Alternative Energy Development and the Future of Eurasian Brown Bears in Croatia

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Submitted for the MSc in Conservation Science

Declaration of Own Work:

I declare that this thesis, "Alternative Energy Development and the Future of Eurasian Brown Bears in Croatia" is entirely my own work, and that where material could be credited as the work of others, it is fully cited and referenced, with appropriate acknowledgement provided.

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List of Acronyms

EU	European Union
NREAP	National Renewable Energy Action Plan
IPCC	Intergovernmental Panel on Climate Change
EWEA	European Wind Energy Association
PA	Protected Area
LCL	Large Carnivore Lab
GWh	Gigawatt-hour
GPS	Global Positioning System
GSM	Global System for Mobile communication
VHF	Very High Frequency
SDM	Species Distribution Model
PCA	Principal Component Analysis
PCC	Pearson Correlation Coefficient
AUC	Area Under the Curve

Abstract

In the hopes of surpassing the European Union's 2020 renewable energy protocol, Croatia plans to introduce nearly 700 wind turbines to their energy grid in the next five years. As required by law, the State Institute for Nature Protection must review all applications for wind farms and deem whether they pose significant risk to protected areas and species. In the absence of literature examining the direct impact of wind farm development on large carnivores, the State Institute is operating under the precautionary principle, and thus, to assist in the review process, I have modeled the probability of denning sites around the country for Eurasian brown bears (Ursus arctos), a protected species. With 53 dens used between 1982-2011 by at least 18 known individual bears, I used the presence-only distribution modeling software Maxent in order to illustrate highly valued denning habitat around Croatia. I found ruggedness and elevation to be the most important habitat variables, with both metrics relating positively to den presence probability. Conversely, the variables indicative of human development were one of the least important in predicting den presence. When overlaid with proposed wind farm sites, only 41 individual turbines were within 10km of a cell containing at least 90% probability of den presence. Furthermore, of the proposed farms to be located within the species' permanent range, the average probability of den presence within 10km of a farm was only 16%. Since the most important habitat variables for denning were structural rather than anthropogenic, and the overlap of proposed wind farm sites in predicted high-quality denning areas is low, I advise that any impact of wind farm construction on bear denning habitat overall would be minimal.

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Chapter 1. Introduction

1.1 *Problem Statement*

Amidst a warming climate, trends in alternative energy production have rapidly increased in recent years as nations seek out more efficient ways to generate electricity. However, despite the myriad of benefits provided by fossil-fuel divestment (Gregson et al 2007; Lenferna 2014; Montgomery & Thomas 1988), alternative energy production is not without cost as wind, solar, nuclear, biomass, geothermal, and hydroelectric energy production all incur some degree of criticism (Hearps & McConnell 2011; Verbruggen et al 2010). Because these technologies are long-term investments with the purpose of establishing energy sustainability and environmental conservation for generations to come, it is important to ensure that the decisions to approve their implementation take all associated risks into account.

The nations of the European Union (EU) are collectively among the world's leaders in alternative energy production and application (Schmidt & Haifly 2012). With their 20/20/20 targets, the EU plans to reach 20% renewable energy by 2020 (EWEA 2011). Yet as the benefits have become clearer, many member states are expected to far exceed the 20% target (EWEA 2013). Croatia, in particular, has proposed the construction of approximately 700 wind turbines within the next five years, a goal with the energy capacity to propel them into the top five wind energy producing nations in Europe. With an already 20-fold increase in wind farm development between 2005-2011 (Dragan, Moccia & Tardieu 2013), Croatia is an ideal place in which to investigate the specific ecological costs associated with large-scale conversion to renewable energy production.

Eurasian brown bears (*Ursus arctos*) are one the most abundant species of large carnivores in both Croatia and Europe overall and their populations have benefited in recent decades due to protection measures initiated by the EU (Decāk et al 2005). However, they remain particularly threatened by habitat loss at a continental scale (Chapron et al 2014). This is specifically due to the infrastructure associated with human development projects (Seiler 2002; Wells et al 1999). Because of their low population density and large home range, bears are particularly sensitive to such changes, and as with many other species, disturbances can generally induce home range shifts, alter movement patterns, and impact gene flow (Linnell et al 1996; Trombulak & Frissell 2000).

With the proliferation of renewable energy sources across Europe, wind farms may represent a wave of infrastructure that could further fragment the bear's core ranges, inhibiting access to the denning areas vital to the species continued growth. To date though, only a single long-term study has examined the impact of wind farms on large carnivores (Álvares et al 2011), and similar studies may require significant amounts of funding and years of observation. In the absence of such information, nations like Croatia are operating under the precautionary principal, commissioning species distribution models in order to locate high-valued habitat. While overlaying projected wind farm sites does not imply direct impact, the State Institute for Nature Protection is poised to heavily scrutinize the proposed sites based on projected proximity to high-quality denning habitat. In such a way, they may reduce any chance of potential environmental degradation before construction, after which, the effects on denning areas may be potentially irreversible. Thus, the expected outcome of this project is the conservation of bear populations through the protection of their habitat in the face of increasing development across their range.

1.2 Project Aims:

The overall aim of this study is to minimize the long-term impact of wind farm development on Eurasian brown bear populations in Croatia.

Specific Objectives:

1. Determine the environmental and anthropogenic variables that dictate den presence

2. Generate den-presence probability maps for Croatia
3. Overlay probability maps with locations of proposed wind farm sites.
4. Rank proposed wind farm sites based on proximity to predicted denning habitat.
5. Provide feedback and recommendations for management to the State Institute for Nature Protection

This project, in cooperation with the University of Zagreb, is vital to the future of Croatia's energy and environmental sustainability, as it will be used to advise the government of Croatia on the most beneficial approach to wind farm development. This thesis will be added to other similar reports on grey wolf reproduction sites and lynx dens in order to fully understand the scope of overlap between wind energy development sites and large carnivore habitat in Croatia.

Overall, this thesis is novel in its investigation of the overlap between alternative energy development sites and habitat vital to the stability of a large carnivore species. As far as I am aware, it is only the second project looking at the relationship between wind farms and large carnivores. As such, for other situations where the precautionary principal is chosen over waiting for long-term field study results, hopefully this study may provide methodological guidance. Lastly, this report represents a rare case where presence-only modeling is used to analyze the important regions for a specific behavior, winter denning in this case, rather than a species' entire range.

Chapter 2. Background

2.1 Wind Energy Production In Europe

The European Commission has set a target of 20% primary energy demand from renewable resources by 2020 (European Parliament 2009). Each member state is responsible for its own implementation of the target through their respective National Renewable Energy Action Plans (NREAP), and by March of 2014, three countries (Sweden, Bulgaria, and Estonia) had already reached their 20%.

Since 2000, wind power has been one of the fastest growing sources of renewable energy used to reach these 2020 targets, with a ten-fold increase in install capacity between 2000-2012 (EWEA 2011; EWEA 2013). According to the IPCC, of all large-scale energy production sources it maintains the lowest median CO_2 output over its lifetime, with most of its environmental costs incurred in the factory (Pehnt 2006; Schlomer et al 2014). Already, approximately 7% of Europe's total energy production was wind-sourced as of May 2014, and with install capacities constantly increasing for member states, significant progress is being made towards achieving the 2020 targets. As of 2013, nearly half of all wind power in Europe was generated in Germany, with the UK containing the highest capacity wind farm sites yet to be developed (EWEA 2013).

As wind energy continues to spread, efficiency is also on the rise, as larger turbines with greater output potential (below 1 MW in the 1990s to 5 MW today) are able to produce more electricity for comparable costs of development (Twidell 2009). This has assisted several countries that once had difficulty in supporting the initial cost of wind energy towards approaching their 2020 targets. Eastern Europe is considered one of the most rapidly evolving sectors in wind energy production because of this increase in energy output to development cost ratio (Dragan et al 2013). This shift provides them with a chance to offset market declines and curb dependence on foreign oil import, both key economic incentives amongst several southern European nations that suffered especially heavily during the 2008 global recession (Dragan et al 2013).

2.2 Wind Energy Development in Croatia

Since 2004 when the first wind farm was built in Croatia, wind energy production has rapidly expanded across the region, increasing by nearly 20-fold between 2005 and 2011 (Dragan et al 2013). Because of its location along the Adriatic Sea and the Dinaric Alps that run south along the coast, Croatia has greater than average wind energy generation potential per surface area compared with the rest of Eastern and Southern Europe (figure 1). Higher and more consistent wind speeds translate to cheaper energy in Croatia compared to the rest of the region as well (figure 2). To access this energy potential, as of May 2015, 36 new wind farms had been proposed to meet and likely exceed the required EU member state targets, and with 15 farms already in operation around the country, around 700 wind turbines are scheduled to be built in Croatia in the next five years. At this rate, Croatia projects to have enough turbines to place them in the top five highest wind energy producing by countries in Europe (by percent of total energy) within ten years. Furthermore, with a 14 year guaranteed feed-in tariff, funding for site development is already secured (Dragan et al 2013).

