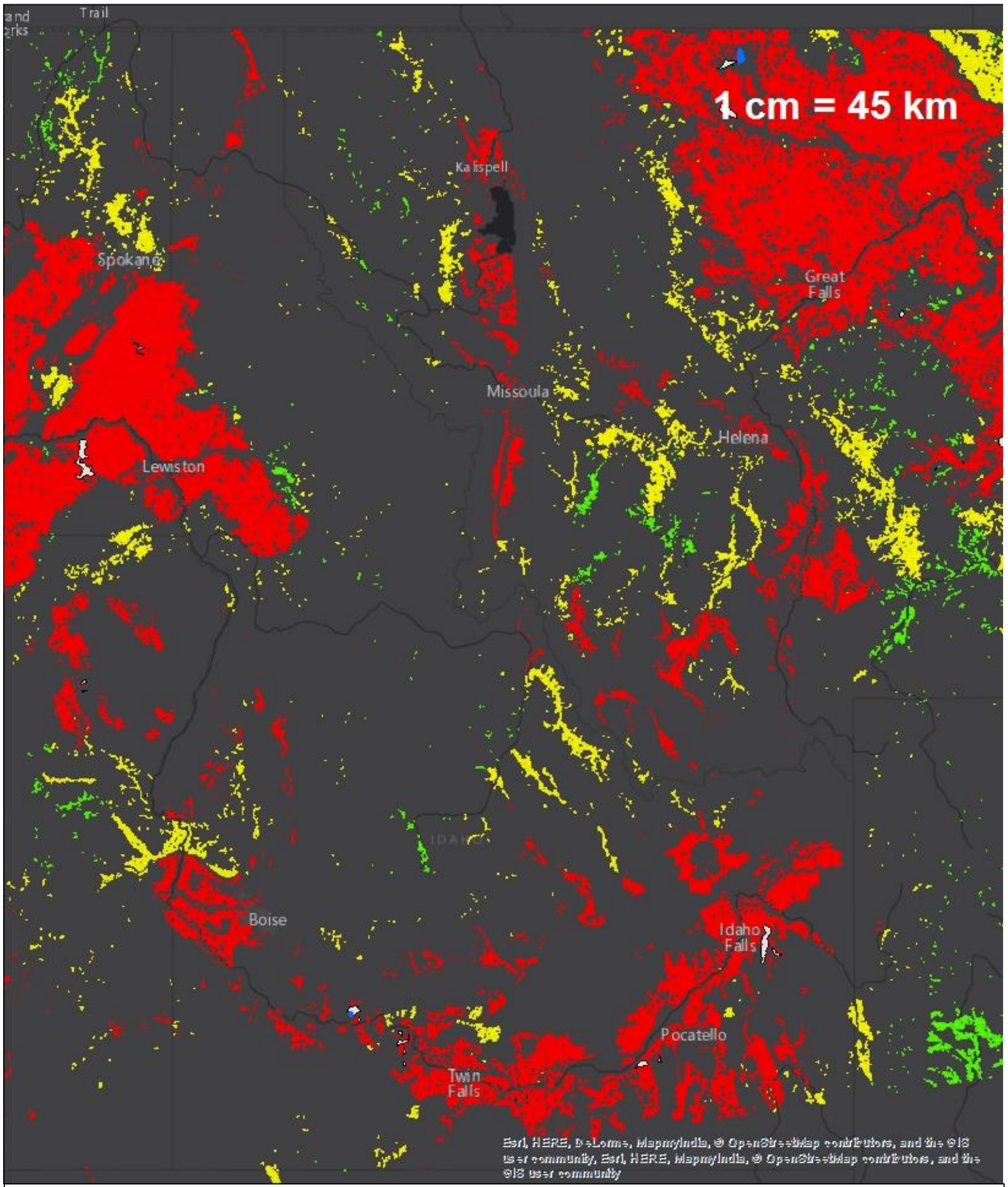


Figure 11: Available land classifications for Idaho State with Important Bird Areas for comparison.

Idaho Site Classification



Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community, Esri, HERE, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

Figure 12: Available land classifications for Idaho State without Important Bird Areas.

