SPATIALLY-EXPLICIT BAT IMPACT SCREENING TOOL FOR WIND TURBINE SITING

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EXECUTIVE SUMMARY

As the U.S. seeks to increase energy production from renewable energy sources, development of wind power resources continues to grow. One of the most important ecological issues restricting wind energy development, especially the siting of wind turbines, is the potential adverse effect on bats. High levels of bat fatality have been recorded at a number of wind energy facilities, especially in the eastern United States. The U.S. Department of Energy contracted with Versar, Inc., and Exponent to develop a spatially-explicit site screening tool to evaluate the mortality of bats resulting from interactions (collisions or barotrauma) with wind turbines. The resulting Bat Vulnerability Assessment Tool (BVAT) presented in this report integrates spatial information about turbine locations, bat habitat features, and bat behavior as it relates to possible interactions with turbines. A model demonstration was conducted that focuses on two bat species, the eastern red bat (*Lasiurus borealis*) and the Indiana bat (*Myotis sodalis*). The eastern red bat is a relatively common tree-roosting species that ranges broadly during migration in the Eastern U.S., whereas the Indiana bat is regional species that migrates between a summer range and cave hibernacula. Moreover, Indiana bats are listed as endangered, and so the impacts to this species are of particular interest.

The model demonstration used conditions at the Mountaineer Wind Energy Center (MWEC), which consists of 44 wind turbines arranged in a linear array near Thomas, West Virginia (Tucker County), to illustrate model functions and not to represent actual or potential impacts of the facility. The turbines at MWEC are erected on the ridge of Backbone Mountain with a nacelle height of 70 meters and a collision area of 72 meters (blade height) or 4,071 meters square. The habitat surrounding the turbines is an Appalachian mixed mesophytic forest. Model sensitivity runs showed that bat mortality in the model was most sensitive to perceptual range and flying height. The BVAT model demonstration found that after 30 model iterations, Red bats suffered greater rates of mortality (i.e., 2.5 times the number of bats killed per 10-day period) than Indiana bats, primarily resulting from the higher flying height of the red bat.

The model described in this report is a first release. There are opportunities to expand and enhance the model in the future. For example, additional focus on the model experience would include adding project level saving/loading, integrating the outputs (trajectory mapping) into the main output window, and providing tools for preparing habitat maps. In addition to the model framework, the actual modeling options could be enhanced by adding associative learning (including additional behavioral states), adding additional movement models, and exploring the information transfer among bats. Ultimately, this standalone model could be integrated into ArcGIS as a plugin.

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1 INTRODUCTION

This project was initiated in response to a request from the DOE EERE–Wind & Water Power Program for research and method development relevant to Topic Area 3: Environmental Impact, Risk Assessment Framework to Identify Siting Questions and Solutions Related to Wildlife and Habitat. The introduction below sets the context for the project in terms of the importance of wind power development, potential impact on bats, need for risk assessment tool, and benefits expected from this Bat Vulnerability Assessment Tool (BVAT).

1.1 WIND POWER DEVELOPMENT

Development of wind power continues to grow in the United States as the nation seeks to increase energy production from renewable energy sources. Over the past decade, the total installed wind power capacity in the U.S. has increased ten-fold to more than 42 GW, almost a quarter of what is currently installed worldwide (www.windpoweringamerica.gov). Although most of the current wind power capacity is found in the western half of the country (Texas has the most with 10,135 MW), development in the east has expanded markedly in the past five years with states in the northeast and Great Lakes Region accounting for roughly 20 percent of capacity; only in the southeast region has wind power development lagged. Through initiatives such as the DOE's Wind Program–Wind Powering America, wind power development will continue to be an important contributor to the nation's energy needs.

Wind power project sites and operations have the potential to adversely affect wildlife. Wind power facilities usually require large expanses of open space during their construction, which can remove or displace wildlife through the loss of habitat. Following construction, as the turbines become operational, there is the potential for injury or death from direct and indirect (pressure-change-mediated barotrauma) contact with the moving turbine blades.

1.2 BATS AND WIND POWER

The impacts to wildlife from wind energy development have been studied since the 70s when the Altamont Wind Facility was constructed in California. Birds, especially raptors (e.g., golden eagles), garnered most of the concern with these western projects, but a number of bat fatalities were also reported from these facilities. Since then, the development of wind energy facilities has proliferated in other parts of the country, including increasingly large development in the eastern U.S. Arnett et al. (2007) evaluated bat fatality data collected at 19 wind energy facilities (21 post-construction surveys) in the U.S. and Canada. Migratory, tree-roosting species of lasiurid bats (e.g., hoary bat, red bat) accounted for most of the fatalities, which consistently peaked in late summer and fall, coinciding with their late-season migration. Many of the studies found low wind speed (< 6 m/s) to be a common factor among fatality events.

Bats are an important part of the ecology of North American ecosystems, providing economic benefits to agriculture worth billions of dollars annually (Boyles et al. 2011). At present, bat fatality is the most important ecological issue facing wind energy development, especially the siting of wind turbines. High levels of bat fatality have been recorded at a number of wind energy facilities, mainly in the eastern U.S.. In one year's study at a West Virginia facility, an estimated 1,364 to 1,980 bats were killed by 44 turbines over 6 weeks of fatality monitoring, during the late summer and early fall bat migration period (Kerns and Kerlinger 2004). So far, fatalities occur mainly among a small number of species, including the migratory tree-roosting bats (eastern red bat, hoary bat, and silver-haired bat) and to a lesser extent the tri-colored bat. Each of these species shares life history characteristics that make them vulnerable to wind turbines, but they also have different habitat requirements for breeding, roosting, and nightly foraging. Using this life history, habitat, and bat behavior information, it should be possible to estimate the potential risk of adverse effect from wind power projects in different landscapes. Reducing impacts to bat populations from wind energy will be critical for many species that are already threatened by other adverse factors such as introduced diseases (e.g., White Nose Syndrome (Boyles et al. 2010; Frick et al. 2010; Meteyer et al. 2012; USFWS 2011)) and climate change (Adams 2010).

1.3 ECOLOGICAL RISK ASSESSMENT FOR WIND TURBINES

Evaluating ecological risks from a spatial perspective is relatively new. Many innovations were incorporated into ecological risk assessment in the early 1990s (Menzie 1995, Menzie et al. 1996, Freshman and Menzie 1996, Kane Driscoll et al. 2002), providing spatially explicit exposure assessment. For too long, the basic ecological risk assumptions and site-wide averages failed to recognize the uniqueness of wildlife populations foraging or migrating across a heterogeneous landscape. Exponent's project staff developed a spatially explicit exposure model (SEEM) in early 2000 to provide risk assessors with a more realistic analytical tool for addressing risks from a spatial perspective; SEEM is accessible to almost any user (Wickwire et al. 2004). In close collaboration with the U.S. Army and U.S. Army Corps of Engineers, the technical bases underlying the model have undergone many levels of review and most recently the credibility of the model and its value were evaluated in real-world field testing for avian exposures (Johnson et al. 2007). The BVAT model is designed using the basic components of the SEEM model platform, lessons learned from the SEEM design process, and the unique aspects of bat habitat use and turbine interactions.

In many regions of the country, the most highly valued and technically feasible wind turbine locations have already been developed or are under consideration for development as wind facilities. Many of the remaining sites with the greatest wind power potential are located where transmission to load centers is very limited. As more optimal sites are developed, wind project siting will likely shift to lower-wind-quality sites. Such lower-quality sites have not been evaluated for potential ecological impacts and will require detailed investigation and analysis. Designing and implementing wildlife studies require both time (often multiple seasons for migratory species such as bats) and funding.

1.4 PROJECT OBJECTIVE

The objective of this project is to develop a spatially-explicit site screening tool for wind turbines that integrates spatial information on locations of turbines, bat habitat, and bat behavior. This bat-wind turbine impact screening tool will estimate the potential for bat fatality from interactions (collisions and barotrauma) with wind turbines. This tool will be built using an existing spatially-explicit exposure tool platform (the Spatially Explicit Exposure Model or SEEM).

1.5 PROJECT BENEFITS

The bat vulnerability assessment tool or BVAT will allow managers to “visualize” and explore quantitatively how alternative placement, designs, and layouts of wind turbines can potentially affect bat populations. This tool should eliminate the need for intensive field studies at sites expected to have high bat-turbine interactions and will help focus studies on sites more likely to be approved. The tool could also facilitate discussions among project proponents and resource trustee agencies by providing a common forum for information and analysis. Lastly, this tool is flexible enough to be refined for local conditions and adapted for other potentially affected species, such as birds.

2 MODEL DEVELOPMENT

As described above, development of a BVAT could enhance efficient and environmentally friendly wind power development. The sections below detail the steps undertaken in this project to develop this tool, including the conceptual basis of the model, characterizing the landscape, compiling essential bat behavior information, use of the SEEM platform, and test runs to refine the model.

2.1 CONCEPTUAL APPROACH

Our approach combines expertise in spatially-explicit exposure modeling with knowledge of bat ecology and wind turbine operations. The BVAT model is a spatially-explicit tool that integrates the relevant spatial information for bat movement on the one hand and the distribution of wind turbines on the other. We assume that the probability of bat-turbine interaction is related to these key factors and that the likelihood of an interaction is governed by the relative spatial distributions of wind turbines and bat movement. The approach involves the following steps:

1. Develop a conceptual model for combining bat movements at wind turbine locations
2. Capture the distribution of bat-relevant habitats and wind turbine locations in a base Geographic Information System (GIS) layer
3. Based on the ecology of the bats, identify ecologically relevant rules for bat movements, using both habitat and seasonal (roosting versus migration) factors
4. Enhance the 2-dimensional, Spatially Explicit Exposure Model (SEEM) by adding a third dimension as a probability to locate a species in a specific vertical horizon
5. Test the draft tool by applying the bat movement rules for two species (red bat and Indiana bat) to a landscape with the habitats and wind turbines from an existing wind facility

2.2 CHARACTERIZING THE LANDSCAPE

Landscapes used for wind energy development are often extensive, ranging in size to hundreds of acres depending on the number of wind turbines installed. The Mountaineer Wind Energy Project in Tucker, West Virginia[1], is a linear array of 44 turbines spanning more than 6 miles. Although the footprint of a single turbine is relatively small (less than 0.1 acre), the interspacing of turbines can be considerable. For the Mountaineer project the distance between

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[1] We use publicly available information on the Mountaineer Site to populate our model. We are not commenting on or critiquing this wind development facility, but rather using real-world inputs to test the model. Any conclusions reached are focused on our unique model inputs and not based on the on-the-ground work completed in the design of the facility.

turbines is approximately 1.5 miles. Given the large extent of landscapes affected, the area surrounding a wind energy facility often includes a variety of habitats such as forests, open waters, and cleared areas for project infrastructure (e.g., access roads and construction laydown areas). To characterize landscapes for wind energy siting, we relied on readily available aerial mapping with habitat classification such as the National Land Cover Database (NLCD). The NLCD 2006 (Fry 2011) provides a 30 x 30 meter resolution map with 16 primary land cover classifications that affords a suitable base map for the BVAT. However, the BVAT tool could accommodate habitat mapping at an enhanced scale depending on the user's proficiency.