The chief obstacle for Croatia's NREAP is that 60-70% of the highest quality wind farm sites occur in protected areas (PA), including eight national parks and eleven nature parks. Furthermore, 47% of Croatia's continental area and 39% of its maritime area are designated as Natura 2000 sites. While building regulations are different for each designation (stricter, yet possible, in National Parks and Natura 2000 sites than nature parks), approval can be contingent on whether or not development poses a threat to the parks "essential characteristics." The State Institute for Nature Conservation must review all infrastructure applications before officially approving a project.

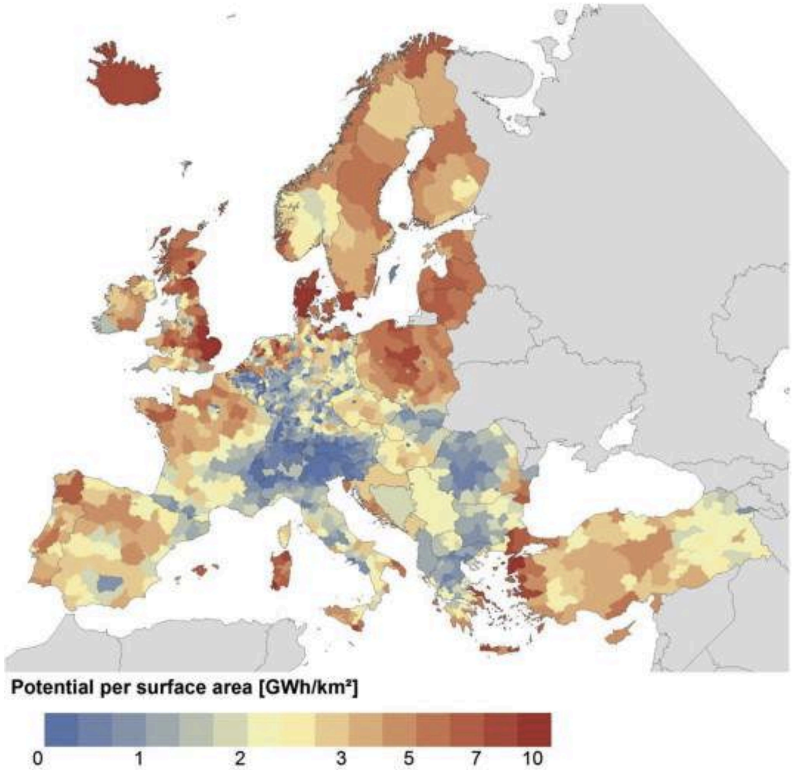

Figure 1. Average potential electricity generation for turbines of 3 MW and larger (McKenna et al 2015)

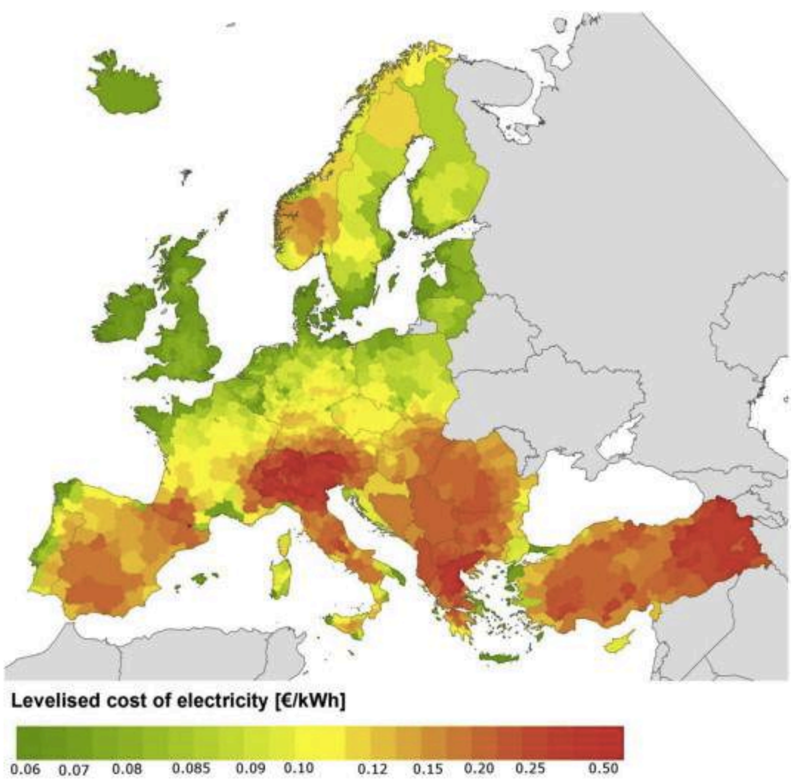

Figure 2. Cost of electricity for turbines of 3 MW and larger (McKenna et al 2015)

2.3 Costs of Wind Energy Production to Terrestrial Vertebrates

2.3.1 Measuring Impact

When discussing the impact of an energy development project, the term most often used is "footprint," though as Denholm et al (2009) discusses, the true temporal and spatial impact of wind energy is difficult to summarize in one figure. There are a number of metrics used to evaluate land-use impacts, yet there is no widely accepted methodology used to quantify the effects of wind energy on local land. One commonly used metric is "area of impact," which attempts to quantify the total acreage of land that will be affected by the addition of a wind farm to the landscape. While land clearing may be easier to measure, "area of impact" assessments do not quantify the more difficult to measure variables such as changes in ambient sound, light, temperature, and human presence (Denholm et al 2009).

Another commonly used metric is "habitat impact area," which attempts to measure the extent of fragmentation or reduction in habitat viability. In "habitat impact area" studies, habitat quality values can be placed on each turbine. Similar to "area of impact" though, degree of fragmentation is difficult to measure and is most useful at providing an estimate of impact rather than an observational change (Denholm et al 2009). For example, in a habitat area impact assessment for a local energy company in Kansas, USA Robel (2002) estimated that a particular wind farm site would reduce viable breeding habitat for greater prairie-chicken by about 800 hectares for each turbine, based on the species' avoidance of roads. Studies such as this are rare though, with most of the wildlife conflict studies examining the effect of turbines on aerial species.

2.3.2 Direct Impacts on Terrestrial Vertebrates

To date, only a single study has reviewed the effect of wind farm development on large carnivores. In this report, Álvares et al (2011), found that grey wolves in Portugal undergo significant changes in spatial distribution for important reproductive sites during and after wind farm construction, including abandoning den sites that were less than 1km from a turbine and potentially settling for less suitable dens post-construction. While wolf reproductive sites were more permanently affected by wind farm construction in Portugal, Álvares et al (2011) conversely found that predation was relatively unaffected, undergoing an initial drop directly around each wind farm before rebounding back to pre-construction levels in the two years following construction. Since this remains the only study of its kind, and no study has used bears as the test species, more long-term environmental impact assessments are needed to verify the exact role that wind farm construction has on large carnivores. Until then, it is impossible to conclusively model exactly how wind farm construction will impact large carnivores in Croatia. However, because of the sensitive locations of proposed sites in and around protected areas, the well-known impact of roads on large carnivores (Coffin 2007; Gibeau L & Herrero 1998; Glista et al 2009; Poessel et al 2014; Tigas et al 2002), and the preliminary evidence from Portugal that wind farms can affect reproductive sites in large carnivores, the State Institute for Nature Conservation will operate under the precautionary principal when examining the potential risk of wind farms on bear denning habitat. Specifically, the State Institute will use results from this study as background evidence during their review of new wind farm site applications.

While metrics for measuring the impact of wind farms on wildlife can be difficult to define, it is widely agreed upon that the majority of the impacts incurred on the land itself take place during the construction of a site, and that costs are significantly reduced once the farm is operational (Dai et al 2015). Despite the degradation that occurs during construction, the environment does indeed return to its pre-disturbance state, yet recovery time can vary greatly, from two to three years for grasslands or as much as decades for deserts (Arnett et al 2007). Furthermore, the specific scale of environmental impacts of wind farms are quite variable and can depend greatly on the environment they are constructed in. For example, forests tend to incur more damage than scrub, as they maintain higher potential for habitat fragmentation due to the additional clearing needed (Denholm et al 2009).

The direct impact of wind farms on wildlife can be split into two categories. The most heavily studied is direct mortality of avian species and bats due to collision with the turbine blades. Over the last decade, the link between wind turbines and aerial species mortality has been investigated in numerous case studies, with a myriad of suggestions given as mitigation procedures (Arnett et al 2008; Drewitt & Langston 2006; Drewitt & Langston 2008; Marques et al 2014; Masden et al 2012; Premalatha et al 2014; Rydell et al 2010; Seaton & Barea 2013; Smallwood 2007; Wang et al 2015;). Overall though, as Premalatha et al (2014) discuss in a comprehensive review on wind energy concerns, such heavy investigation has only uncovered more questions. Specifically, recent inquiries into the role of wind energy development on scavenger removal (Smallwood 2007), trophic cascades (Dahl et al 2012; de Lucas et al 2008) and bird or bat species population dynamics have complicated the picture even further (Carrete et al 2009; Drewitt & Langston 2006; Drewitt & Langston 2008). While exact numbers on aerial species mortality are difficult to attain, collision is still a primary source of conflict for such species around wind farm sites. When compared to other sources of energy though, wind farms may actually cause the least amount of avian mortality. A study by Sovacool in 2009 estimated that wind farms and nuclear power plants are responsible for 0.3 and 0.4 respective avian fatalities per GWh while fossil-fueled power plants are responsible for as many as 5.2 fatalities per GWh. This preliminary assessment found approximately seven thousand birds killed by wind farms in the U.S. in 2006, compared to 327,000 killed by nuclear power plants, and 14.5 million killed by fossil-fuel development plants. Wind power may simply be the most often seen form of avian mortality, leading to inflated concern regarding scale of impact.