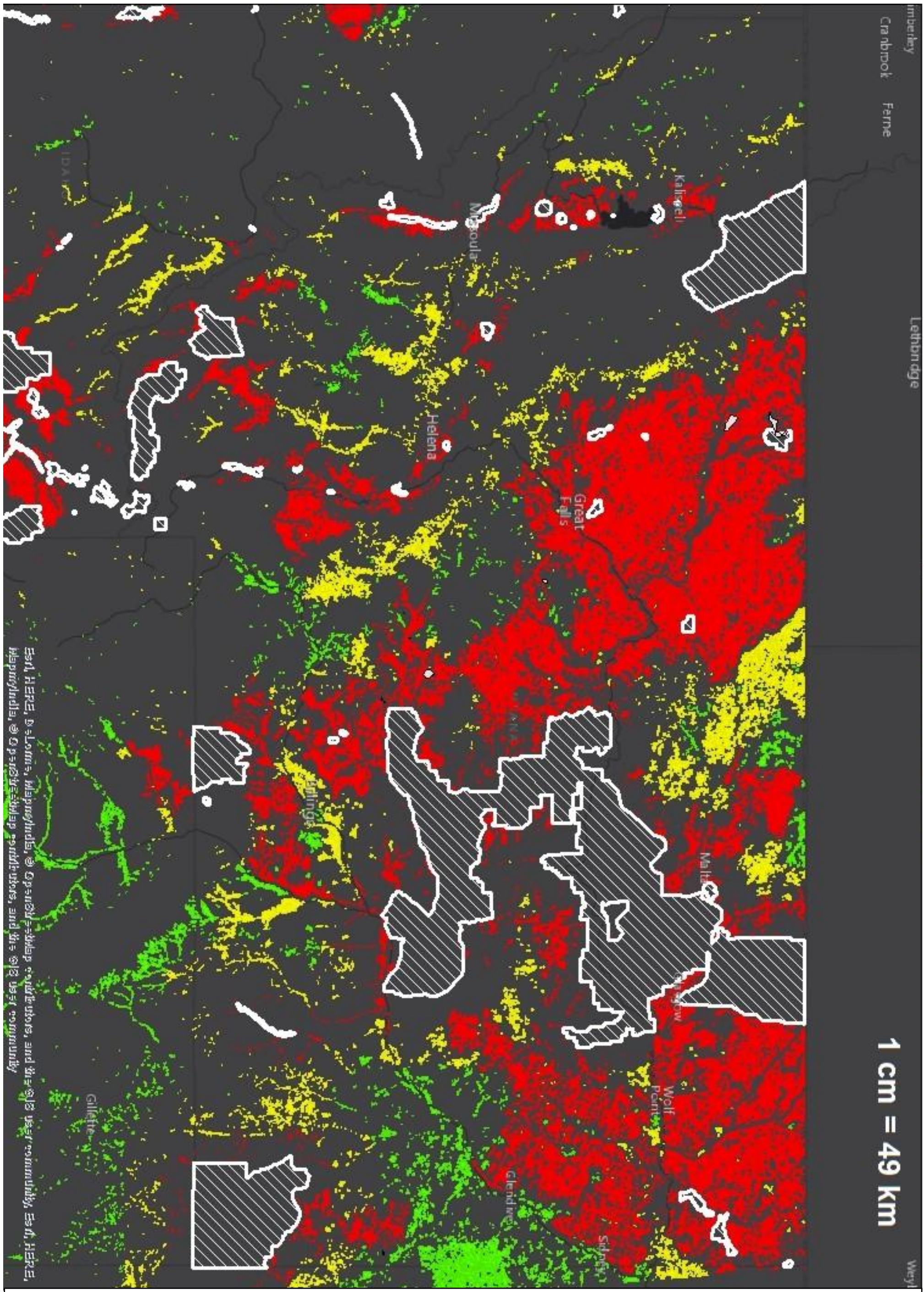


Figure 13: Available land classifications for Montana State with Important Bird Areas for comparison.