2.3 BAT BEHAVIOR

With more than 40 known species, bats are one of the most diverse groups of animals in North America. Bats occur in a wide range of habitats including forests, deserts, scrublands, as well as around aquatic habitats, where they are primarily generalists or specialists on insect prey (a few species in North America rely on fruits or plant nectar). As an attribute of this diversity, bats exhibit a remarkable variety of ecological behaviors and life histories. In any one region, there are likely to be several species of bat, each suited to its own ecological niche. To provide ecological context to the BVAT model, we considered the following bat behaviors, which we concluded would have the most bearing on how species interact with and are affected by wind energy facilities. Below we provide a general discussion of each ecological behavior and follow with a more detailed description of the two species we examined using the model: eastern red bat and Indiana bat.

- Flight speed
- Home range
- Foraging distance
- Roosting habitat
- Foraging habitat
- Flight height
- Time spent foraging

Bats are primarily active from April to November, so we assumed that bats in winter would be hibernating and would not be at risk from wind turbines. At the same time, we recognize that bat behavior varies by season, so we considered the different phases of the flight season–spring migration, summer breeding, and late-summer/fall migration. During the breeding or flight season, most species prefer forested habitats with mature trees that provide roost sites (e.g., cavities, loose bark); bats generally stay in the same area but will shift roosts from day to day. The foraging strategies of bats have been well researched and relate directly to the diversity of bats occurring on the landscape. Bat activity is often highest around aquatic habitats or riparian corridors. Bats are generally categorized as open foragers (e.g., silver-haired bat), edge foragers (e.g., little brown bat), intermediate clutter foragers (e.g., red bat), or clutter foragers (e.g., northern long-eared bat). However, species such as hoary bat and big brown bat feed more often above the forest canopy. In general, the height at which bats fly is related to habitat preference. For example, more clutter-adapted species (*Myotis* spp.) fly at the lowest altitudes, whereas larger, faster-flying species such as hoary bat fly at the highest altitudes. Bats are generally most active just after dusk, when they feed for several hours before returning to roost. The size of foraging areas and the length of nightly commuting distance depends upon the species.

Speed of flight in bats has been measured for only a few species, and in some cases, only under artificial conditions. Salcedo et al.'s (1995) study using Doppler radar readings of bat flight speed estimated that the average foraging rate is 6.7 m/s for red bats and 7.7 m/s for hoary bats. Earlier studies conducted under artificial conditions indicated slower flight speeds for both species. Most reports of bat activity describe them flying from ground level to heights at or above tree canopy, although this may be an artifact of methods for studying bats. Mist-nets can only be efficiently managed up to 3 or 4 tiers (less than 10 meters) and bat acoustic detection equipment is limited as ultrasonic calls of bats attenuate within a few tens of meters. Although exceptionally high-altitude bat flight has been reported, McCracken et al. (2008) reported echolocating calls of Brazilian free-tailed bats (*Tadarida brasiliensis*) flying up to 1,118 m above ground level (AGL). Most of the calls in that study indicated that the peak feeding activity of the bats was at 400-500 m AGL. Other studies using visual triangulation and radar techniques show this species ascending to 3,000 m AGL (Williams et al. 1973). Peurach et al. (2009) summarized records of bats colliding with aircraft over a decade and reported 36% of reported collisions occurred between 300 and 3,000 m AGL, with an average altitude of 345 m AGL. Bat species most commonly reported colliding with aircraft included Brazilian free-tailed bat, red bat, and hoary bat, with 57% of collisions occurring between August and October. One high-altitude occurrence of note was a hoary bat (*Lasiurus cinereus*) that collided with an aircraft at 2,438 m AGL over Oklahoma (Peurach 2003).

The construction of industrial-scale wind energy facilities has provided additional insight into the flight habits of bats. Post-construction fatality studies have repeatedly documented adverse effects on bats either from direct contact with turbine blades (Arnett et al. 2008) or from barotrauma, i.e., damage to the respiratory system caused by a sudden loss of air pressure near moving blades (Baerwald et al. 2008). The development of wind energy has revealed that bats often fly at the heights of turbines, as evidenced by the high levels of fatality at many facilities (Arnett et al. 2007). Horn (2005) used a thermal imaging camera to record bats flying around turbine blades at more than 100 m AGL. Arnett et al. (2006) reported differences in bat activity measured by ultrasonic acoustic detection at different heights above ground. Bat detectors deployed on meteorological towers that were 44 m AGL recorded more low-frequency bats (e.g., hoary bat, red bat), whereas detectors positioned near the ground recorded more high-frequency bats (e.g., *Myotis* species). Detectors mounted on portable towers at an intermediate height of 22 m showed no difference between the two groups of bats.

2.4 BATS AT RISK

While many bat species are at risk of fatality from wind turbines in the eastern U.S., those commonly referred to as migratory tree roosting bats, e.g., the eastern red bat (*Lasiurus borealis*) and hoary bat (*Lasiurus cinereus*), are believed to be most vulnerable. These two species account for a large percentage of the bat fatalities at wind farms in North America (Arnett et al. 2008). Both species range broadly in North America throughout the year, but generally migrate between summer breeding ranges in the north and wintering ranges in the south (Cryan and Veilleux 2007). Although long-term population trends for these two species are uncertain and suspected to be declining (Carter et al. 2003b), eastern red bat is still relatively common in eastern North America as a resident and migratory species. For this reason, we have chosen the eastern red bat as a model species for developing the BVAT. The ecological and behavioral variables associated with the red bat were used to construct and test the model. In addition, we chose a second species, the federally endangered Indiana bat (*Myotis sodalis*), as a second model species for developing the tool. Indiana bats are migratory and make seasonal movements between winter hibernacula (i.e., caves) and their summer ranges consist mainly of woodland habitats (USFWS 2007). Because of their endangered status, the vulnerability of Indiana bats to wind turbines is of special interest. By using both species, the ability of the model to incorporate different variable inputs is demonstrated.

Eastern Red Bat

The eastern red bat (*Lasiurus borealis*) is broadly distributed in the eastern United States, ranging from Southern Canada to the central Gulf Coast States, and west to the eastern Rocky Mountains and northern Mexico (BCI 200; Shump and Shump 1982). The area of greatest abundance for this species is the Midwest and east-central states (Barbour and Davis 1969). Although some red bats remain year-round in the southern part of their range, many migrate during spring into the northern U.S. and Canada to give birth to and raise offspring (Cryan et al. 2004). Autumn migration occurs mainly in August and September and mating occurs during this time as well. During winter, eastern red bats hibernate in the southern part of their range (Cryan 2003), although males may overwinter farther north than females (Dunbar and Tomasi 2006). They use a variety of locations including tree hollows and other places of concealment in trees, as well as leaf litter and other vegetation on the forest floor (BCI 2001). Summer roosting of the eastern red bat usually occurs in deciduous trees. However in more urban landscapes, they have been found roosting in leaf litter, dense grass, and roof shingles (Mager and Nelson 2001). When roosting in trees, the bats hang from branches within foliage surrounding them. Summer roosts often have a southern exposure, where the foliage is most dense and becomes warmest (BCI 2001).

Eastern red bats generally prefer deciduous forests for roosting habitat during the flight season, but can occur in a variety of other habitats when foraging. In the Coastal Plain of South Carolina, Menzel et al. (2005a) found eastern red bats preferred riparian to upland areas based on bat activity measured by acoustic detection. Within the riparian area, eastern red bats were detected more often in cluttered than open settings as measured by detectors placed below (2 and 10 meters) and above the forest canopy (30 meters), respectively. Based on wing aspect ratio (wing length/wing width) and wing loading (mass/wing area), Menzel et al. (2005a) classified eastern red bat as clutter-adapted, indicating that this species would be more likely to forage in cluttered environments such as those found in forested habitats. Eastern red bats have been found hibernating in forest leaf litter during winter (Boyles et al. 2003).

Flight behavior varies diurnally. Eastern red bats are among the earliest to emerge after sunset to forage. Caire et al. (1988) found most foraging activity within the first four hours after sunset based on capture data using mist nets. Although feeding activity is greatest in the early part of the night, some bats will feed throughout the night including females that are nursing young (BCI 2001). They will fly high at first, but descend closer to the ground to forage as darkness increases (BCI 2001). Eastern red bats feed primarily on beetles and moths (Carter et al. 2003). The monthly mist net capture height averaged between 2.2 m and 3.4 m from May through August (Caire 1988). Their flight speed is swift on narrow wings, which lessens their maneuverability.

Flight behavior varies with land use type. Eastern red bats forage in a variety of habitats including along the edges of pastures, croplands, and woodland openings. Walters et al. (2007) radiotracked red bats as they foraged during the summer in Indianapolis, Indiana. They found that bats foraged in woodlands, over areas newly planted with trees, and over open water, park, and pasture lands, but avoided urban areas. Red bats were loyal to both foraging and roosting areas with each bat foraging in the same areas each night and returning to roosts in the same tree or nearby. The maximum distance flown on a night ranged from 0.42 to 1.76 km, but overall averaged slightly less than 1 km. Red bats foraged mostly in woodlots (32.4%), followed by agricultural areas (25.5%), and open habitats (23.2%, either fields with newly planted trees or pastures). Less time was spent foraging in residential areas, over water, and parklands. The home range size of red bats in this setting were surprisingly low (68.72 ha) in comparison to other bat species and red bats at other locations with more heavily forested areas.