The second leading cause of wind farm impact is the habitat loss that results from building each site. This interaction is far less studied than aerial species mortality, though roads, transmission lines, and maintenance facilities are likely to cause comparatively higher damage to wildlife due to subsequent habitat fragmentation (Kuvlesky et al 2007). While specific examples are limited, habitat loss due to wind farm site construction has in fact been observed to reduce densities of ground-nesting birds in remaining habitat (Leddy et al 1999). Additionally, avifaunal species diversity and abundance is lower in undeveloped habitat adjacent to wind farms than at control sites without wind farms (Osborn et al 2000). This indicates that studies which purely examine acreage of habitat lost may not provide an accurate picture of overall impact, as adjacent patches of remaining habitat may have incurred negative edge effects during construction.

Habitat loss as a result of wind farm development may induce long-term sustainability concerns for local wildlife, especially in low-density populations, as fragmentation can exacerbate Allee effects in species living near people (Cheptou & Avendaño 2006). For example, as individuals disperse to avoid development sites, populations may decrease in density, therefore decreasing the likelihood of individuals finding a mate and increasing the likelihood of predation (Stephens & Sutherland 1999). While this has not been studied in great detail with regard to wind farms specifically, impacts can be inferred from studies in road ecology surrounding similar scale development.

As roads comprise the majority area of a total wind farm site (95-98%), the actual turbine itself (between 0.08ha to 0.2ha) is not generally a significant source for habitat damage, though there is evidence that it may induce locally permanent effects on soil and vegetation (Arnett et al 2007). Furthermore, a report by the U.S. Department of Energy on permanent versus temporary impacts of wind farms found that for permanent impact sources, roads comprise 79% of the total area (table 1). This indicates that while the area around the turbines may well recover from construction damage, the impacts of roads are more likely to be felt long-term.

Permanent Impact Category	**% Of Area**	**Temporary Impact Category**	**% Of Area**
Turbine Area	10%	Staging Area	30%
Permanent Roads	79%	Temporary Roads	62%
Substation	6%	Substation/Transmission Construction	6%
Transmission	2%	Other	3%
Other	2%		

Table 1. Direct impact source from 172 wind farm projects in the United States(Denholm et al 2009)

In a sweeping review on the effects of roads on terrestrial and aquatic communities Trombulak & Frissell (2000) found widespread support for the conclusion that roads are associated with “negative effects on biotic integrity.” They describe seven main impacts of roadways, each of which may result from wind farm development: mortality from road construction, mortality from collision with vehicles, modification of animal behavior, alteration of the physical environment, alteration of the chemical environment, spread of exotics, and increased use of areas by humans. Low populations, populations with low genetic diversity, populations with uneven demographics, or species with specific habitat requirements may incur greater effects of road development than healthy populations as well. They do note however, that not all species are affected equally. Habitat generalists or urban synanthropes may not be affected as negatively, while scavenging or wide-ranging species may even benefit from the increased supply of food and ease of mobility.

The impact of roadways on bear movement and mortality specifically is equally ambiguous, having been heavily studied in recent decades, primarily in North America. In Montana, grizzly bears (*Ursus arctos horribilis*) exhibited a significant avoidance of highways, which led to reduced local population growth over time (Mace et al 1996). When they do cross though, frequency depends on both the type of road and the individual sex, as crossings occur more often with females than males and more often at narrow points in the road rather than multi-lane highways (Graham et al 2010). Furthermore, bears in Montana appear to cross more during the night, when traffic volumes were reduced to around 10 vehicles per hour (Waller & Servheen 2005). Despite overall avoidance, bears still do seem to be somewhat attracted to roads, as Graham et al (2010) also found that in the spring, females with cubs were located within 200m of a road more often than expected. This may be due to the roads increasing bear feeding viability, as Roever et al (2008) found that roadside ditches maintain an increased abundance and diversity of ant species that grizzly bears commonly feed on. Similarly, while bears seem to avoid high traffic volume, they are less likely to avoid closed off forest roads, especially at night (Wielgus et al 2002). As Gibeau & Herrero (1998) noted, there exists a “dynamic tension between road avoidance and attraction.” This tension is what leads to such high mortality figures, as Gibeau L & Herrero (1998) found that between 1975-1996 over 80% of recorded bear mortalities in the Central Canadian Rocky Mountains occurred within 500m of a highway. In Croatia, Huber et al 1995 found similar figures, as 73 Eurasian brown bears were killed by vehicles between 1963-1994 in the heavily forested region of Gorski Kotar. As noted previously, the lasting impact of wind farm development is the construction of roadways across the landscape. While these roadways will not be high volume highways, the combination of low vehicle density and increased food options may potentially lead to habituation, a common driver of increased collision risk (Coffin 2007).

Overall though, the presence of roads is highly correlated to changes in species composition, population sizes, and shifts in hydrologic and geomorphic processes. Infrastructure construction is then likely to impact humans as well, as fluctuations in functional processes risk affecting crucial ecosystem services (Tardieu et al 2015). With wind farm development projects on the rise all over Europe, multifaceted assessments may be needed to determine the full breadth of impact projected at each site.

2.4 Eurasian Brown Bears in Croatia

The Eurasian brown bear is the most abundant large carnivore in Croatia and is protect by both the Nature Protection Act in Croatia as well as the EU Habitat Directive, of which it is a priority species for conservation under Annex II and IV (Kaczensky et al 2012). Croatia's bears occur in the geographic center of the Dinara-Pindos population (Kocijan et al 2011), which expands north into Slovenia and south into Bosnia & Herzegovina. Permanent bear habitat in Croatia averages at least one individual per $10km^2$, and densities are highest in the protected areas (Decāk & et al 2005). While Croatia's bear management plan estimates a total capacity of 900-1200 individuals, it notes that overall estimates vary widely and actual numbers may as low as 400-600 individuals (Decāk & Et.Al 2005; Kaczensky et al 2012). The population relies on young males to disperse to peripheral areas of the range, limiting intraspecific competition and promoting genetic diversity (Kaczensky et al 2012). A prior study on den classifications found that most dens are built in rocky caves, likely a result of the karstic geology of the region (Huber & Roth 2009). Conservation of these denning areas is of central concern for the sustainability of Eurasian brown bears (Huber & Roth 2009), especially if increased human presence due to wind farm development leads to mid-winter den abandonment. In a review on the consequences of den disturbance Linnell et al (2000) explains that brown bears as well as black bears (*Ursus* americanus) and polar bears (*Ursus maritimus*) exhibit variable responses to den disturbance, but when human activity of any scale occurs less than 1km away and especially when it occurs less than 200m away, den abandonment increases significantly. This leads to increased rates of cub mortality and can lead to population declines over time if disturbance and den abandonment occurrence continues to rise (Linnell et al 2000; Swenson et al 1997). Despite the majority of proposed wind farms occurring outside the known range of the species in Croatia, the State Institute for Nature Conservation must review any infrastructure applications for sites in proximity to crucial habitat of a protected species.

Chapter 3. Methods

3.1 Conceptual Methodological Summary:

As discussed in the introduction section above, my overall objective of this study is to assist in the management of Eurasian brown bear habitat by projecting the potential overlap of wind farm construction on denning habitat across their domestic range. To do so, I will utilize three distinct processes in order to achieve this goal: data accumulation and organization which includes gathering information on both bear dens and habitat variables, species distribution modeling (SDM) using Maxent, and a wind farm overlap assessment.

3.2 Bear Presence Data

3.2.1 Den Sources and Sites

The LCL of the Faculty of Veterinary Medicine at the University of Zagreb has spent nearly 40 years collecting data on bear behavior and ecology in Croatia. Their cumulative dataset of 61 total den sites is a combination of their efforts as well as those by the Faculty of Forestry at the University of Zagreb. The LCL located most of their dens using telemetry on collared individuals, VHF before 2003 and Vectronic GPS/GSM after 2003. Throughout winter, LCL staff would determine areas of limited daily movement before confirming actual den locations with field surveys in the spring and summer.

Besides using telemetry, the LCL and Faculty of Forestry located dens using field surveys guided by detailed local knowledge of recurring bear denning habitat. Specifically, established local hunting clubs and PA offices maintain chronicles of areas where dens have historically been located. Throughout the last 30 years, local hunters have worked with LCL and Faculty of Forestry members to survey such areas. Upon den confirmation in-situ, LCL staff conducted detailed assessments including soil sample extraction, hair or scat collection if possible, and taking photographs and illustrations of the dimensions of the structure. From 1982-2011, the LCL catalogued 34 different dens using telemetry. An additional 27 dens were catalogued by Faculty of Forestry surveys using hunting club records.