Montana Site Classification

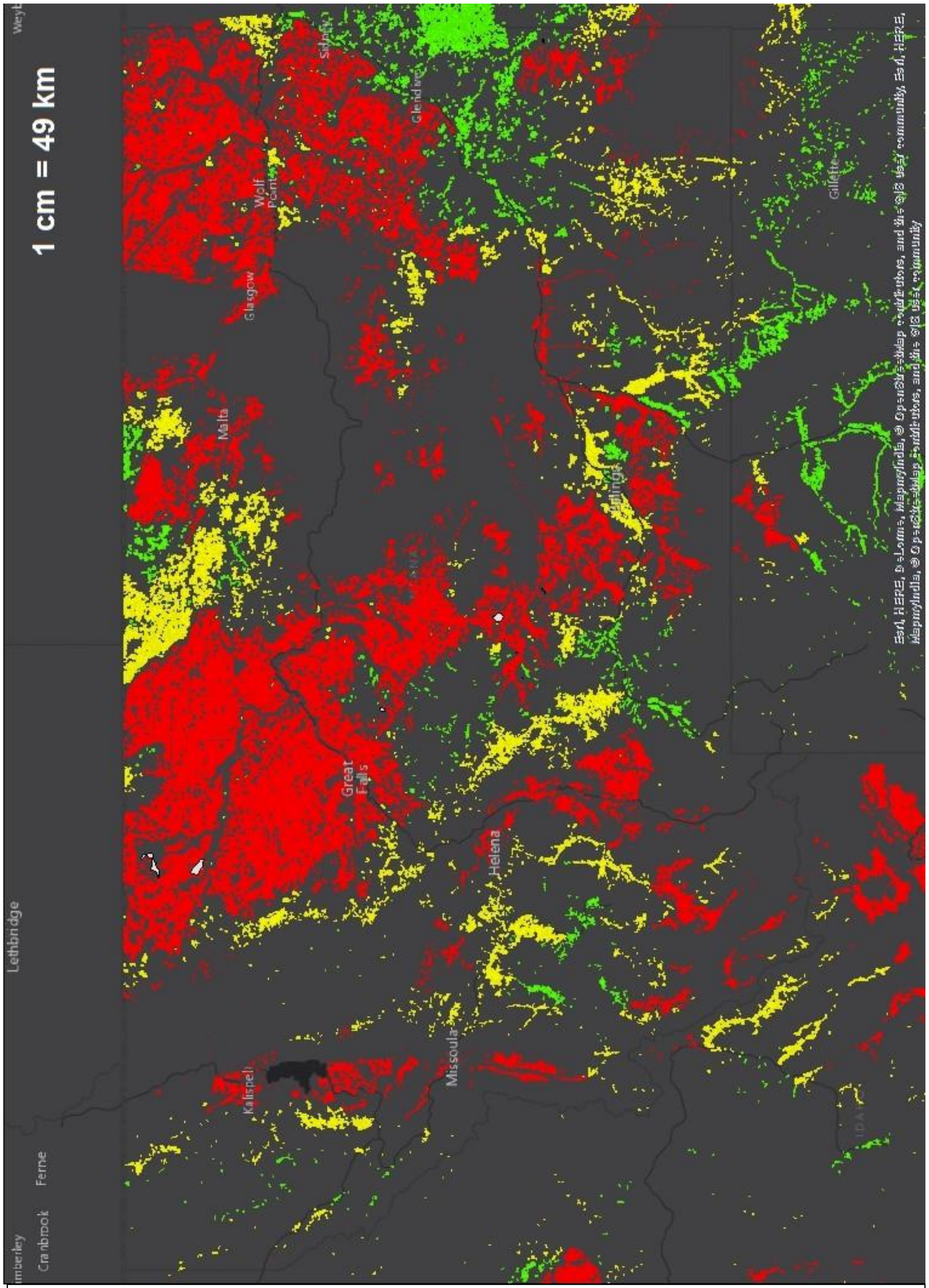


Figure 14: Available land classifications for Montana State without Important Bird Areas.

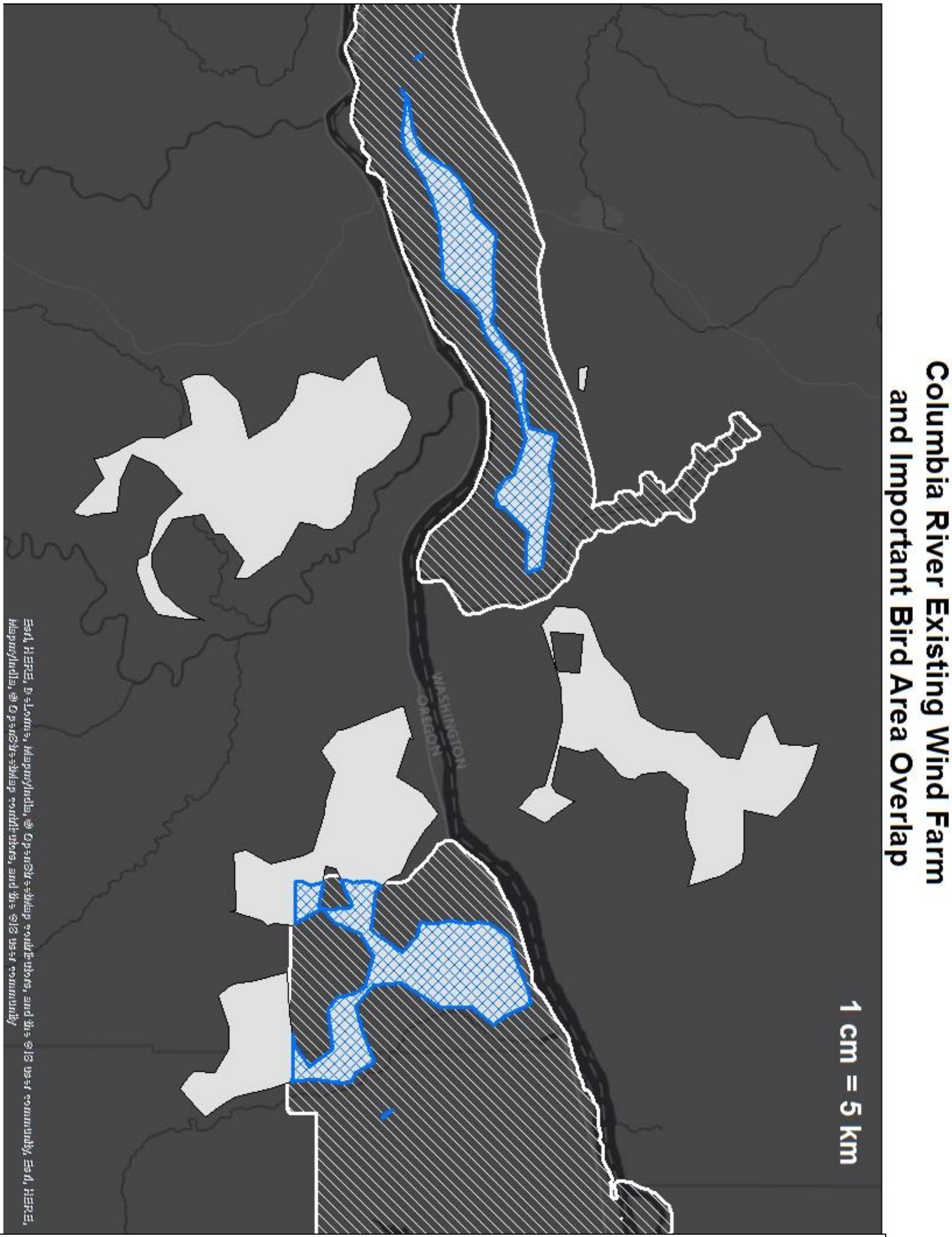


Figure 15: Columbia River Scenic Area along the border of Washington and Oregon States. Overlap of existing wind farms with Important Bird Areas.