Flight behavior varies on a seasonal basis. Eastern red bats may be distributed irregularly over their range during the breeding season. Kurta (2010) found significantly more adult males than females in Lower Peninsula Michigan from June into August. Britzke et al. (2009) suggested that, based on analyses of stable isotopes of hydrogen in hair, male red bats may migrate north later than females, which could explain the late season influx of males positioning themselves for the return migration of females in late summer/fall. Caire et al. (1988) found that the numbers of adult male red bats in eastern Oklahoma peaked during August. In central Iowa, Kunz (1971) found relatively few adult males from spring to early summer, but even numbers between sexes from late summer into fall.

Population estimates of eastern red bats are uncertain given that they are broadly dispersed over a vast landscape and because of their solitary nature and nocturnal habits. Historical accounts of autumn migration suggest that many migratory tree roosting or lasiurine species (e.g., red bat, hoary bat) have been much more abundant in the past (Carter et al. 2003b). Eastern red bats are one of the most adversely affected species by wind energy development in eastern North America (Arnett et al. 2008). Many hypotheses have been developed to explain the high fatality to this species, but to date none have been accepted unanimously (Cryan and Brown 2007; Cryan 2008; Cryan and Barclay 2009). The variables for red bat model construction are shown in Table 1 below.

Table 2-1. Red bat model inputs

Ecological Variable	Value	Notes	Reference
Flight speed	6.7 m/s (Average foraging speed)[1] On a level, straight course, the flight of this bat is swift, and it may attain a speed of 64 km/h (40 mph)[2]	Mean flight speed while foraging measured using a Doppler radar system	[1]Salcedo et al. 1995 [2]Saunders, D. A. 1988.
Home range	68.72 ha (Indianapolis)[3] 94.4 ha	Minimum convex polygon (MCP) from radio-tracking data in urban-rural landscape 95% adaptive kernel estimator from radio-tracking data in managed pinelands	[3]Walters et al. 2007 Elmore et al. 2005
Foraging distance	0.95 km (Max. avg.) 0.7 to 2.1 km (Max avg.)	Maximum distance flown by an individual bat from roost to foraging area Range of maximum distances flown among male and female, juvenile and adult bats reported separately	Everson 2005 Elmore et al. 2005
Roosting Habitat	Deciduous Forest Roost in open areas; edges of woolots[4] Large diameter live hardwood trees; foliage[5] Prefer to roost in hardwoods, even when pines are present[4] Roost closer to roads than random sites[4,6] Hutchinson and Lacki never found roosts < 50m from edge habitat[7] Choose roost sites near water more than expected by chance on Eastern Shore of Maryland[4] Choose urban sites to roost more than expected by chance on Eastern Shore of Maryland[4]		[4]Limpert et al. 2007 [5]O'Keefe et al. 2009 [6]Perry et al. 2007 [7]Hutchinson and Lacki 2009
Foraging Habitat	Forage mostly in woodlots (32.4%)[3] Prefer to forage in open habitats[8] Bats foraged in woodlands, over areas newly planted with trees, open water, park and pasture lands and avoided urban areas[3] Bat activity was greater in open upland habitats than cluttered upland forests[9]		[3]Walters et al. 2007 [8]Menzel et al. 2002 [9]Menzel et al. 2005a
Flight Height	Are known for their extremely high feeding (300 to 600 feet) early in the evening		http://www.bobpickett.org/order_chiroptera.htm#erb
Time spent foraging	Forage 25.5% of the time in agricultural areas[3]		[3]Walters et al. 2007

Indiana Bat

The Indiana bat (*Myotis sodalis*) was originally listed on March 11, 1967 as being in danger of extinction under the Endangered Species Preservation Act of 1966, but is currently protected under the Endangered Species Act (ESA) of 1973, as amended (USFWS 2007). Given its migratory nature, the distribution of this species depends upon the season. In winter, Indiana bats roost colonially in caves, most of which are located in the Appalachian Mountain region. In summer, Indiana bats disperse over the landscape into primarily forested habitats with pregnant females forming maternity colonies. In 2006, the USFWS (2007) had records of extant winter populations at approximately 281 cave hibernacula in 19 states and 269 maternity colonies in 16 states; the 2005 winter census estimated the population was 457,000 bats. Historical accounts of the abundance of Indiana bats are unclear. Extensive areas of staining in caves and presence of bones in widespread raccoon scats suggest more expansive populations in the past. More recent data on the distribution of Indiana bats indicates a shift in range from south to north (USFWS 2007). It is not known whether this is related to climate change, but suggests a certain degree of plasticity of bats when choosing winter hibernation sites.

Indiana bats generally follow a regular pattern of seasonal activity. The bats hibernate in caves from late fall through winter (Barbour and Davis 1969) and emerge in early spring with a short “swarming” period, where some mating activity may occur (Whitaker and Hamilton 1998). Female bats usually depart earlier, migrating to summer ranges in the surrounding region, where they form maternity colonies of up to 100 bats (Kurta 2004). Females give birth to a single young from mid-June to early July (Thomson 1982) and, shortly thereafter, the female and young bats begin their migration to cave hibernacula, generally arriving in August (Barbour and Davis 1969). The bats remain active in the region surrounding the cave, and engage in “fall swarming” when most mating activity occurs (Whitaker and Hamilton 1998). At this time, bats continue to roost in trees, preferring those in close proximity to the cave (Brack 2006). The majority of bats settle into hibernation by November (Barbour and Davis 1969).

The roosting behavior of the Indiana bat has been well studied. Kurta (2004) summarized roosting habitat preferences of Indiana bats based on information collected on 393 roost trees distributed in 11 states. Maternity colonies composed of females either pregnant or with young were more likely to be found in agricultural areas with fragmented forests rather than in extensively forested areas. Roost trees are more likely to be situated in relatively open areas or along the edge of a forest, where there may be good sun exposure and roosting sites are more accessible (Whitaker and Brack 2002); less commonly, Indiana bats have used buildings for maternity roosting (Butchkoski and Hassinger 2002). Individual trees used usually have larger diameters than surrounding trees, are deciduous with exfoliating bark, and either dead or dying. Maternity colonies composed of up to 100 Indiana bats occupy a number of roost trees in an area and regularly change roost location every 2 to 3 days. Larger roost locations that are more consistently used are referred to as “primary roosts,” whereas those used secondarily or less frequently are referred to as “alternate roosts.” Indiana bat maternity colonies show fidelity to a home range and roosting location, returning to the area in consecutive years. Although some males may remain in caves during the summer season, most disperse in the region and also roost singly in trees with similar characteristics as those of maternity colonies. Carter (2006) stressed the importance of hydric habitats to Indiana bats, especially in the Midwest where maternity colonies are larger (up to 100 or more individuals) than other parts of its range.

Foraging patterns in Indiana bats have also been well studied. During the summer, Indiana bats usually emerge from their roosts to forage within a half-hour after sunset (Viele et al. 2002). Indiana bats forage primarily in forested habitats either within or beneath the tree canopy (BCI 2001). Brack (1989) described Indiana bats foraging in the forest canopy of both riparian and non-riparian habitats, and using subcanopy habitats of riparian forests as travel corridors along streams. Lee and McCracken (2004) reported that captures using a 10-meter mist net declined with increasing height, and approximately 90 percent of all captures were below 6 meters. However, at sites where Indiana bats were captured with little brown bats, the Indiana bats were netted at 4 to 7 meters whereas little brown bats were netted at 1 to 3 meters. This suggests a partitioning of foraging habitat. Indiana bats occasionally roost during the night. Murray and Kurta (2005) reported both pregnant and lactating females night roosted as solitary individuals in trees within their foraging areas. Night roosting occurred up to 6 times per night for 14±1 min each time. Bats foraged for most of the night, with the total duration of flight equaling 375±16 min/night.

Time of year, habitat types and their extent, as well as the method of calculation all affect the home range and/or foraging area size of Indiana bats. In Indiana, the foraging range of female bats averaged 335 ha (ranging from 0.5 to 7.4 km^2) and the maximum distance flown from the roost averaged 3.0 km (ranging from 0.8 to 8.4 km; Sparks et al. 2005). The bats in this study preferred foraging in forested habitats (including riparian habitats with wooded buffers). This was illustrated by the finding that woodlands accounted for only 13% of total area and tracked bats were located in them 45% of the time. In Michigan, female bats used foraging areas that were located up to 4.2 km from the day roost (Murray and Kurta 2005). Bats did not fly over open fields but travelled along wooded corridors, even though this behavior increased commuting distance by 55±11%. In Ohio, Kniowski and Gehrt (2011) reported average home ranges sizes for female bats of 210.5 ha and 374.2 ha. Although this site was heavily agricultural (85% cropland), the Indiana bats showed a preference for forest and open water habitats for foraging (7% and 1%, respectively). Overall, 95% of day roost trees were within 4,000 m of foraging ranges, and 75% were within 1,200 m. One Indiana bat was tracked in consecutive years and showed a fidelity to the area with an overlap of home ranges between years of 23.1%. In this highly fragmented landscape, bats foraged in remote wooded areas often reached after crossing cropland expanses of 1 km or more. The variables for Indiana bat model construction are shown in Table 2-2.

Table 2-2. Indiana bat model inputs.

Ecological Variable	Value	Notes	Reference
Flight speed	4.8 m/s	Measured in cave	Patterson and Hardin 1969
Home range	144.7 ha (females 161 ha; males 116 ha) 210.5 ha/374.2 ha (females) 335 ha (all females)	95% ADK Fixed kernel/MCP 95% MCP	Menzel et al. 2005b Kniowski 2011 Sparks et al. 2005
Foraging distance	3.02 km (range 0.80 to 8.37 km)	Maximum distance traveled from roost	Sparks et al. 2005
Roosting Habitat	Forested wetlands		Kurta 2002
Foraging Habitat	Riparian forests, upland forests, forest edges Woodlands; some agricultural lands; transit through riparian corridor	Used light-tags	Brack 1989 Sparks et al. 2005
Flight Height	Forest canopy or subcanopy 90% captures less than 6 meters		Brack 1989 Lee and McCracken 2004
Time spent foraging	Emergence averaged 23-25 min after sunset 375 min/night Two feeding bouts – early evening and before sunrise	Maternity colonies in MI & IL Foraged most of the night; with occasional night-roosting	Viele et al. 2002 Murray and Kurta 2004 BCI 2001

2.5 USING THE SEEM PLATFORM

The development of the Bat Vulnerability Assessment Tool (BVAT) was guided conceptually by the development of an earlier wildlife exposure model called the Spatially Explicit Exposure Model (SEEM) (Wickwire 2011a, b). Conceptually, both models focus on:

- Using key wildlife behavioral characteristics to model movement across a landscape
- Balancing user accessibility with mathematical/programming sophistication
- Tabulating interactions with a stressor by individuals
- Allowing for assessment of a (mathematical) population of individuals rather than the more standard assessment of a representative individual
- Providing user flexibility to develop sensitivity analyses and customized research questions

The rules-based movement algorithms differ between the models, but generally rely on the user to input key site and species data. In both models, the input sources range in specificity from general literature defaults to directly measured values collected from a specific study site.