The LCL dens were primarily located in the Gorski Kotar and Plitvice regions. These are highly forested regions of approximately 70% forest cover, ranging from 417m to 1,528m above sea level. They are characterized by the presence of two national parks, Risnjak National Park in Gorski Kotar and Plitvice Lakes National Park in Plitvice. Plitvice National Park, which attracts 1.1 million visitors annually, has nearly 1,300 plant species, 50 mammal species, and has been a registered UNESCO World Heritage Site since 1979. Despite this, both regions are among the most heavily populated mountainous regions of Croatia, with thriving logging, agriculture, and tourism-based economies outside the boundaries of the reserves. In both Gorski Kotar and Plitvice, the primary habitats are dinaric beech forest, mesophilic beech forests, and mesophilic grasslands on calcareous soils. Common beech (*Fagus sylvatica*) and Norway spruce (*Picea abies*) are the most abundant forest trees, growing in a shallow soil over dolomite and limestone. Terrain in both is typical karst, with an abundance of caves, depressions, and gorges. Mountain peaks and slopes (>60 degrees) are covered in bare rock (Huber et al 1995; Podaci 2009; State Institute for Nature Protection 2015).

The Faculty of Forestry dens were primarily located in the Velebit region. As compared to Gorski Kotar and Plitvice, Velebit is far less forested. It is the heart of the Dinaric Alps and represents the largest, though not the highest, mountain range in Croatia, running north-south along the Adriatic coast. It is a vastly mosaicked landscape, with pockets of forest, grassland, karst canyons, bare peaks, and lakes. Above 800m, common beech and spruce dominate the forests, especially on the inland side of the range, a biogeographic region known as Lika. At higher elevations, subalpine forests of beech and hollyfern (*Cyrtomium falcatum*) give way to rocky plateaus, dry grasslands, and bare jagged karstic rock from 1,100m to 1,650m above sea level. On the Adriatic side, forest cover is low and the habitat is sub-Mediterranean dry grassland and coastal thermophile forest. Like Gorski Kotar and Plitvice, two national parks occur in the Velebit region, Paklenica National Park and Sjeverni Velebit National Park. Between both National Parks, there are over 1000 plant species, 40 species of amphibian and reptile, 230 bird species, and 53 species of mammals. Human density is lower in Velebit than in Gorski Kotar and Plitvice, yet several major highways bisect the region, sites of newly assembled green bridges (Podaci 2009; State Institute for Nature Protection 2015). Bears are common both within and outside the boundaries of both region's PAs (Decāk & et al 2005)

Of the 61 total dens across Gorski Kotar, Plitvice, and Velebit, three known individuals held multiple dens in the same winter, usually within 70-300m of the others. In the case of a bear utilizing more than one den in the same season, I selected one den out of the cluster to be used as the test sample in order to prevent spatial autocorrelation in the SDM. If the dens were in the same cell (250m^2), I selected the one closest to the center, and if the dens straddled two cells, I selected the one closest to the center of the cell with the majority of dens. The final dataset to be used in SDM had 53 total dens spanning from 1981-2011, 24 from the LCL database and 29 from the Faculty of Forestry survey database. 18 known individuals, of which half were male and half were female, each contributed one den to the set, while four of those individuals contributed two dens from different years. The confirmed dens found from the hunting chronicles do not maintain details on individual.

In presence-only SDM, spatial autocorrelation of data is likely to result in biased distribution outputs, as a cluster of highly concentrated locations, such as multiple dens from the same season and individual, can command a proportionally concentrated cluster of high-quality habitat (Diniz-Filho et al 2003). This can be an unrealistic measure of habitat value, especially with GPS collar data, as without data from every individual in the area, spatial clusters of points may simply indicate territoriality or individual preference rather than habitat quality. Spatial autocorrelation is widely accepted to be a concern in distribution modeling (Diniz-Filho et al 2003), yet to date, no clear solution exists to address it (Dormann et al 2007). Proposed methods (De Marco et al 2008) have been met by equally fervent support and criticism, and while the methods described above were used to address the issue in this study, comprehensive review of the literature indicates that no solution provides clear escape from risk (Dormann 2009).

3.3 Environmental Variables

The environmental variables used in SDM came from a variety of sources and I chose them to represent a broad spectrum of common habitat features limiting distribution (table 2). After selecting a raster file with cell sizes of 250m^2 for each variable, I masked them to include just the political boundaries of Croatia. The environmental variables included structural habitat elements as well as anthropogenic features of the landscape. For the structural elements, I used elevation, forest cover, ruggedness, total precipitation of the coldest quarter of the year, total precipitation of the warmest quarter of the year, mean temperature in the coldest quarter, and mean temperature in the warmest quarter. For the anthropogenic features, I used human density, land type diversity, agriculture, grassland, and distance to nearest settlement. Rather than using every individual layer in the overall model, I required key modifications in order to satisfy the statistical assumptions of SDM, namely the limiting of correlation between habitat layers.

Correlation between habitat layers is a common concern with SDM, as the value of each individual variable can be difficult to discern if the presence or absence of one is correlated with the presence or absence of another. In order to limit potential environmental correlation, I conducted a spatial correlation analysis on ArcGIS (ESRI 2013) using the value of each cell for each habitat layer. The function allowed me to identify redundancy among habitat variables, essentially quantifying the similarity of distribution between each variable across space. By examining resulting Pearson correlation coefficients (PCC), I found that grassland, agriculture, and distance to nearest settlement were highly spatially correlated to each other (PCC > 0.30) and thus if kept in the model independently, would be difficult to determine their individual contribution. Furthermore, because agriculture and grassland were derived from 2005 the while distance to nearest settlement came from 1991, their strong spatial correlation indicates that between 1991-2005, farming and settlement development in Croatia has occurred in relatively consistent areas, thus satisfying the potential issue of temporal habitat variation across the bulk of my sample data. In order to limit the impact of environmental layer correlation between these variables, I merged the correlated anthropogenic raster files together in order to create a single raster of the weighted average cell value and labeled it "Farms and Settlements."

Environmental Variable	*Description*	*Source*
Farms and Settlements	Weighted Average Cell Value of: • Percent of each cell covered by agriculture: o Defined as permanent and intermittently arable land for crops • Percent of each cell covered by grassland: o Defined as artificially established grasslands for pasturing • Distance to nearest settlement: o Defined as the distance from the center of the cell to the boundary of any registered human settlement	• Percent of each cell covered by agriculture o State Institute for Nature Conservation, Land Cover Map, 2005. • Percent of each cell covered by grassland o State Institute for Nature Conservation, Land Cover Map, 2005. • Distance to nearest settlement o 1991 Census, Settlement Map.
Elevation	Average elevation (m) of the total area of the cell	State Institute for Nature Conservation, 2001.
Forest Cover	Percent of each cell covered in forest	State Institute for nature Conservation Land Cover Map, 2005.
Human Density	Number of people per unit area (km^2) of each settlement, scaled to $250m^2$ cell size.	Large Carnivore Lab, 1991, using the 1991 Census and Settlement Map.
Coldest Quarter Temperature	Average temperature across December to February from 1950-2000 using every operating weather station in Croatia	WorldClim Global Climate Data, 2005.
Warmest Quarter Temperature	Average temperature across June to August from 1950-2000 using every operating weather station in Croatia	WorldClim Global Climate Data, 2005.
Coldest Quarter Precipitation	Total precipitation (mm) averaged across December to February from 1950-2000 using every operating weather station in Croatia	WorldClim Global Climate Data, 2005.
Warmest Quarter Precipitation	Total precipitation (mm) averaged across June to August from 1950-2000 using every operating weather station in Croatia	WorldClim Global Climate Data, 2005.
Ruggedness	Ratio of surface area (m^2) to cell plane area	LCL, 2014, using the elevation map from State Institute for Nature Conservation, 2001.

Table 2. Title, description, and source of each environmental layer used in the Species Distribution Modeling (SDM) in Maxent for bear dens and general movement locations on

3.4 Species Distribution Modeling (SDM)

3.4.1 Running Maxent

Maxent (Phillips et al 2004) is a software specifically designed for a presence-only species distribution modeling. This approach to SDM allows scientists to create probability distribution maps without absence points, or essentially, without a traditional control. While presence-only SDM is not without controversy (Halvorsen 2013; Yackulic et al 2013), Maxent remains a popular tool amongst ecologists for mapping species distribution probabilities when one solely possesses a set of confirmed locations, as is common in methods ranging from GPS collaring to citizen science campaigns. Instead of providing known absence points, one must provide Maxent with an area known as a bias. The bias area is meant to account for sampler bias (Phillips 2008), indicating to Maxent the spatial boundaries of the survey conducted to collect the sample data. Maxent will then use that bias area to select randomized background points as pseudo-absences. With all provided habitat features overlapped, those randomized background points are then used to score the probability of presence across the entirety of the map, as a cumulative threshold is set whereas cells containing random background points have a given likelihood of containing suitable habitat (Merow et al 2013; Phillips 2008).