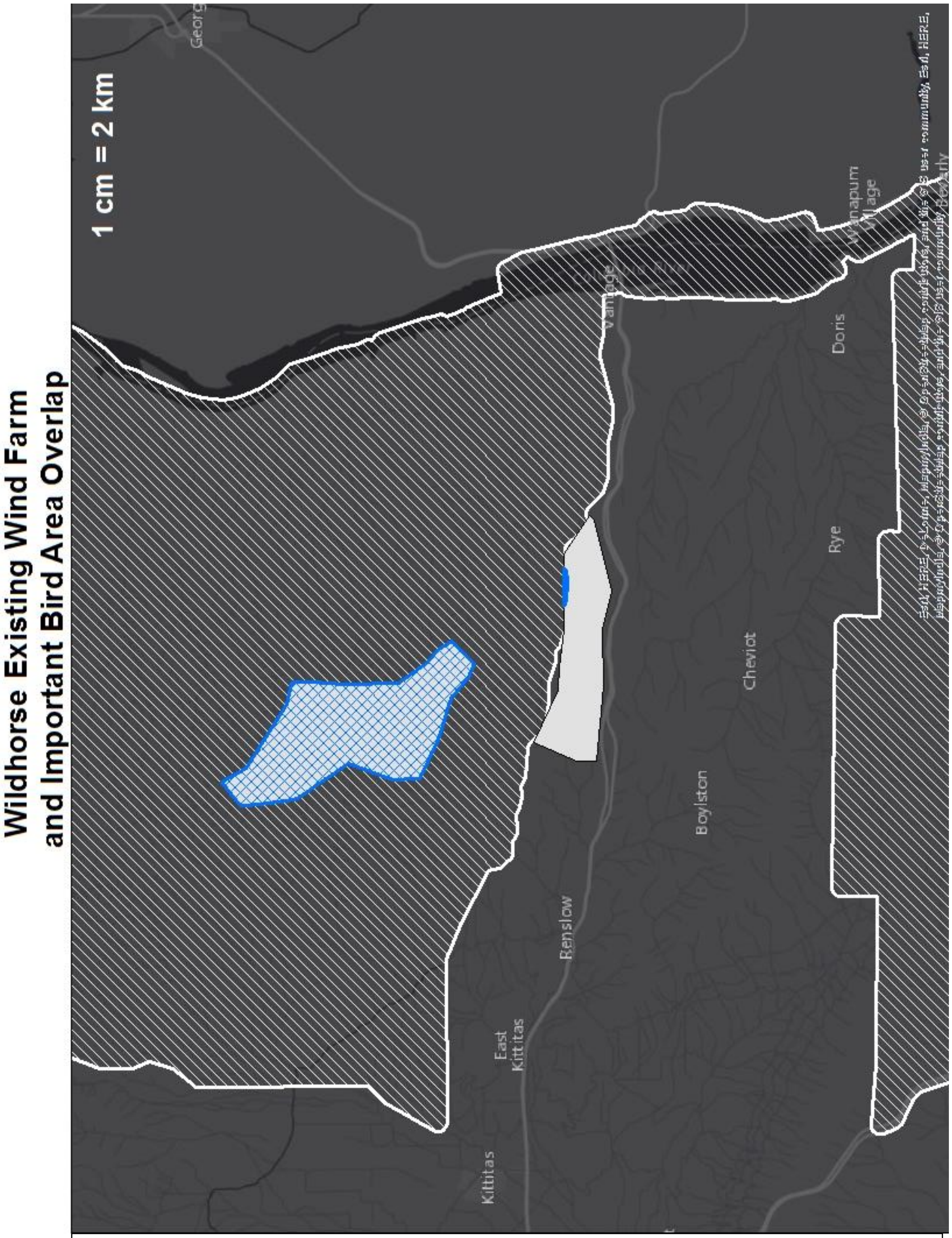


Figure 16: Wildhorse wind farm in Washington State overlap with Important Bird Area.