With respect to the movement algorithm, SEEM relies on users to establish a daily foraging range and select the number of daily foraging events. Using a combination of habitat suitability and random numbers, individuals are placed on the defined landscape. Movement is guided by a rejection method in which new potential positions are identified and compared with a bias toward higher habitat suitabilities. For BVAT, movement is instead defined by a combination of time spent foraging in a location and the density of foraging (or roosting) locations in various habitats. Conceptually, movement is guided by a combination of habitat suitability and randomness.

The modeling platforms used by SEEM and BVAT differ. Over the 10 years SEEM has been operating, programming languages and approaches have changed. The programming platform selected uses the most efficient, transparent and adaptable approach for the development of BVAT. SEEM has a basic internal polygon drawing tool that was not needed in BVAT given the prevalence of freely available digital maps. However, the overall development approach builds from lessons learned in developing and subsequently updating SEEM over the years.

3 MODEL OVERVIEW

The BVAT tool is designed to assess, in a screening, the interaction of bats with potential turbine locations based on (1) the characteristics of the turbines (zone of influence and X, Y coordinates), (2) the bats (foraging and roosting densities, height of flight, roosting vs. foraging time), and (3) habitat. Habitat is built into the foraging and roosting densities, i.e. bats are more likely to forage and roost in higher quality habitat.

3.1 KEY ASSUMPTIONS

As is the case with all models, BVAT attempts to replicate behaviors and interactions that are complex and subject to variability and uncertainty. The assumptions that underlie the development and application of the model are as follows:

- The model is not designed to estimate absolute bat mortality – rather it is a comparative tool useful for site selection and turbine placement risk management.
- A model is only as powerful as the inputs. BVAT can operate with default inputs, but the value for site-specific assessment will be lower than using inputs that are directly measured at a site or represent a specific bat species.
- BVAT is one of many tools likely to be applied during the wind turbine siting process. Evaluating conditions on the ground will greatly enhance the value of the model at specific sites.
- The version described in this report is the first release and has not been externally reviewed. We welcome and encourage use and comment.
- We recognize that inputs such as foraging density and roosting density are not readily obtained without some level of field verification. We are in the process of developing a tool to assist in distributing densities across a study area by pixel and specific habitat type. The total density, however, is dependent on the size of the assessment area and the quality of the mixture of different habitats for the bat species of interest. Multiple runs with varying densities will provide insights into the most appropriate total densities.
- Access to geographic information system (GIS) services is needed to use the model. We assume that data such as wind turbine locations are available with X, Y coordinates in an electronic file and that users of the model will have access to the internet from which habitat maps are available. A basic primer on projections is provided to facilitate the selection and correct incorporation of spatially explicit map data (Appendix A).
- The model will enhance the existing siting process, but will not replace existing components of that process; for example, the model is not intended to replace direct field assessment of wildlife interactions with turbines.

3.2 BASIS FOR DESIGN

The design goal for BVAT, which is consistent with the design goal for SEEM, is to create a model that is quantitatively sound, reflects ecological realities to the extent possible, but also remains accessible to risk managers and planners. In addition, we incorporated insights from previous model efforts and studies of bat behaviors. The required inputs were selected based not only on the importance with respect to predicting bat movements, but also based on the availability of the inputs either through literature studies or direct field measurement. As discussed previously, the model is designed to fit into a much larger siting and development process, not to replace any existing step in that process.

3.3 UNCERTAINTIES

The model requires rigorous review in order to best understand the uncertainties, strengths, and weaknesses, and to more completely understand its role in the selecting wind power development sites. The most effective approach for managing the following uncertainties is a sensitivity analysis.

- Density dependent inputs (foraging and roosting point densities) are subject to variability across users and sites. There is no specific path to determining the density beyond a field assessment.
- The model does not currently account for external factors such as weather, elevation, and disease that may influence bat behaviors with respect to turbine interactions.
- Care must be used when selecting inputs so as not to bias the results. Running multiple iterations with varying inputs will protect against this potential uncertainty.
- Specific to this release, BVAT Release 1.0 has undergone only basic internal testing. To reduce the uncertainties the model requires external review as well as peer review of the modeling assumptions and approach.

4 MODELING APPROACH

4.1 PROGRAMMING PLATFORM[2]

BVAT was primarily developed in cross-platform C++ using the Qt application framework, including components of QGIS (QGIS Development Team 2013), GRASS (GRASS Development Team 2008), and GDAL (2008) for GIS interoperability. The simulation and plotting functions were developed in R (R Core Team 2013), and are loaded on-demand from the application folder so advanced users can customize the simulation for particular needs without recompiling the main application. An embedded R interpreter and all required packages are included in the software distribution. In addition, the simulation can be run using supplied R programs alone, fully independent of the BVAT graphical user interface (GUI).

4.2 MOVEMENT DESIGNS

BVAT is a spatially-explicit, agent-based model, which simulates the movement of individual bats as a function of local habitat characteristics. Local habitat is defined in terms of a raster image with foraging and roosting point densities assigned by cell value. Typically a user would use existing high-resolution, satellite-derived land cover data, produced by the USGS and other agencies and organizations.[3] The NLCD 2006 (Fry 2011), a 30×30 meter resolution map with 16 primary land cover classifications, is used for prototype examples.

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[2] The user of this Bat Vulnerability Assessment Tool ("Tool") understands that it is an Early Version Release provided to Versar, Inc. and the Department of Energy pursuant to written agreement and provided pursuant to an experimental conceptual model along with some additional development and testing pursuant to written agreement. The Tool has not undergone rigorous internal or external testing and therefore may not be sufficiently debugged. This Early Version is released to solicit comment and for some additional testing and there is no warranty, guarantee or representations regarding the use or the results of the use of the Tool or that operation will be uninterrupted or error-free.

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[3] The USGS Land Cover Institute maintains a database of land cover data sources available for North America and globally: http://landcover.usgs.gov/landcoverdata.php

The simulation is initialized by generating a random number of roosting and foraging points within each grid cell, according to a Poisson point process. At each grid cell, a random number of points are generated from a Poisson distribution with intensity parameter λ equal to the density, or expected number of points to be generated for that grid cell. A “jitter” function, random values between 0 and 0.5 times the cell width and cell height, are added to the center point of the cell to randomly distribute points within each cell. This approach to a realization of the inhomogenous Poisson process on an image was adapted from the R spatstat library.[4]

After a suitable set of foraging and roosting points are generated across the terrain, individual bats represented in X, Y, Z coordinates are randomly allocated among roosting points. User-entered roosting or foraging probabilities by hour are used to randomly select either a roosting or foraging state for each bat. Depending on the state, the bat will randomly select either a roosting or foraging point within the perceptual range and start moving toward that point; if no roosting or foraging point is within the perceptual range, the bat will move in a random direction until one is encountered. Bearings are simulated from a wrapped Cauchy distribution centered on the angle toward the roosting/foraging point where the bat is flying. A “tortuosity” parameter ranging from 0 to 1 corresponds to the concentration parameter of the distribution. In effect, values closer to 0 tend to cause the bat to move in less directed paths toward the selected point, and paths approach a straight line with values closer to 1. The wrapped Cauchy distribution is frequently used for trajectory simulations in ecology; a number of additional circular distributions are provided with the model for advanced users.

Bats move toward the roosting/foraging point with a constant step length, e.g., 30 meters/minute, and by default their position is updated every minute. When the bat is within one step length of the selected point, it will remain at that position for a random number of minutes simulated from an exponential distribution, with the expected number of minutes entered by the user. After that time has elapsed, a roosting/foraging state is selected based on the current model time and transition matrix, and the bat repeats the process of selecting a new point and moving toward it. Bat flying heights are simulated from a normal distribution with specified mean and standard deviation.

Wind turbines are represented by spheres, with specified X, Y, Z center coordinates, typically represented by nacelle height, and a specified collision radius, which would typically be a blade length plus an additional offset to account for barotrauma. When the bat is within the sphere representing the turbine, it collides with a user-defined probability of collision for each turbine. The collision is recorded and the bat is removed from the remainder of the simulation.

4.3 LIMITATIONS AND POTENTIAL FUTURE ADDITIONS

The model described in this report is a first release. There are opportunities to expand and enhance the model in the future. For example, additional focus on the model experience would include adding project level saving/loading, integrating the outputs (trajectory mapping) into the

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[4] http://cran.r-project.org/web/packages/spatstat/index.html

main output window, and providing tools for preparing habitat maps. In addition to the model framework, the actual modeling options could be enhanced by adding associative learning, including additional behavioral states, adding additional movement models and exploring the information transfer among bats. The BVAT model presently has a number of capabilities in the simulation program, such as customized time step size and different distributions for simulated bearing, height, and residence time, which are not shown to the user through the GUI. The option to modify these capabilities could potentially be added in a future version. Ultimately, this standalone model could be integrated into ArcGIS as a plugin.

4.4 MODEL RUNS

Running the BVAT model requires three groups of inputs:

- Bat population inputs defining movement/behaviors on a landscape
- Wind turbine characteristics and location
- Habitat types and suitability for bat roosting and foraging.

The team selected inputs to be consistent with readily available, ecologically accurate characteristics of different bat species (or in the case of turbines, consistent with design specifications). However, we recognize that some of the inputs may require professional judgment and deeper research than others. The model has been designed as one tool among several needed for assessment. It is most powerful as a research screening tool (e.g., comparing different locations based on similar inputs or how varying inputs influence results within a given location). As inputs improve the accuracy of the model will improve, but even with a base level of input detail, the model can have value in comparing scenarios.

Along with the bat ecological parameter inputs, the BVAT model requires an estimate of density of “targets” that conceptually bats within a landscape would move toward based on their habitat preferences during roosting and foraging states. The number of targets selected by the user is apportioned across the project landscape based on habitat preferences that are also under user control. By allowing the user to manipulate target density, the BVAT model can be adjusted to different scales, which may reflect more meaningful output of predicted bat fatality. In practice, when comparing alternative wind turbine arrangements on a candidate landscape, target density would remain constant for all of the comparative model runs.