The smaller the bias area, or the more tightly contained it is around the sample data, the more likely it is that a random background point will fall closer to a presence point. As the variation in habitat reduces with area and background points would likely fall on cells containing presence points, this would indicate that the probability of a species' presence across the landscape is relatively random. Maxent would then project close to a 50% probability of occurrence across the rest of the map, accompanied by relatively higher standard deviation. However, because habitat variation would not be completely eliminated across small bias area, this method of output may provide an overestimated probability presence rather than a completely random prediction. That being said, it would also be more indicative of the actual area where samples were gathered.

Conversely, a large bias area, which would envelop greater space between presence points, would result in the opposite effect. The likelihood of a background point randomly falling on a presence point is low since the sample area is much larger and habitat variation is therefore much greater as well. This would indicate to Maxent that sample points are highly nonrandom and thus would produce a map with very low or very high probability of presence with comparatively few areas of 50% presence likelihood. While this sounds ideal, an SDM with a large bias area is likely to underestimate probability of presence, as the larger the area, the more space that one supposedly did not find samples despite searching for them. As a result of using a bias area much larger than the actual area surveyed, output maps may falsely inflate the species' selectivity.

For this study, I chose to use both approaches, as I each comes with different costs and benefits, and both occur on a continuous spectrum straddling the unknown optimum bias area size that would provide the most accurate picture of known study site without the risk of overestimated probability upon output. Furthermore, I needed to know what affect the bias area size would have on the overall fit of the model. Overall, while the small bias area makes more conceptual sense since it more accurately depicts the surveyed areas, I needed the large bias area SDM to compare it with, essentially confirming whether the small bias SDM provided significantly overestimated presence probabilities or not. Without confirming the statistical similarities between them, it would be irresponsible to choose one based on conceptual knowledge of the study area boundaries alone. Since bias area size is a known cause for concern with Maxent (Fourcade et al 2014), and this study is the first illustrated example of those differences using the same sample data, I can hope to account for or at least describe the discrepancies between their respective outputs.

I drew the larger bias areas to include all points in the respective dataset (figure 3) and the smaller bias areas by data source (LCL or Faculty of Forestry) to limit sampler method bias (figure 4). In total, I conducted two SDMs: dens with a small bias area, dens with a large bias area. Each SDM used the same array of environmental variables described above in order to compare the subtle differences provided by the bias areas. Furthermore, I used jackknife graphs to illustrate the specific role of each variable in the overall model and ran each SDM with 25 replicates. Maxent uses a specified percentage of the sample data in order to verify the model's strength, and thus, I indicated 25% of my samples to be used in verification as this is a common fraction used in the literature for such purposes.

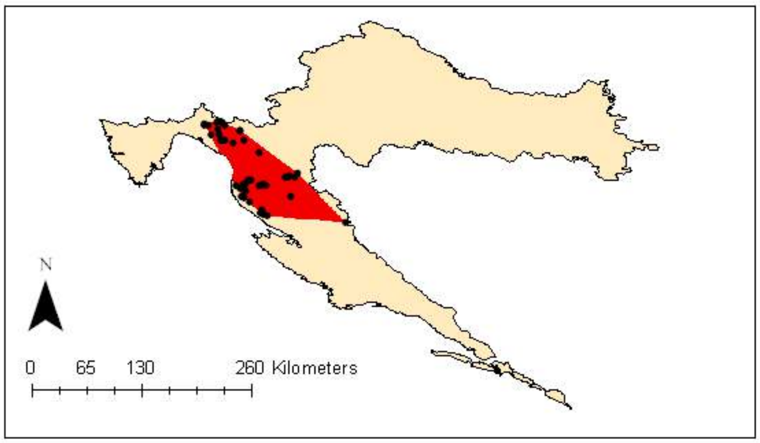

Figure 3. Illustration of large bias area size for dens (black dots) in Croatia from 1982-2011.

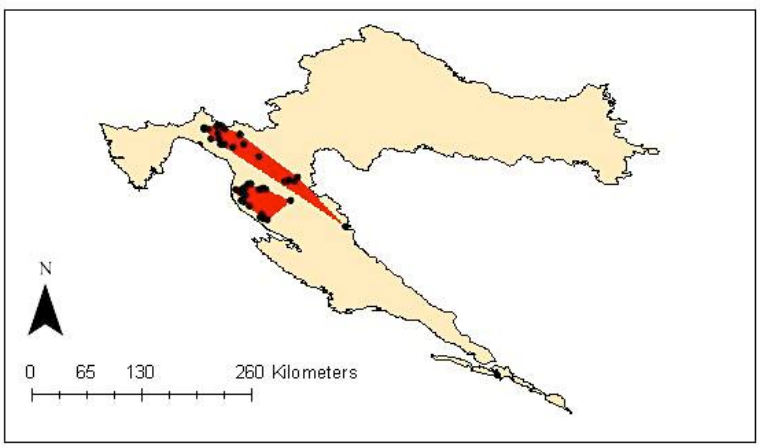

Figure 4. Illustration of small bias area size for dens (black dots) in Croatia from 1982-2011.

3.5 Overlap Assessment

3.5.1 Wind Farm Data and Project Ranking

There are 36 wind farm project applications that are currently under review by the State Institute for Nature Conservation. Each farm is a different dimension and different capacity, with the lowest projected energy output at 10 megawatts and the highest at 186 megawatts. Overall, the 36 potential wind farms would include 697 individual turbines to compliment the 15 wind farms of 230 turbines that are already active. Based on the distance of affected reproductive sites among wolves around wind farms in Portugal (Álvares et al 2011), I drew a 1km buffer around each wind farm in order to include any potentially similar effects that may be incurred upon construction. I also drew two additional buffers, one at 10km and one at 4km, in order to incorporate the $128km^2$ and $58km^2$ average domestic home range areas of male and female bears respectively (LCL 2015 unpublished). Then, I used the SDM output maps in order to map potential overlap of the 36 potential wind farms. Finally, I compiled rankings of inclusion of cells with presence likelihood over 50%, over 75%, and over 90%. The projects and turbines planned to include cells of those respective values would rank as highest potential risk while the projects further from cells of those respective values would rank as lowest potential risk. Because high probability denning areas would likely be less common than random or low probability denning areas across large areas, I ranked each turbine by the maximum probability cell per buffer area before providing an average for the entire area around the turbine. I compiled rankings for each SDM output in order to account for the differences in each bias area.

Specific wind farm information (turbine type, coordinates, project name, wattage, operating company, and associated bear denning habitat overlap) is property of the State Institute of Nature Protection and is not publically available at this time. Proposed sites are constantly being added, deleted, accepted, and rejected.

Chapter 4. Results

4.1 Species Distribution Models

The results of both bias SDMs indicate predictive qualities greater than random. Overall, the small bias area SDM (AUC=0.77) appeared slightly less predictive than the large bias area SDM (AUC=0.80), though a t-test of each SDM's 25 replicates AUC score confirmed no significant difference between them (*df*=48; *p*=0.33).

In terms of the percent that each habitat variable contributed to the overall model, again there was little variation between bias area sizes (table 3). Ruggedness was the most influential variable to both models overall (fig. 5; fig. 6), contributing to 56.2% of the overall model with the small bias and 50.3% with the large. A jackknife figure demonstrates that eliminating ruggedness from the total analysis incurred the steepest drop in AUC for both the large (figure 5) and small bias (figure 6) area SDMs. This was followed by elevation, though the drop in AUC after eliminating it was less severe than with eliminating ruggedness. Both ruggedness and elevation were positively associated with den probability (figure 7).

The average ruggedness ratio of each cell containing a den site was 1.069, the most rugged cell containing a den was 1.267, and the flattest cell had a ratio of 1.003. For elevation, the average den occurred at 992m, with the highest set at 1570m, and the lowest at 392m. All eight remaining habitat variables cumulatively contributed less than 30% to the overall model.

	Percent Contribution	
Variable	Large Bias	Small Bias
Ruggedness	50.3	56.2
Elevation	18.9	19.6
Precipitation in the Warmest Quarter	13.3	6.9
Forest Cover	6.2	6.1
Land Type Diversity	4.8	5
Farms and Settlements	3.8	3.2
Temperature in the Coldest Quarter	1.8	2
Human Density	0.4	0.6
Precipitation in the Coldest Quarter	0.4	0.4
Temperature in the Warmest Quarter	0.1	0