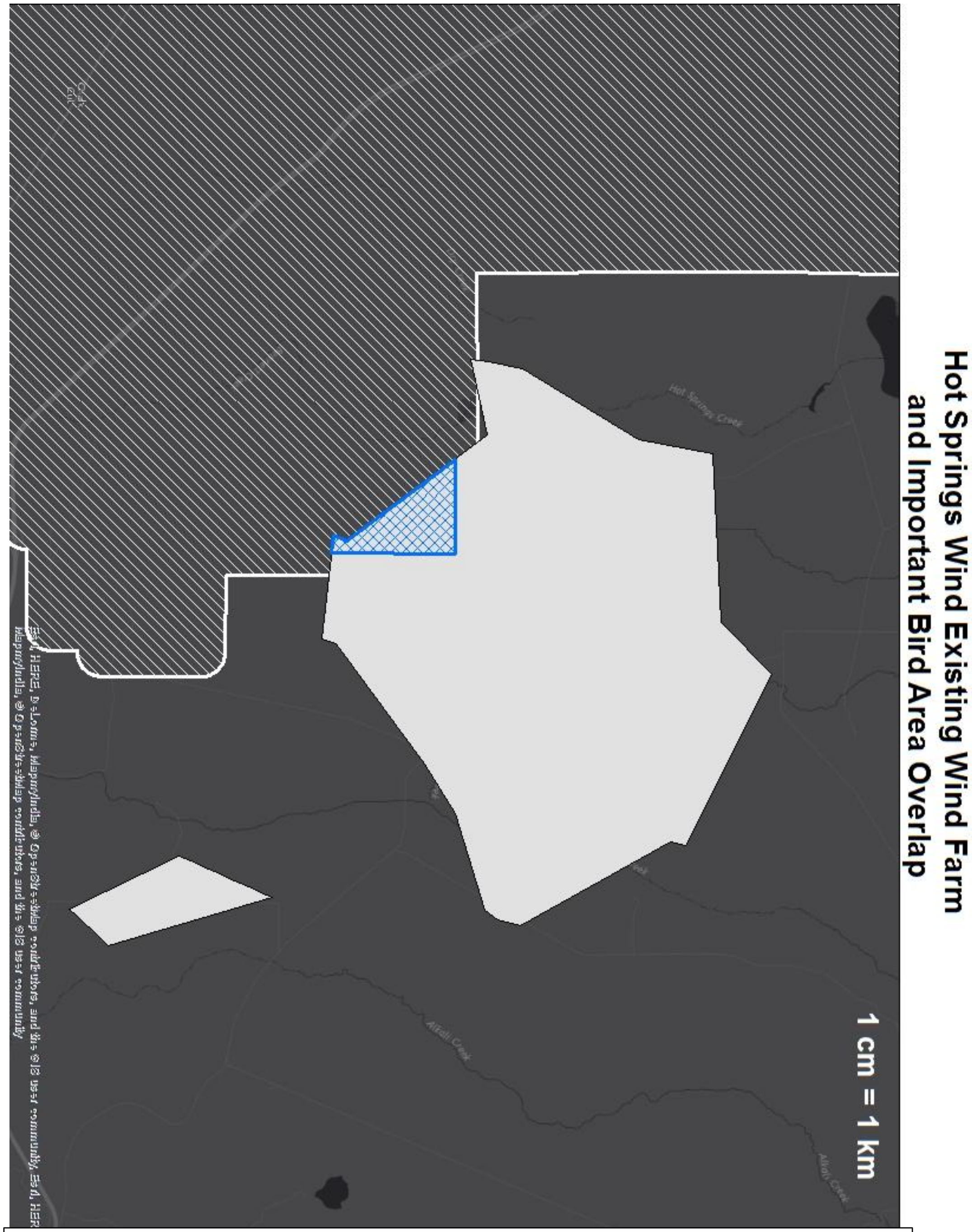


Figure 17: Hot Springs Wind wind farm overlap with Important Bird Areas in Idaho.