Detailed descriptions about the model inputs, running the model and model outputs are provided in Appendix A.

4.5 MODEL DEMONSTRATION OVERVIEW

A case study using the BAT MODEL was performed using habitat and turbine information from the existing Mountaineer Wind Energy Center (MWEC)[5]. The MWEC consists of 44 wind turbines near Thomas, West Virginia, in Tucker County (Kerns and Kerlinger 2004). The turbines were erected on the ridge of Backbone Mountain with a nacelle height of 70 meters and a collision area of radius of 72 meters (blade height) or 4,071 meters square (Horn et al. 2008). The habitat surrounding the turbines is an Appalachian mixed mesophytic forest.

Between April 4th and November 11th, 2003, all 44 turbines were searched on 66 days (Kerns and Kerlinger 2004). Searches conducted 60 meters around each turbine found 475 bat carcasses of multiple bat species including big brown (*Eptesicus fuscus*), hoary (*Lasiurus cinereus*), little brown (*Myotis lucifugus*), eastern red (*Lasiurus borealis*), silver-haired (*Lasionycteris noctivagans*), northern long-ear (*Myotis septentrionalis*), and tri-colored (*Perimyotis subflavus*) bats.

Between July 31st and September 11th, 2004, half of the 44 turbines were searched for bat carcasses every day and the other half were searched once a week (Kerns et al 2005). 398 bat carcasses were found during this time period.

During ten nights in August 2004, three cameras were used to record interactions of nightly flight activity of bats and the wind turbines at MWEC (Horn et al 2008). 998 bats were observed during the ten nights with 5 bat collisions of the turbine blades and 41 bats changing flight patterns to avoid being struck by the blades.

For the model demonstration, detailed descriptions about the model inputs, running the model and model outputs are provided in Appendix A. In summary, model sensitivity runs showed that bat mortality in the model was most sensitive to perceptual range and flying height. Fatalities in Indiana bat increased substantially with increases in either perceptual range or flying height, but increased less with increases in step length (flying speed). Fatalities in Indiana bat remained similar over the full range of tortuosity. The BVAT model demonstration found that after 30 model iterations, Red bats suffered greater rates of mortality than Indiana bats, primarily resulting from the higher flying height of the red bat.

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[5] The case study is for model testing purposes and is in no way a comment on historic analyses completed at this location.

5 DISCUSSION AND NEXT STEPS

As the development of wind power in the U.S. expands, selecting new wind turbine locations will continue to require consideration of the potential adverse effects on bats. High levels of bat fatality have been recorded at a number of wind energy facilities, especially in the eastern United States. The BVAT allows managers to explore quantitatively how alternative placement, designs, and layouts of wind turbines can potentially affect bat populations. This tool should reduce the need for intensive field studies at sites expected to have high bat-turbine interactions and will help focus studies on sites more likely to be approved. The tool can also facilitate discussions among project proponents and resource trustee agencies by providing a common forum for information and analysis. Lastly, this tool is flexible enough to be refined for local conditions and might be amenable to adapting for other species, such as birds.

The importance of quantifying and mitigating bat fatalities is magnified by the recent declines in bat populations and the continuing threats they face. Some bat species may be adversely affected by climate change. Adams (2010) found lower reproductive rates for several western bat species during drought conditions, which current climate change models predicted to be more pervasive in the west. More recently White Nose Syndrome (WNS) has been described as a particularly virulent disease that causes the mortality of hibernating bats during the winter. To date, the disease has killed more than 1 million bats in the Northeastern U.S. and Canada (USFWS 2011). Although endangered Indiana bats are known to have been killed by WNS (Thogmartin et al. 2012), it is not known how the disease and the proliferation of wind energy facilities in the northeast will ultimately affect their populations. It is possible that limits on the siting and operation of wind turbine facilities can reduce the additional stress on bat populations posed by collision and barotrauma fatalities. Arnett et al. (2011) reported that fatality at fully operational turbines was greater than fatality at curtailed turbines by a factor of 5.4 in 2008 and by a factor of 3.6 in 2009. Curtailment reduced bat fatality 44% to 93% with annual power loss of less than 1% of total annual output.

The BVAT was developed using an existing spatially-explicit exposure tool platform (the Spatially Explicit Exposure Model or SEEM) and integrates spatial information on locations of turbines, bat habitat, and bat behavior. This version of BVAT allows the user to select key parameters of bat behavior—perceptual range, mean flying height, roosting wait time, foraging wait time, and tortuosity of bat movement. It also has a number of capabilities in the simulation program which are not exposed to the user through the GUI. Future versions could add the following:

- customized time step size and different distributions for simulated bearing, height, and residence time
- save/load function for a complete project, including population parameters and simulation results
- integration of bat trajectories with the dynamic habitat map in the bat tool GUI
- options to customize symbology that would reduce the need for external software programs to visualize simulated trajectories in detail.

The model demonstration provided with this version of BVAT focuses on two bat species, the eastern red bat and the endangered Indiana bat. Additional bat species could be evaluated in future model runs. The model simulation was based on the conditions at the Mountaineer Wind Energy Center (MWEC), which consists of 44 wind turbines arranged in a linear array within Appalachian mixed mesophytic forest near Thomas, West Virginia. Other existing, proposed, or hypothetical wind turbine facilities could also be evaluated. Model sensitivity runs showed that bat mortality in the model was most sensitive to perceptual range and flying height.

We recommend that DOE pursue additional testing to improve the utility of BVAT for wind power siting. In particular, we suggest that a comparative analysis of different wind turbine siting options be conducted to refine the model for this critical function.

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APPENDIX A

MODEL DEMONSTRATION USING MOUNTAINEER WIND ENERGY CENTER AS A CASE STUDY

A1. MODEL INPUTS

TURBINE INPUTS FOR THE CASE STUDY

Data input values for the turbines in the model demonstration (Table A-1) are based on the actual values at the Mountaineer Wind Energy Center.

Table A-1. Turbine Inputs

Turbine #	X Coordinate (UTM)	Y Coordinate (UTM)	Turbine Nacelle Height in meters	Blade Height in meters	Probability of Collision
ID	**X**	**Y**	**Z**	**Radius**	**Probability**
1	627060.5	4339083	70	72	0.01
2	627008	4338873	70	72	0.01
3	626917.1	4338671	70	72	0.01
4	626769.1	4338525	70	72	0.01
5	626621.6	4338360	70	72	0.01
6	626479.2	4338204	70	72	0.01
7	626338.9	4338049	70	72	0.01
8	626185.3	4337892	70	72	0.01
9	625981.8	4337789	70	72	0.01
10	625916.5	4337572	70	72	0.01
11	625823.2	4337380	70	72	0.01
12	625749.3	4337175	70	72	0.01
13	625702.3	4336974	70	72	0.01
14	625597	4336781	70	72	0.01
15	625472.8	4336586	70	72	0.01
16	625306.6	4336478	70	72	0.01
17	625175	4336277	70	72	0.01
18	625074.3	4336075	70	72	0.01
19	624899	4335885	70	72	0.01
20	624791.5	4335674	70	72	0.01
21	624583	4335627	70	72	0.01
22	624485.2	4335430	70	72	0.01
23	624447.6	4335214	70	72	0.01
24	623980.9	4335318	70	72	0.01
25	623886.1	4335127	70	72	0.01
26	623780.1	4334934	70	72	0.01
27	623691.5	4334695	70	72	0.01
28	623588.7	4334541	70	72	0.01
29	627433.8	4339888	70	72	0.01

Table A-1. (Continued)

Turbine #	X Coordinate (UTM)	Y Coordinate (UTM)	Turbine Nacelle Height in meters	Blade Height in meters	Probability of Collision
ID	**X**	**Y**	**Z**	**Radius**	**Probability**
30	627496.1	4340100	70	72	0.01
31	627576.6	4340261	70	72	0.01
32	627766.3	4340397	70	72	0.01
33	627947.7	4340509	70	72	0.01
34	628127.9	4340664	70	72	0.01
35	628220.7	4340860	70	72	0.01
36	628368	4341053	70	72	0.01
37	628492.7	4341212	70	72	0.01
38	628616.9	4341407	70	72	0.01
39	628686	4341616	70	72	0.01
40	628811.9	4341790	70	72	0.01
41	629002.4	4341922	70	72	0.01
42	629119.6	4342127	70	72	0.01
43	629238.5	4342294	70	72	0.01
44	629369.7	4342468	70	72	0.01

INDIANA AND RED BAT DENSITY INPUTS FOR CASE STUDY MODEL

To calculate the estimated densities:

1. Calculate Area (m2) by multiplying the number of pixels by the case study area (grid size in meters):
   a. Area = # pixels per habitat * 30* 30
2. Calculate the percent of pixels for each habitat from the total number of pixels:
   a. % Pixels in Habitat i = # Pixels in Habitat i /Total number of Pixels
3. Calculate the estimated density for each Habitat Type:
   a. Estimated Forage Density in Habitat i = [(Foraging Habitat Probability in Habitat i)*(Percent Pixels in Habitat i)*(Target # of Foraging Points)]/(# of Pixels in Habitat i)

   b. Estimated Roosting Density in Habitat i = [(Roosting Habitat Probability in Habitat i)*(Percent Pixels in Habitat i)*(Target # of Roosting Points)]/(# of Pixels in Habitat i)