Table 3. Percent contribution of each habitat variable to each SDM bias area

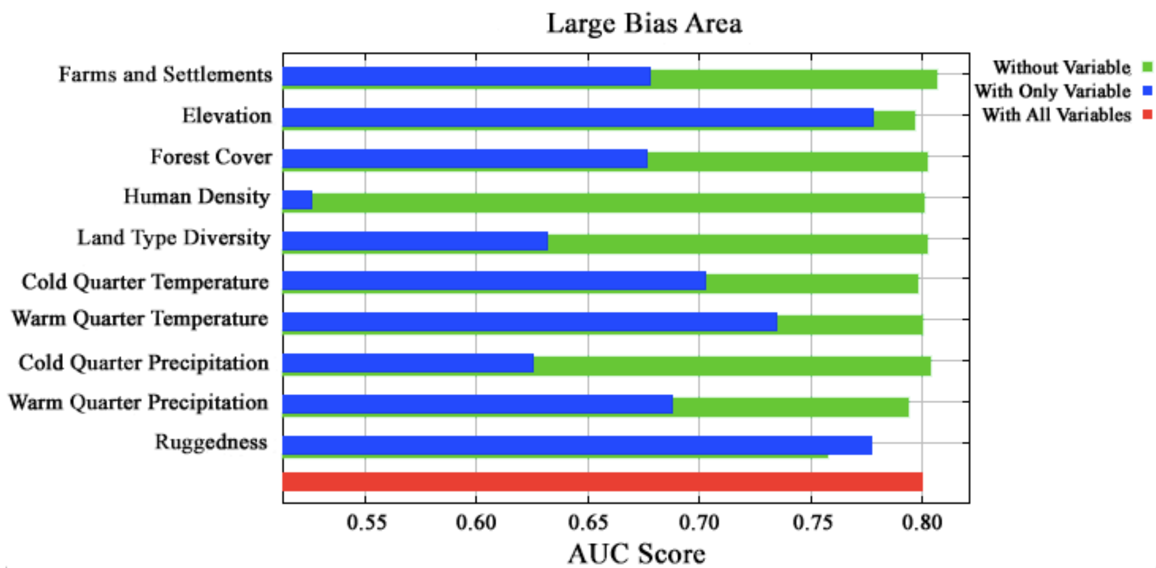

Figure 5. Relative impact of each habitat variable on model AUC score overall for the large bias area SDM

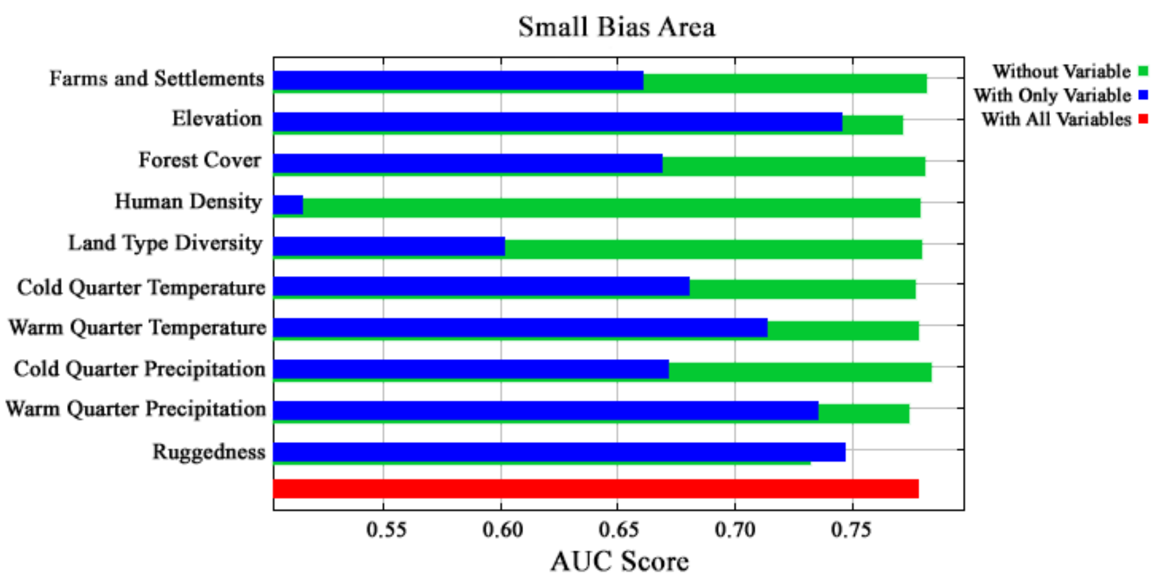

Figure 6. Relative impact of each habitat variable on model AUC score overall for the small bias area SDM

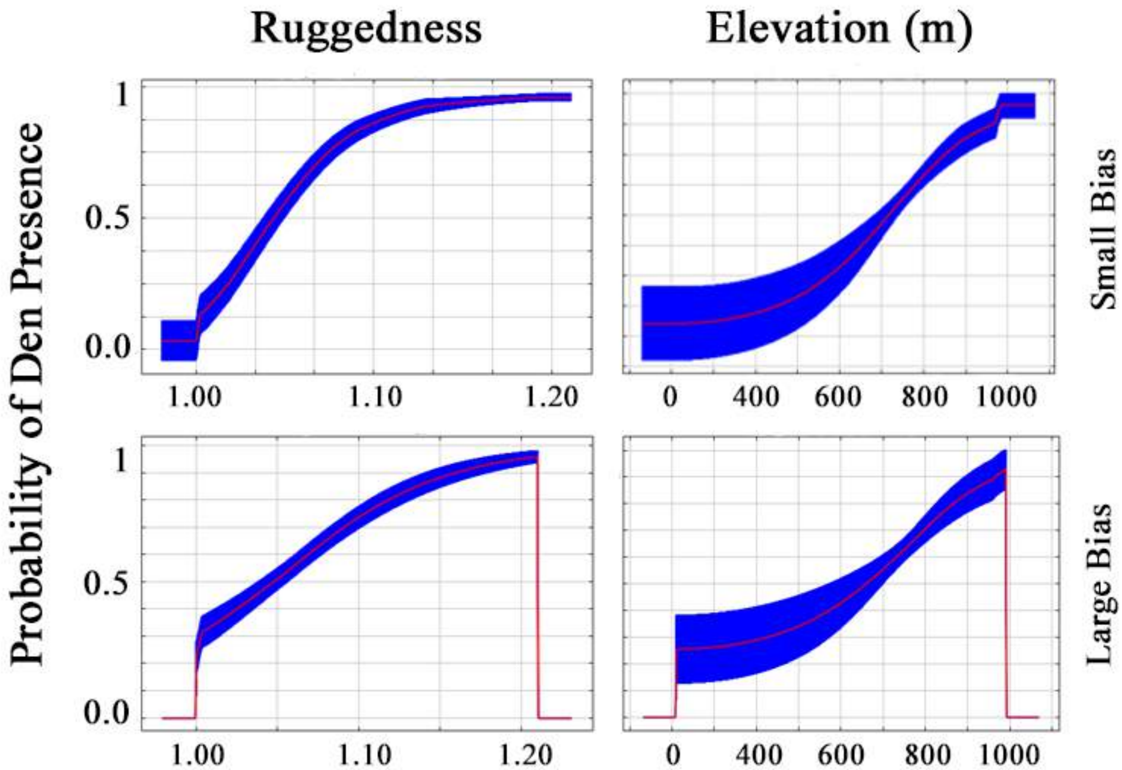

Figure 7. Effect of ruggedness (ratio of surface area to cell plane area) and elevation (m) on the probability of den presence in Eurasian brown bears in Croatia for two different bias area SDMs. Blue area is SD.

The probability of den presence maps across the country are also relatively similar, though the large bias area SDM (figure 8) produced slightly less random predictability than the small bias area SDM, specifically outside the known range of the species (figure 9). Minute differences can be seen more clearly when scaled down to the known range of bears in Croatia, as the large bias area SDM (figure 10) was able to illustrate more positive or negative probabilities compared to the small bias area SDM (figure 11) which produced slightly more cells with probabilities closer to random.

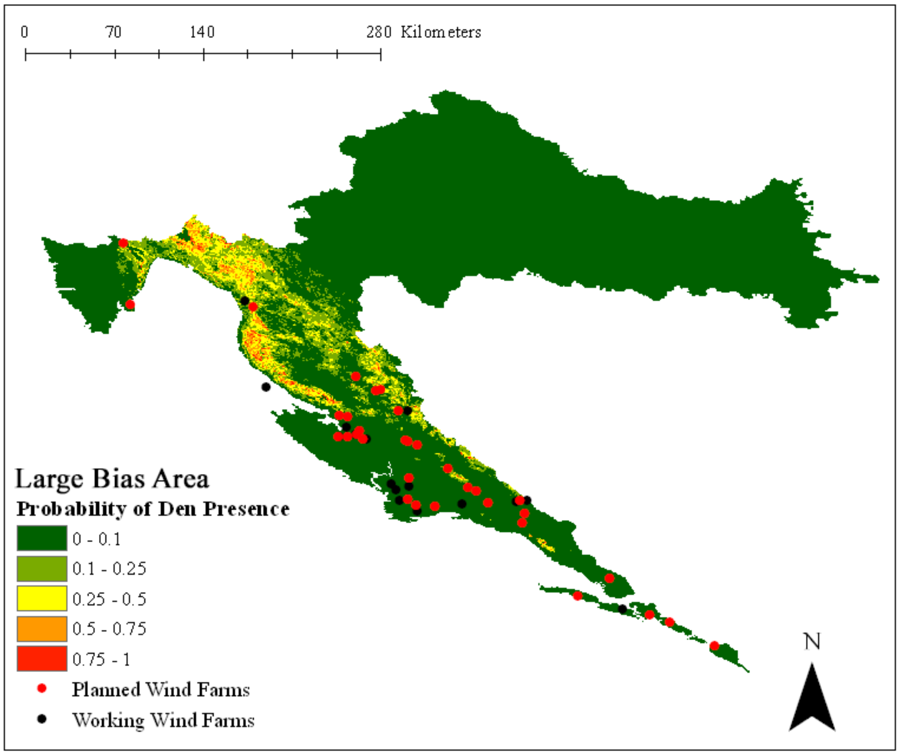

Figure 8. Probability distribution map for Eurasian brown bear den sites in Croatia using a large bias area