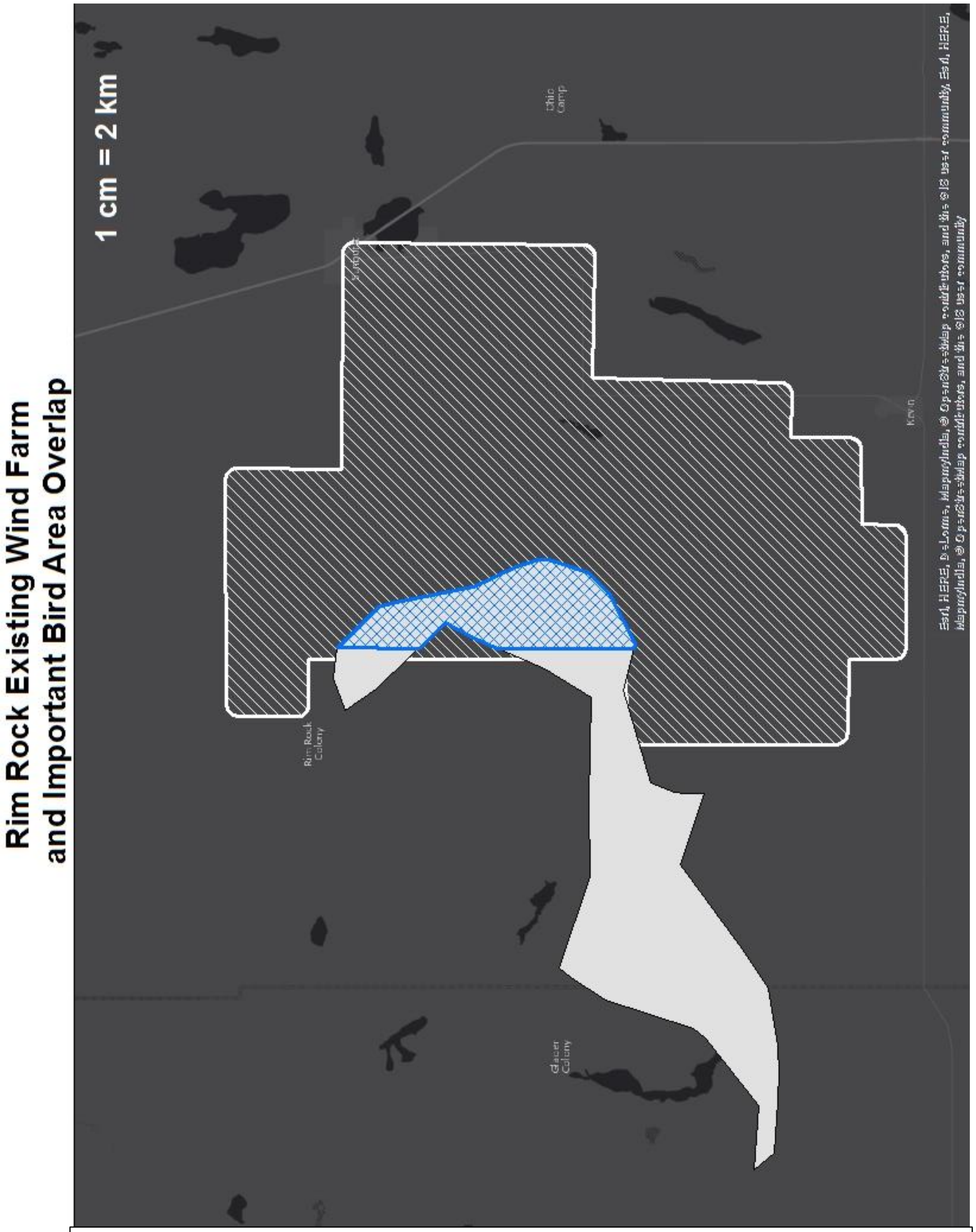


Figure 18: Rim Rock wind farm overlap with Important Bird Areas in Montana.

Results

Existing Windfarm Sites

In the PNW existing windfarms cover 1,398 square kilometers (km^2) of the landscape, with 446 km^2 in conflict with the IBA's. This is about 32% of the windfarms presently in operation, conflicting with 0.2% of the National Audubon Society's IBA's. The areas of conflict are primarily located along the Washington/Oregon border with single instances in Mid-Washington, Northern Montana, and South-western Idaho (Figures 15-18). The names of the conflicting sites are the Windy Point/Windy Flats in the Columbia Hills, Shepards Flat North in the Boardman Grasslands, Wild Horse in the Quilomene-Colockum Wildlife Area, Rim Rock at Kevin Rim, and Hammet Hill Wind/Hot Springs Wind in the Snake River Birds of Prey NCA/CJ Strike Reservoir.

Potential Windfarm Sites.

The total area available for multipurpose landscape potential is 171,872 km^2. This total area is divided into the three class described in the methods chapter.

Area per Quality Classification Type

Quality	Poor	Intermediate	Good
Area (kmsq)	143,514	14,916	13,442

Table 1: Area available for each of the classification types developed.

The majority of the available land area falls into the “Poor” category, since it is close to an IBA. The smallest amount of land is “Good” for wind farm development, based on the standards of this study.

At a distance it appears some of the potential sites should not be accounted for as "Poor" quality. For example, Figure 5, does not contain detail seen in the close-up maps of the individual states. In Washington, it appears from a distance that no IBA's should cause the large amount of "Poor" quality land. Upon closer examination, however, IBA's appear. In the following map, Figure 19, the large map shows Washington and the circle identifies a location that cannot be seen clearly from the full view distance.

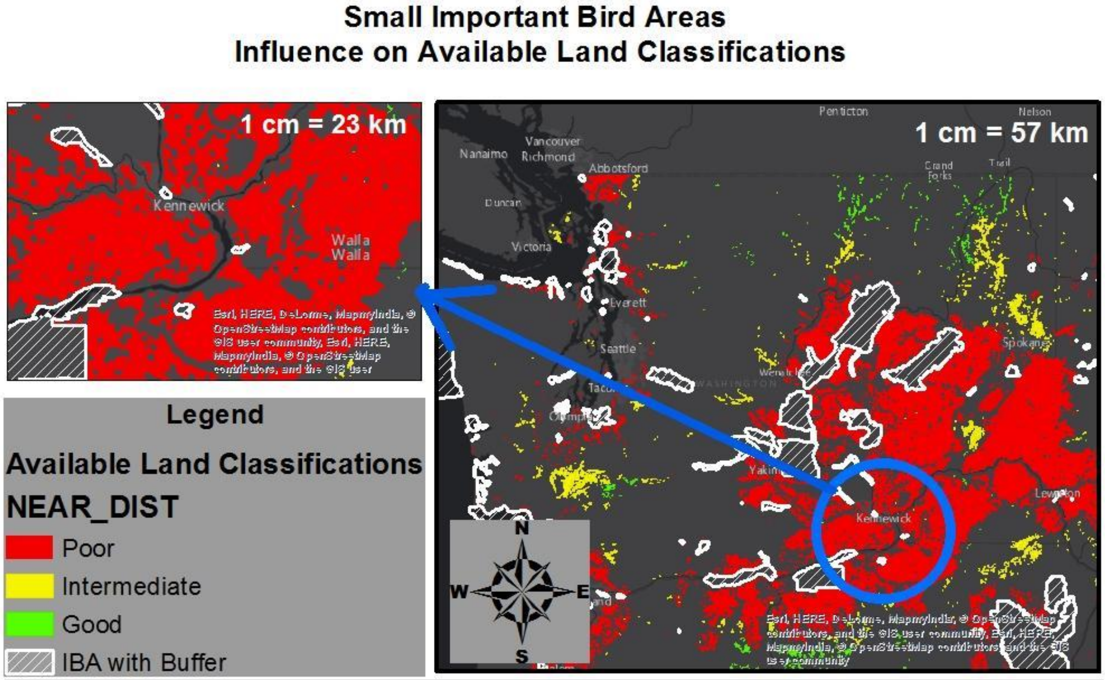


Figure 19: Example of a location where closer images are important for seeing the details that caused the resulting classification of the available land for future wind farm development. Location is found in Mid-Washington.