Table A-2. Indiana bat density per habitat model inputs*

Inputs needed to calculate the model inputs						Inputs into the model							
	Summer Time Period											Calculated Density Estimates	
Habitat	Target # Forage Points	Target # Roost Points	# of Pixels	Foraging Habitat Proba-bility	Roosting Habitat Proba-bility	Value	R	G	B	A	Label	Forage	Roost
Open Water	5,000	100	380	0.3	0	11	71	107	161	255	Open Water	0.009375	0
Developed Open Space			8907	0.00625	0	21	222	202	202	255	Developed Open Space	0.000195313	0
Developed Low Intensity			527	0.00625	0	22	217	148	130	255	Developed Low Intensity	0.000195313	0
Developed Medium Intensity			361	0.00625	0	23	238	0	0	255	Developed Medium Intensity	0.000195313	0
Developed High Density			43	0.00625	0	24	171	0	0	255	Developed High Density	0.000195313	0
Barren Land (Rock/Sand/Clay)			3780	0	0	31	179	174	163	255	Barren Land (Rock/Sand/Clay)	0	0
Deciduous Forest			119139	0.1	0.1	41	104	171	99	255	Deciduous Forest	0.003125	0.0000625
Evergreen Forest			8216	0.05	0.05	42	28	99	48	255	Evergreen Forest	0.0015625	0.00003125
Mixed Forest			12902	0.05	0.05	43	181	202	143	255	Mixed Forest	0.0015625	0.00003125
Shrub/Scrub			255	0.05	0	52	204	186	125	255	Shrub/Scrub	0.0015625	0
Grassland/Herbaceous			473	0.025	0	71	227	227	194	255	Grassland/Herbaceous	0.00078125	0
Pasture/Hay			2705	0.025	0	81	220	217	61	255	Pasture/Hay	0.00078125	0
Cultivated Crops			1051	0.025	0	82	171	112	40	255	Cultivated Crops	0.00078125	0
Woody Wetlands			861	0.3	0.8	90	186	217	235	255	Woody Wetlands	0.009375	0.0005
Emergent Herbaceous Wetlands			400	0.05	0	95	112	163	186	255	Emergent Herbaceous Wetlands	0.0015625	0

* values provided in this case study model are estimates based on our understanding of Indiana bat biology through literature review

Table A-3. Red Bat Density per Habitat Model Inputs*

Inputs needed to calculate the model inputs						Inputs into the model							
	Summer Time Period											Calculated Density Estimates	
Habitat	**Target # Forage Points**	**Target # Roost Points**	**# of Pixels**	**Foraging Habitat Proba-bility**	**Roosting Habitat Proba-bility**	**Value**	**R**	**G**	**B**	**A**	**Label**	**Forage**	**Roost**
Open Water	5,000	100	380	0.1	0.1	11	71	107	161	255	Open Water	0.003125	0
Developed Open Space			8907	0.005	0.005	21	222	202	202	255	Developed Open Space	0.00015625	0
Developed Low Intensity			527	0.005	0.005	22	217	148	130	255	Developed Low Intensity	0.00015625	0
Developed Medium Intensity			361	0.005	0.005	23	238	0	0	255	Developed Medium Intensity	0.00015625	0
Developed High Density			43	0.005	0.005	24	171	0	0	255	Developed High Density	0.00015625	0
Barren Land (Rock/Sand/Clay)			3780	0.005	0.005	31	179	174	163	255	Barren Land (Rock/Sand/Clay)	0.00015625	0
Deciduous Forest			119139	0.375	0.375	41	104	171	99	255	Deciduous Forest	0.01171875	0.000375
Evergreen Forest			8216	0.05	0.05	42	28	99	48	255	Evergreen Forest	0.0015625	0.0000625
Mixed Forest			12902	0.2	0.2	43	181	202	143	255	Mixed Forest	0.00625	0.000125
Shrub/Scrub			255	0.05	0.05	52	204	186	125	255	Shrub/Scrub	0.0015625	0
Grassland/Herbaceous			473	0.05	0.05	71	227	227	194	255	Grassland/Herbaceous	0.0015625	0
Pasture/Hay			2705	0.025	0.025	81	220	217	61	255	Pasture/Hay	0.00078125	0
Cultivated Crops			1051	0.05	0.05	82	171	112	40	255	Cultivated Crops	0.0015625	0
Woody Wetlands			861	0.05	0.05	90	186	217	235	255	Woody Wetlands	0.0015625	0.0000625
Emergent Herbaceous Wetlands			400	0.025	0.025	95	112	163	186	255	Emergent Herbaceous Wetlands	0.00078125	0

* values provided in this case study model are estimates based on our understanding of red bat biology through literature review

BEHAVIOR PARAMETERS FOR CASE STUDY MODEL

Table A-4. Probability of foraging or flying*

Indiana Bat		Red Bat	
Hour	**Probability of Foraging/Flying**	**Hour**	**Probability of Foraging/Flying**
0:00	0.9	0:00	0.90
1:00	0.9	1:00	0.90
2:00	0.8	2:00	0.80
3:00	0.8	3:00	0.80
4:00	0.75	4:00	0.75
5:00	0.75	5:00	0.75
6:00	0.25	6:00	0.50
7:00	0	7:00	0
8:00	0	8:00	0
9:00	0	9:00	0
10:00	0	10:00	0
11:00	0	11:00	0
12:00	0	12:00	0
13:00	0	13:00	0
14:00	0	14:00	0
15:00	0	15:00	0
16:00	0	16:00	0
17:00	0	17:00	0
18:00	0	18:00	0
19:00	0.75	19:00	075
20:00	1	20:00	1.0
21:00	1	21:00	1.0
22:00	1	22:00	1.0
23:00	1	23:00	1.0

* values provided in this case study model are estimates based on our understanding of Indiana and red bat biology through literature review

FLYING HEIGHT FOR CASE STUDY MODEL

Flying Height (meters)

1. Indiana Bat: 6 meters +/- 3 meters (90% of captures < 6m (Lee and McCracken 2004); but also noted flying in forest canopy and subcanopy (Brack 1989))
2. Red Bat: 25 meters +/- 20 meters (flies higher early, and lower as darkness increases (BCI 2001))

FLYING SPEED FOR CASE STUDY MODEL

Step Length (Flying Speed (meters/minute))

1. Indiana Bat = 4.8m/s or 288m/m (Patterson and Hardin 1969)
2. Red Bat = 6.7m/s or 402m/m (Salcedo et al. 1995)

PERCEPTUAL RANGE (HOME RANGE) FOR CASE STUDY MODEL

Perceptual Range (Home Range (meters)):

1. Indiana Bat = 95% of bats are within 4,000 meters of their roost
2. Red Bat = The maximum distance flown from a roost tree (Table 1) by an individual bat ranged from 0.42 km to 1.76 km and had a mean of 0.95 km (Everson 2005) = 9,500 square meter area or within 4,750 meters of roost

A1. MODEL RESULTS

A2.1 INDIANA AND RED BAT MORTALITY

Using the literature-based, default input parameters and running the model for 30 iterations per species, the number of bats killed over a 10-day period by the 44 turbines was greater for red bats than Indiana bats (Figure A-1, Table A-4). This is likely attributable to the higher mean flying height of the red bat.

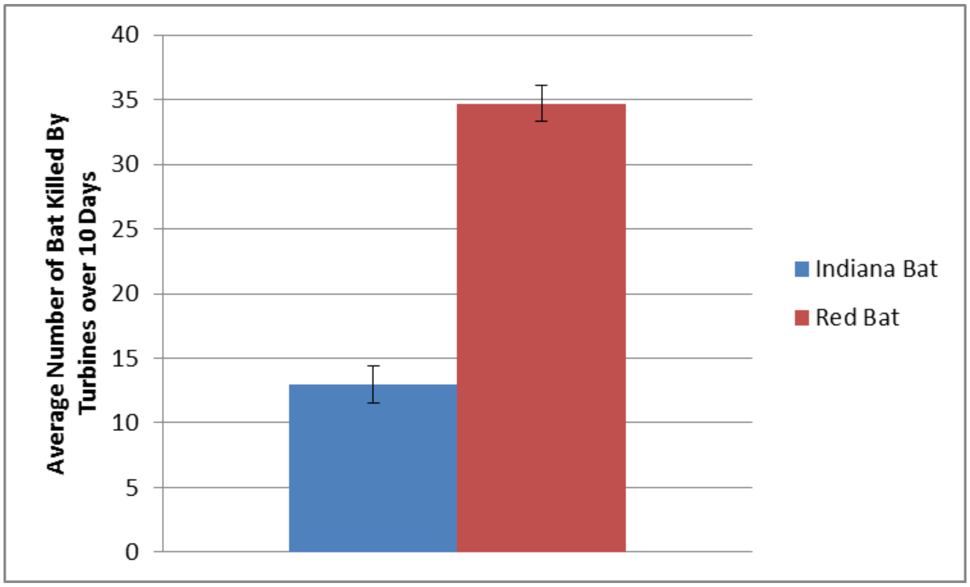


Figure A-1. Average number of Indiana and red bats killed by turbines over 10 days (±1 SE).

Table A-4. Default input parameters for the Indiana bat and red bat used in the model		
Input Parameter	Indiana Bat	Red Bat
Population Size	100	100
Days	10	10
Step length (Flying Speed minutes/meters)	288	402
Perceptual Range (Home Range of Bat (meters))	4000	4750
Mean Flying Height (meters)	6	25
Standard Deviation of Flying Height	3	20
Roost Wait Time (minutes)	15	15
Foraging Wait Time (minutes)	5	5
Tortuosity	0.5	0.5

A3. Model Parameter Sensitivity–Indiana Bat Case Study

Each key input parameter of the model was varied while keeping all other input parameters constant to determine model sensitivity to each parameter. The key input parameters that were varied were tortuosity, step length, perceptual range, and mean and standard deviation (SD) of flying height. Each combination of input parameters was used to run the model 20 times from which an average and standard error of the number of bats killed was calculated.

A3.1 TORTUOSITY

Tortuosity determines the randomness of bat flight and ranges from zero (random walk) to one (linear flight). Tortuosity for the Indiana bat was varied while keeping all other variables constant to examine how this parameter affected the number of bats killed over a 10-day period. Results showed that the average number of bats killed was similar across the range of tortuosity examined, however, the standard error associated with the average increased when higher values of tortuosity were used (Figure A-2).