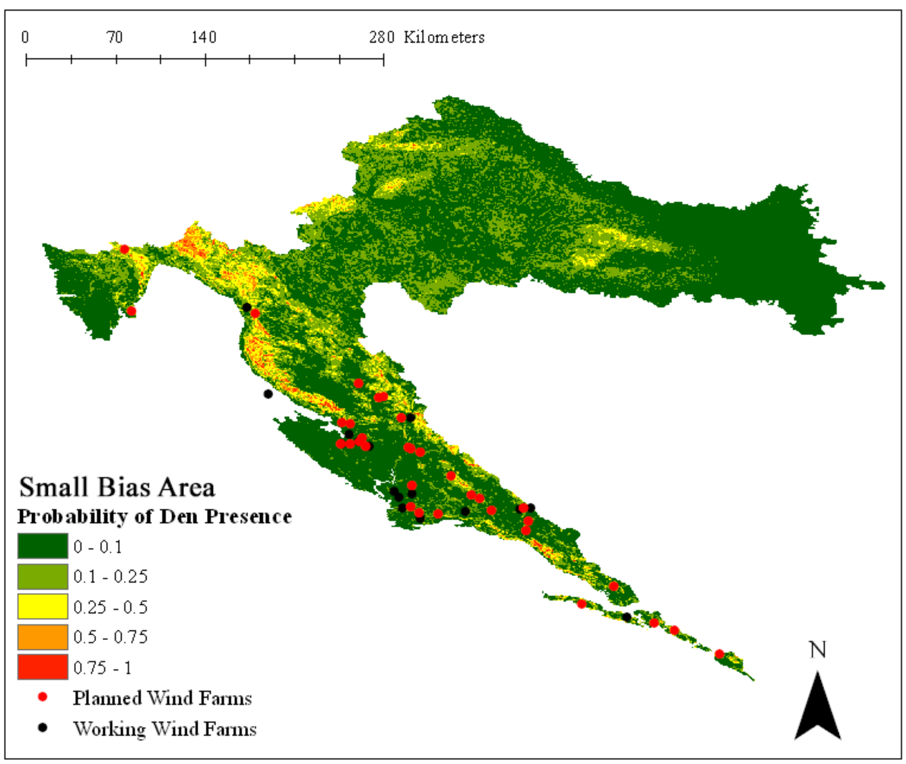

Figure 9. Probability distribution map for Eurasian brown bear den sites in Croatia using a small bias area

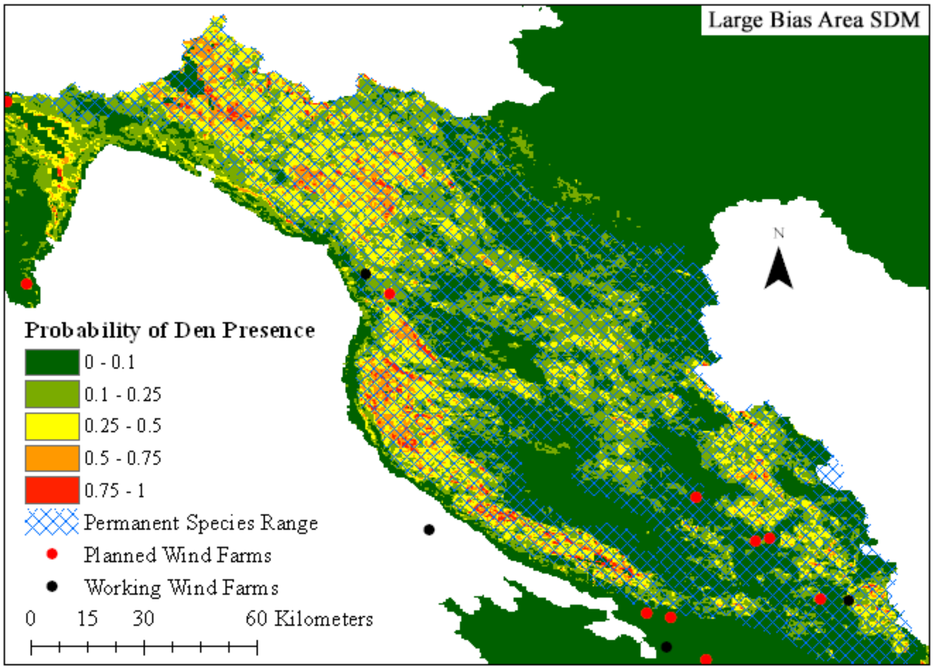

Figure 10. Probability distribution map for Eurasian brown bear den sites in Croatia using a large bias area, scaled to only include permanent species range

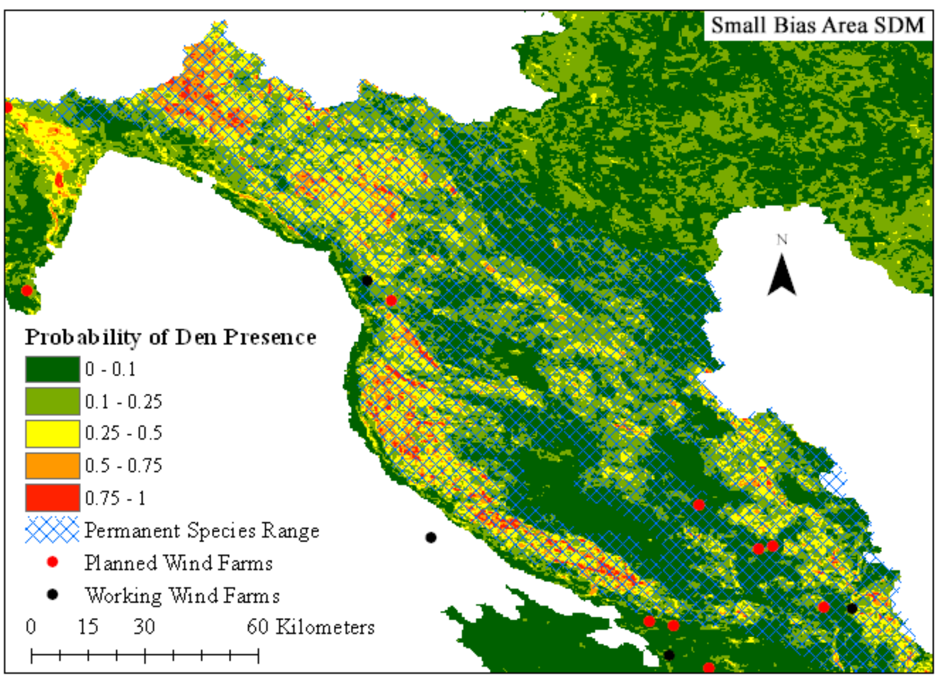

Figure 11. Probability distribution map for Eurasian brown bear den sites in Croatia using a small bias area, scaled to only include permanent species range

4.2 Wind Farms Data and Project Ranking

Overall, the vast majority of proposed turbine sites appear to be located either away from predicted high-quality denning habitat or simply outside the extent of the known species range, especially in southern Dalmatia. However, there are six proposed wind farms located the bear's permanent domestic range and plans to incorporate more or remove existing ones are ongoing. Of the 189 turbines planned for those farms, several do overlap with highly probable denning areas. In the large bias SDM, 37 turbines included cells of 90% den probability with a buffer approximately the size of a male bear's home range (10km from the turbine). In the small bias SDM, 41 turbines overlapped with cells of 90% den probability when given the same buffer (Table 2). While all six of the wind farms within the species range included cells of 80% or greater den presence probability, the highest average den presence probability was still just 20% within 10km of a farm and the average across all was only 16%.

	Over 50% Probability	**Over 75% Probability**	**Over 90% Probability**
Large Bias Area			
1km	32	0	0
Female (3.9km buffer)	138	22	0
Male (10.01km buffer)	189	150	37
Small Bias Area			
1km	36	0	0
Female (3.9km buffer)	149	40	0
Male (10.01km buffer)	189	164	41

Table 1. Number of wind turbines with corresponding buffers that overlap cells of den presence probability over 50%, 75%, and 90%. Male (10.01km) and female (3.9km) buffers are based on approximate home range sizes of 12 GPS-collared bears in Croatia from 2005-2013 (LCL 2015, unpublished).

Chapter 5. Discussion

5.1 Model Differences

The relative statistical similarity of predictability between the two bias area size SDMs prohibits me from confidently supporting one model over the other. If the State Institute for Nature Conservation chooses to take a more lenient approach to reviewing each proposed site, the large bias area results do indicate slightly less overlap with wind farm buffers (Table 3 in Results). Still, the differences between each output in both AUC and standard deviation are statistically insignificant, even though the smaller bias area is more representative of that actual study area.