The smaller image is a close-up view of the location that shows the amount of detail missed in the larger images. This view shows that there are, in fact, IBA's, influencing the classification.

On a similar note, the more area a map covers, the less defined the border of the available lands. It can give a sense of continuity where there is none. In the example below, Figure 20, the circled area in the Oregon view appears to have a contiguous line of “good” available land for wind farm development. However, when zoomed to the same area at a 1cm to 8 km scale, we can see that there are several small polygons instead of a few contiguous polygons.

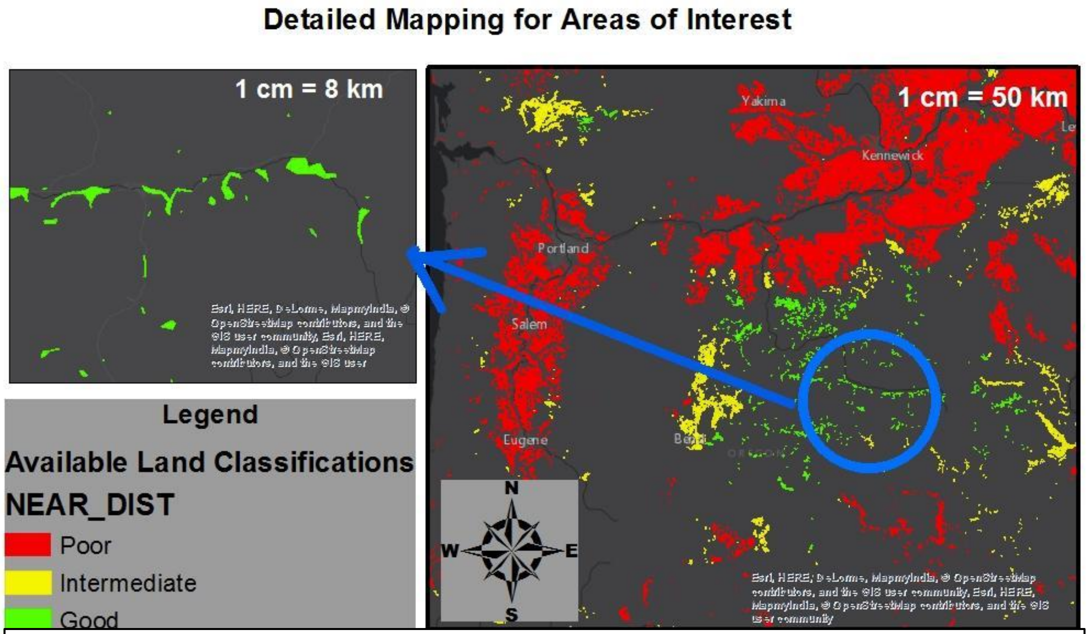


Figure 20: Example of a location where connecting polygons are deceiving at a distance and a zoomed in map reveals greater boarder details.

Discussion

The mapping tool proposed in this study takes several concerns regarding ecological impacts in to consideration; that the ecological impact of future wind farm development may be reduced if this map product is used when making siting decisions. By taking the precaution to not only exclude IBA's, but to include an excluded buffer zone around them, I have narrowed down the potential sites as much as possible to protect birds from heightened mortality risk using currently available knowledge. As a result, the majority of the potential sites fall within the "Poor" classification. This also indicates that there are many important habitat sites for birds within or near agricultural and pasture/hay land types.

Fortunately, there are several square kilometers of available land within the "Good" and "Fair" classifications. Pursue wind farm development in the "Good" polygons, would increase the total land area in the PNW for wind energy by 961% versus the current area used. This would not require use of undeveloped lands; this number solely reflects the amount of farmland that may be available for multipurpose use. Despite the fact that there is plenty of land available in a multipurpose landscape without interfering with the IBA's, there were a few instances where the existing farms overlap with an IBA (See Figures 11-14).

Based on the evidence from the literature, we can assume that some level of displacement of local and migratory species occurs within the sites where existing wind farms and IBA's conflict. These IBA’s are important to pay attention to when using the maps, because they should be avoided whenever possible to prevent total displacement of the local species. This is part of the reason we need to establish multipurpose landscapes whenever possible and must do so as far away from important habitat zones as possible. Creating buffers allows some leniency for placing wind farms near IBA's, but the "Poor" quality of the close potential locations signals caution when evaluating those sites.

Limitations

Despite the classification into which each polygon is placed, it should not be excluded from investigation for wind farm siting. Errors that can be expected when using GIS that can influence the results. In this study I needed to simplify the data by aggregating the polygons, because the data was too dense to classify. As a result, the polygons are much larger than they were initially. There may be parts of the "Poor" classification that may be the same quality as the "Intermediate" classification, but is not shown at that level since it was a part of a contiguous polygon in the "Poor" quality classification. In the end, the size of the polygons could affect the classifications.