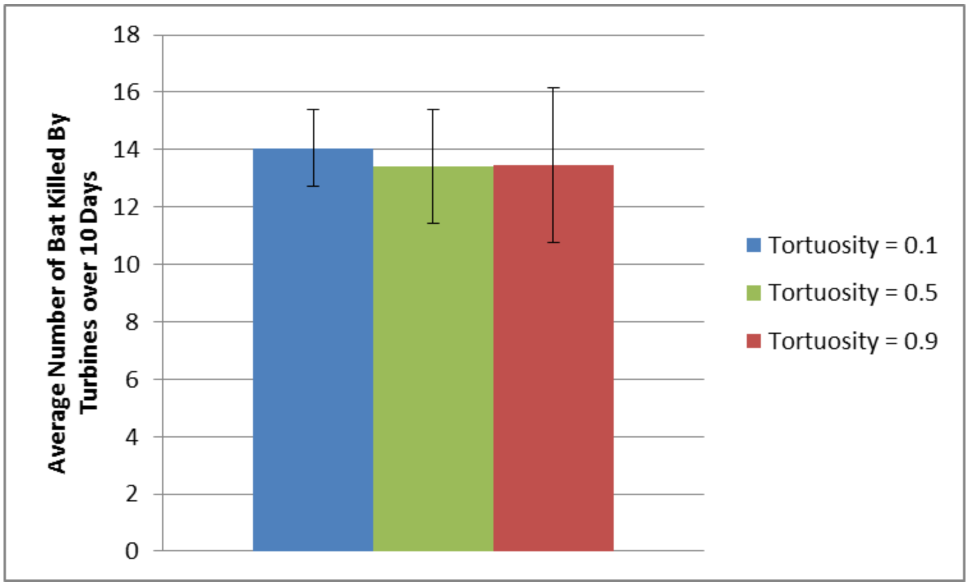


Figure A-2. Average number of Indiana bats killed (+/- SE) by turbines with varying tortuosity in bat flight for a 10-day period

A3.2 STEP LENGTH (FLYING SPEED)

Step length is the bat flying speed in the units of meters per minute. The average number of bats killed over a 10-day period increased when step length was increased.

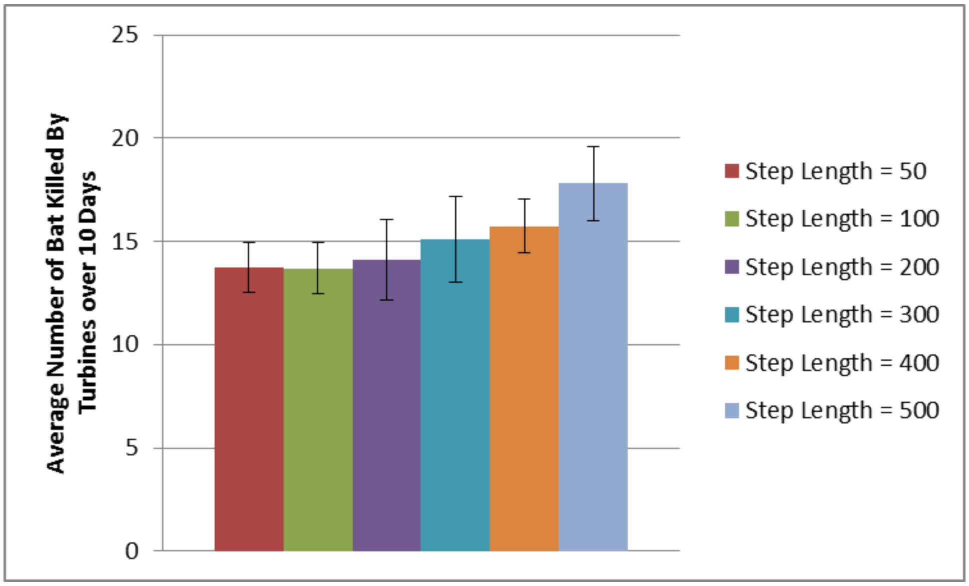


Figure A-3. Average number of bats killed (+/- SE) by turbines with varying step length (meters/minute) for a 10-day period

A3.3 PERCEPTUAL RANGE

Perceptual range is the bat home range size. The sensitivity analysis showed that the average number of bats killed over a 10-day period increased with larger bat home ranges (Figure A-4). As bats travel farther away from their roost to forage, there is a greater likelihood that they will intercept a turbine.

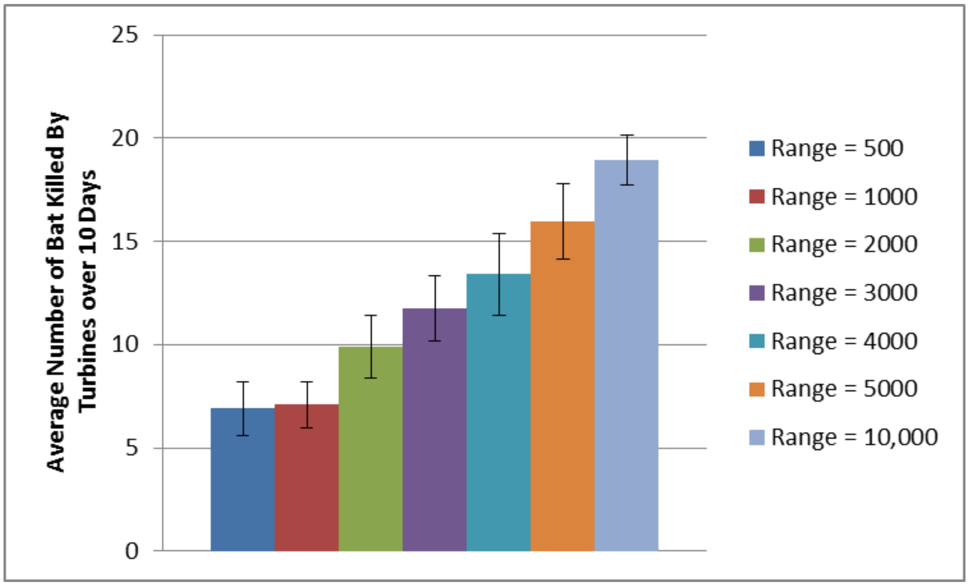


Figure A-4. Average number of bats killed (+/- SE) by turbines with varying perceptual range (meters) for a 10-day period

A3.4 MEAN FLYING HEIGHT AND STANDARD DEVIATION IN FLYING HEIGHT

The mean flying height and standard deviation in flying height describe the height at which bats forage. The average number of bats killed over a 10-day period tended to increase as bat foraging height was increased (Figure A-5).

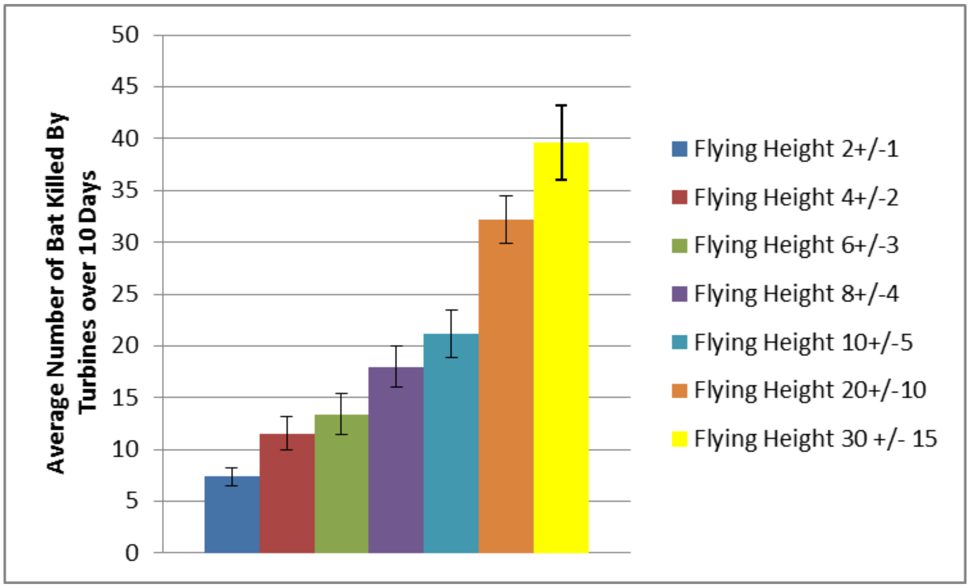


Figure A-5. Average number of bats killed (+/- SE) by turbines with varying mean flying height and standard deviation of flying height for a 10-day period

A4. Turbine Location–Red Bat Case Study

The model can be used to determine turbine locations corresponding to the least amount of bat mortality given (1) the surrounding land use for each turbine and (2) the bat preference of the surrounding land use. Using the output from the red bat demonstration in Figure A-6, coordinates showing where each bat was struck and killed by a turbine were recorded and associated with an individual turbine (turbine coordinates are found in Table A-1). The largest differences in bat mortality were between turbines 12 and 27 (Figure A-7).

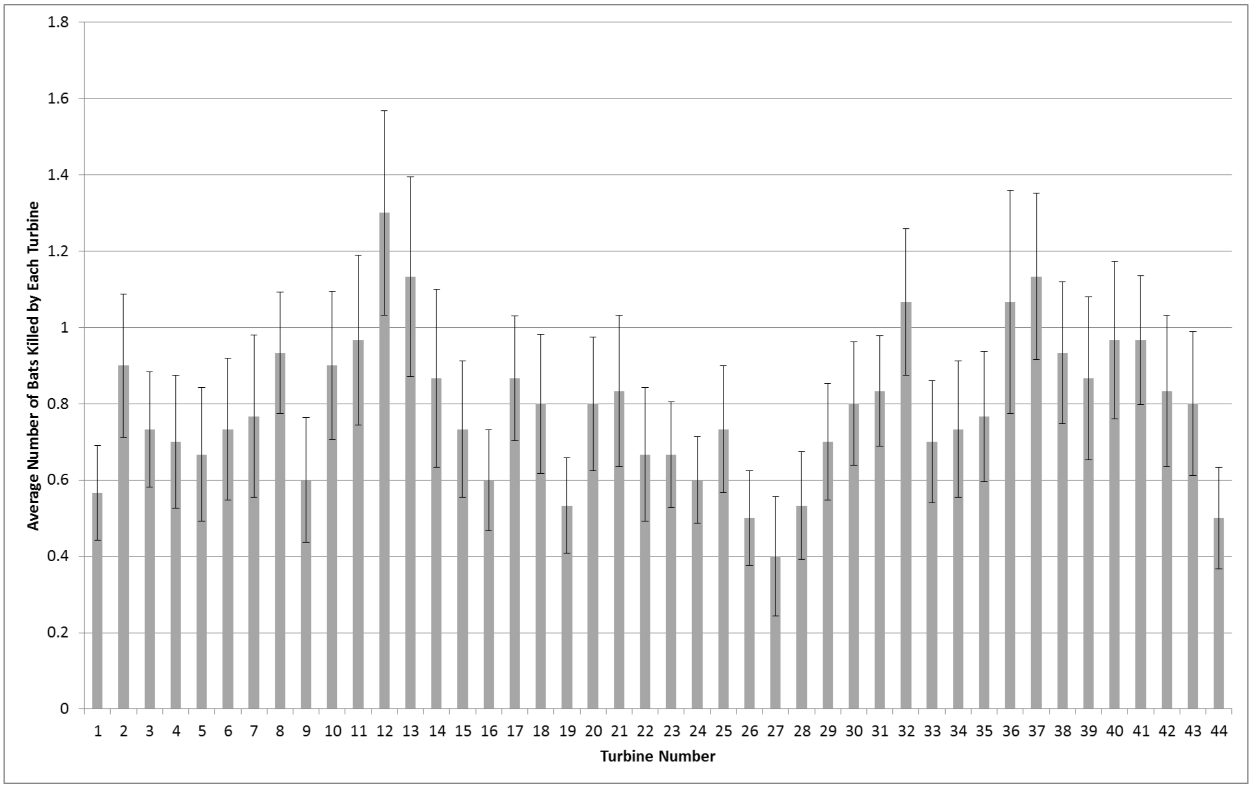


Figure A-6. The average number of bats killed (+/- SE) over 10 days by each turbine.