Despite this, the large bias area SDM does has fewer random likelihood cells, especially outside the species known range, but is less conceptually sound due to the model assuming that we had searched a far larger area for dens than we actually had. The smaller bias area better represents the specific areas that LCL and Faculty of Forestry staff surveyed dens without sacrificing confidence in presence probability, and thus for presentation sake, the output map for the small bias area SDM may be a more accurate picture of true den presence likelihood than the large. As stated in my Methods section, each SDM simply represents a different approach to presence-only occupancy modeling and this comparison was required to be able to choose which output should be trusted most.

That being said, there are several statistics besides AUC used to verify model accuracy (Macal 2005), and while AUC is a widely accepted measure of presence-only habitat model verification, it is not without criticism (Lobo et al 2008). AUC can be especially misleading when models of specialist species are compared to models of generalist species, as generalists, with their comparatively broad habitat selectivity, often have lower AUC scores compared to specialists (Drew et al 2011). The results of my model (AUC=0.77-0.80) are consistent though with other Maxent outputs on bears (Nielsen et al 2010; Roberts et al 2014) and can be considered a good predictor of den presence. Again, a great predictor (AUC>0.9) would likely be an unreasonable goal given the species' wide range and general variation in habitat selection preference. Still, was the first known study to use Maxent modeling on a specific behavior rather than an overall distribution and hopefully it can provide guidance to similar systems where presence-points only represent specific behaviors, such as dens, carcasses, or scent-mark sites.

5.2 Environmental Drivers of Den Distribution

When examining the drivers of den presence likelihood across Croatia, I found that ruggedness and elevation were the principal predictors. On their own, the AUC scores were lower than in the overall model though, suggesting that the added combination of other variables was important to increasing fit overall. Still, ruggedness and elevation are clearly important habitat features for den presence predictability in Croatia. Considering the local abundance of karstic cave formations, high den likelihood in rugged terrain is not surprising. This was confirmed by a study that found 78% of Croatian brown bear dens surveyed between 1980-1992 were located in karstic caves (Huber & Roth 2009). Outside Croatia, bears denning in steep terrain is also common occurrence, as Ciarniello et al (2005) found that mountain dwelling grizzly bears in Canada prefer excavating into slopes or denning in existing hillside caves. Still though, den selection varies greatly both within regions and between them as well, as Vroom et al (1980) found wide variation among north American brown bear denning sites, while Elfström et al (2008) conversely found a strongly preferred set of habitat variables among Scandinavian brown bear denning sites. Brown bears in the Himalayas provide a counterexample to those in Croatia, as they exhibit a strong avoidance of the steepest slopes and highest elevations (Nawaz et al 2014). Furthermore, even among dens in my study, there was variation in site type. While the proportions were consistent with Huber & Roth's 2009 study, dens included both karst caves on highly rugged hillsides (figure 12) as well as forest floor excavations in relatively flat areas at the base of trees (figure 13).

Figure 12. Karst cave used as a wintering den for a Croatian brown bear (*Ursus arctos*) in 2013

Figure 13. Forest floor excavation used as a wintering den for a Croatian brown bear (*Ursus arctos*) in 2013

Perhaps most surprising of all variable contributions was the relatively low impact of farms and settlements to the overall model's prediction of den sites. While brown bear behavior amid anthropogenic disturbance can depend greatly on demographics or individual preference (Fagen & Fagen 1996; Mccullough 1982), evidence from North American brown bears does suggest a site-specific avoidance of people, increasing with decreasing distance to development (Berland et al 2008; Stewart et al 2012). This greatly depends on the type of disturbance though, as individuals may actually prefer travelling on man-made forest roads or trails than through undeveloped areas (Wielgus et al 2002). Forest roads and logging communities are abundant across the species range in Croatia, perhaps to an extent that den selection in their proximity either cannot be avoided or does not represent significant risk. Since the presence of human development contributed less than 4% to the overall model though, it's unlikely that anthropogenic disturbance is a strong predictor of den presence.

The most interesting support for these results comes from a study on brown bears in Slovenia, using an extension of the same population that exists in Croatia. This study found a similarly surprising lack of contribution of all direct human influence on den location. In results consistent with mine, the more rugged the terrain, the more it was used, with dependably little to no attention paid towards human development across the study range (Jerina et al 2003). Both of our results are in contrast to evidence that suggests brown bears are especially sensitive to human disturbance during the denning season (Linnell et al 2000; Swenson et al 1997). Since now two studies have indicated regional contrast of the literature, perhaps this indicates the presence of localized variable whose benefit counteracts the cost of human development.

One hypothesis could be the presence of feeding sites for baited bear hunting. Regulated bear hunting in Croatia relies on bears habituating to man-made feeding sites, usually either a trash dump or an automated feeder timed to release corn each night. Since these feeding sites are in areas that must be accessed by vehicles, bears may be willing to accept the risk of encountering disturbance in exchange for a reliable food source, as habituation to recreational feeding sites in Finland may indicate (Kojola & Heikkinen 2012). If proven in Croatia, this would be similar to the dietary benefits that roads provide bears despite the costs of collision (C. L. Roever et al 2008) or, more directly, the growing attraction of bears to dumpsters in large urban centers (Beckmann & Lackey 2008). Feeding sites could not be included in this model for a number of reasons. Many of these sites may have gone undocumented for decades, many are relocated without notifying the government, and all sites are unevenly distributed around the country, spatially biased towards ease of vehicle access. We also cannot confirm whether the sites are placed where bears are common or whether bears have become common where feeding sites have been placed.

Forest cover presents another interesting metric, as the relative lack of effect is surprising given the local importance of beech (*Fagus silvatica*) as a food source. Two hypotheses may explain this is result though. First, while beech nuts represent the most important source of fat accumulation in the fall (Decāk & et al 2005), bears may eventually leave dense forest areas for more open rocky or karstic terrain when they are ready to den. A second hypothesis is that Velebit, the region to the southwest that was primarily surveyed by the Faculty of Forestry, is less wooded than the regions of Gorski Kotar and Plitvice that primarily compose the northeast clustering of dens, surveyed by the LCL. The relative lack of dense forest cover at high elevations in the Dinaric Alps of Velebit may have reduced the contribution of forest cover in the overall model, since the dens in that area would collectively be located in an area of reduced forest cover compared to the others. As any variation in habitat across all presence points will reduce the contribution of that variable to the overall model, the relatively low contribution of forest cover may be a measure of variation across the two main population sites of this study.

Overall, this study did not examine year-round species distribution, and thus, relative indifference towards human development, forest cover, or any other variable included in the denning season analysis does not imply similar preference throughout the rest of the year. Collectively, the literature indicates that across the brown bear's range, variation in overall habitat preference is high, begging for site-specific studies to determine distribution prior to discussing management decisions.

Specifically, more studies are needed to determine whether the locations of feeding sites are related to high quality den areas and whether the presence of other large carnivores can be related to bear habitat as well. In addition, an SDM of all known bear locations in Croatia would be helpful in comparing winter behavior to the rest of the year, though significant dilution of points would be necessary to avoid spatial autocorrelation of high resolution GPS collar data.

5.3 Wind Farms Impact Prediction and Final Statement

It must first be acknowledged that the vast majority of proposed wind farms do not occur within the known range of brown bears in Croatia. While grey wolf and lynx ranges may incur more overlap with proposed construction sites than bears since their populations expand further south into Dalmatia, my general conclusion is that the construction of the currently proposed wind farms in Croatia is unlikely to significantly influence high quality den habitat over the scale of the brown bear's domestic distribution.

Using the largest buffer size, which approximates the home range size of a male brown bear in Croatia, less than 50 turbines included cells of 90% den presence likelihood. Since one cell is only 0.0002% of the entire buffer, the average chance of den presence across all farms inside the bears range was only 16%. Furthermore, considering the minimal influence of human development on bear den locations, construction appears unlikely to reduce the viability of an area for denning. Despite wind farm development, the ruggedness or elevation of the terrain would not be changed, thus preserving the two most important predictors of den habitat quality.

This does not mean that other communities are also unlikely to be affected, as the wide ranging effects of road construction may be felt by all levels of the food web (Trombulak & Frissell 2000). My study though is a prediction of impact based purely on overlap, as there still remains a major need for pre and post construction analysis of wind energy on ecological processes, specifically relating to large carnivores. It is impossible to predict exactly how the landscape will change with the proliferation of wind energy, yet as Croatia attempts to surpass its EU 2020 goal of becoming one of Europe's top wind energy producing nations, I strongly support on-the-ground examinations of the long-term impacts that such infrastructure development has on protected species.

In the absence of such data, I intend the methodology and results of this report to serve as a template for future review of PA development. Specifically, throughout the course of this project and throughout the next five years, the sites of proposed wind farms have been and will continue to change, often with daily or weekly frequency. As a result, I have given full access of my output maps and data to the State Institute for Nature Protection so they can repeat my methodology whenever sites are added, deleted, or changed.

In conclusion, wind energy represents just one of the many sources of renewable energy that Croatia is exploring. Geothermal plants, solar farms, and hydroelectric dams are currently in the process of review as well, and as such, the State Institute for Nature Conservation may utilize this report in a similar fashion. As a result, Croatia may ideally plan for a future of energy sustainability and independence without compromising the conservation of their natural landscapes.

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