However, this is not always true. As displayed in the results section (Figure 15), some of the IBA’s are very small and ill-defined at a distance, which makes them difficult to identify. Using the zoom function in the GIS program is important for understanding why some of the expansive “Poor” zones are so large where is seems there should be more “Intermediate” and “Good” zones.

A similar concept applies to understanding the expanse of individual polygons. Figure 16 shows how a map at a greater scale may provide deceiving information on the continuity of the available lands polygons. Where they appear to be connected, they are actually several smaller polygons in a concentrated area. Therefore, depending on the use of the map products, the user may need to have closer images for the maps to be effective.

While this map series can provide valuable information on the potential locations for placing wind farms, there were a number of other limitations involved with completing this study. First of all, these maps were produced strictly based on raster data relationships. The study has not incorporated data or maps for wind speed, flight behaviors of the local avifauna, or individual state regulations. Additionally, the map scale for the printed series will not be suitable for planning site assessments because the detail is not refined enough to find the border. Solutions to these problems will be discussed in the following section.

User Recommendations

After completing the study I have developed a few user recommendations for this map series so that the best, most informed wind farm placement decisions can be made. First and foremost, these maps should always be used as a preliminary resource for beginning a wind farm siting assessment. This spatial analysis will be most effective for reducing impact of wind farm development on the bird community when combined with other spatial analysis on flight and feeding behaviors. Additionally, the user should measure wind speed and complete any other siting regulations before selecting a site for development.

It is possible to create a printed map series using the same tools presented in this study, however since there is so much detail to the data it is better to use the map product on the ArcGIS software. By doing so, the user can zoom in further on a location if they are interested in pursuing it as a wind farm location.

Conclusion

Future Research

Continuing to develop the available knowledge on wind turbine impacts on birds is key to improving the available resources for siting wind farms in an ecologically sensitive manor. One of the major research gaps that will be important for understanding the impact of wind farms on birds, is the cumulative impact of wind farms along individual corridors and within individual regions. As discussed in the study of the North Sea Migratory Corridor, the cumulative impact of the wind farms along the corridor likely causes greater impact on bird mortality than the individual wind farm estimates can predict (Brabant, et al, 2015). If we understand the cumulative impacts of wind farms in the PNW, then we can more deeply understand the risks associated with bird mortality as a result of wind turbine collisions.

Another major knowledge gap is on fatigue resulting from avoidance behaviors. As discussed in the Literature Review "Fatigue" section, there is very little research specifically focusing on how fatigue from avoiding wind turbines specifically can impact bird populations. While we know that extra expenditures of energy can damage otherwise healthy birds, there are other dynamics at play when looking at the situation with a wind farm in the mix. Since wind farms can and have displaced bird species from their now unsuitable habitat, food, water, and nesting resources are reduced significantly (Kuvlesky, et al, 2007; Langston, et al, 2013; Steven, et al, 2013). With little knowledge on the subject there is no way of knowing what the population impacts are, so exploring it will provide the opportunity to develop more accurate mortality estimates for existing and future wind farms. Once we know what the impacts of fatigue are more precisely, the depth of the buffer used for the mapping process may need to be adjusted to reduce the impact of fatigue on the local and migratory bird species throughout the PNW.

Lastly, developing a spatial flight pattern analysis for birds in regions of the United States where there are existing or proposed wind farms is one way to improving available data. Liechti et al (2013) developed a 3-dimensional model for the flight behaviors of birds along their migratory routes in Sweden. The key aspect that the study in Sweden addresses, but this study does not, is the third dimensional space. Without considering the patterns of the PNW bird species, we cannot fully understand the impact of wind turbines along migratory corridors or between IBAs. Creating a similar spatial flight pattern analysis will give the map product greater depth and will better define the best areas for new wind farm development.

Final Remarks

Understanding the ecological impacts of the technology we develop is one of the most important things we can do as develop sustainable options for energy resources. Birds are particularly susceptible to wind farm development because they are predisposed to heightened mortality risk. While the current mortality impact is estimated very low, the number is only based on carcass removal surveys at individual wind farms. There are several other factors that need to be considered when discussing the impact of wind turbines on bird mortality, including the collective impact of wind farms along corridors or regions, displacement, fatigue.

Since we are aware of these problems it is entirely within our power to preemptively strike and a take an active stance on minimizing these problems, while encouraging continued renewable energy resource development. Avoiding key habitat areas, such as key nesting sites and locations with high bird population densities, and protected lands will be the best way to start dealing with ecological impacts of wind farms while promoting the development of renewable energy resources. To successfully do this we must plan sufficiently based on the available knowledge about local birds species.

This study acts as a starting point for successfully planning wind farms in an ecologically conscious manor. By avoiding establish important habitat (IBA's), riparian areas, and undeveloped land for the development of wind farms the PNW now has some direction for developing the local wind industry. However, as stated previously, this study is a starting point and is not meant to be used without additional spatial understanding. Performing a flight behavior analysis for local birds, as was completed in Sweden, for the identified potential wind farm and using it in tandem with the map series is highly recommended, because it will help provide more accurate information about where the birds are the most vulnerable so that we can avoid those locations.

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