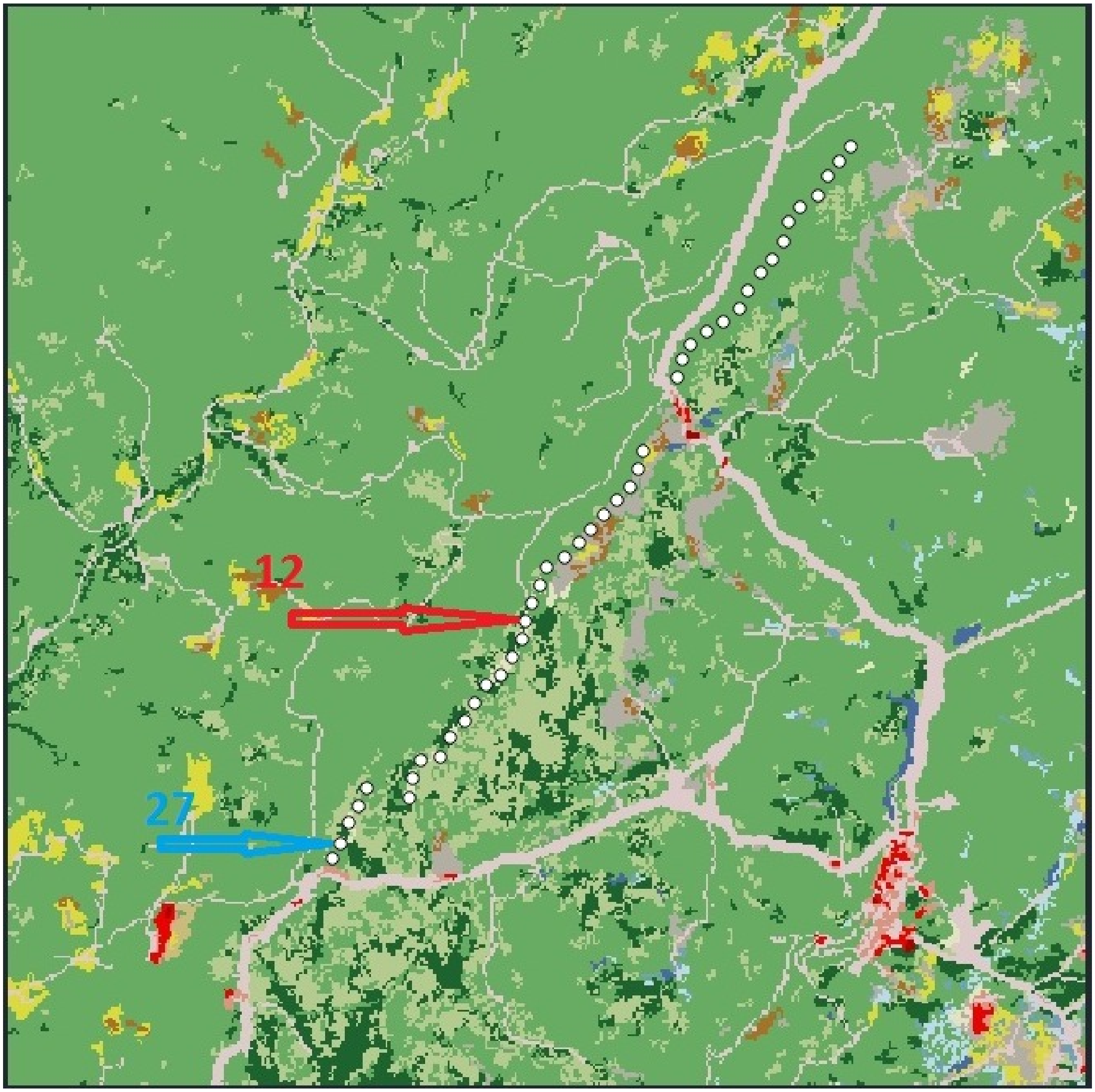


Figure A-7. Locations of turbines 12 and 27 at the Mountaineer Wind Energy Center in West Virginia.

APPENDIX B

BAT VULNERABILITY ASSESSMENT TOOL (BVAT) QUICK START GUIDE

B1. MODEL HOME SCREEN

The BVAT model home screen contains four panels (Figure B1): model browser, properties, map/pathway viewing window, and output panel. Each is briefly introduced below:

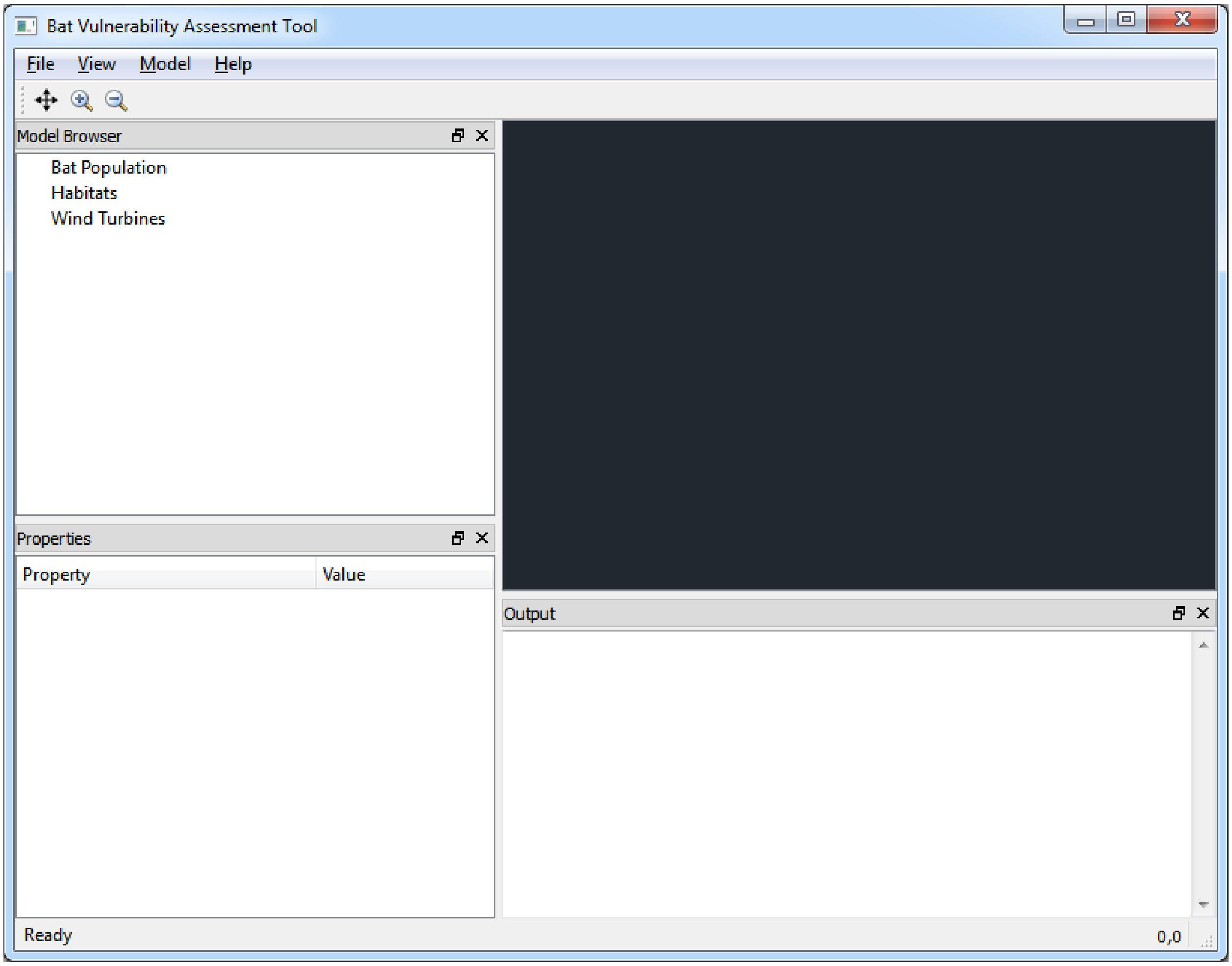


Figure B-1. Model Home Screen

Model Browser: The central point for model input navigation. The three input data types are listed here in drop-down menus. When a user clicks on Bat Population, the required inputs for this model component appear under properties (Figure B-2). By using the MODEL tab at the top of the screen, users can *Add a Habitat Layer* or *Add Wind Turbine Layers*. By right clicking on the added layers, a user can upload site-specific feature data.

Properties: This panel allows the user to see and, in the case of bat population data, edit/input data for model operation. Highlight the input data type and the relevant properties will appear in this window. Modify values directly in this panel. The habitat and wind turbine input screens are displayed by right-clicking on the layer name within the Model Browser panel.

Map/Pathway Viewing Window: The panel in the upper right-hand corner of the model home screen displays any maps that have been added to the project. The habitat map, once added to the project, will appear in this window. In addition, turbine locations, once loaded, will display on top of the habitat layer. It is currently a view-only window.

Output Panel: The output panel displays the summary statistics from model runs, including the number of roosting and foraging points (bias points[6]), the number of collisions that occurred per total number modeled, and, for each bat that collided with a turbine—the number of the bat and the coordinates of the turbine/collision. For example, typical results are as follows:

```
81 bias points generated (roosting)
288 bias points generated (foraging)
6 collisions/100 bats modeled (6.0%)
bat 39 collision at x = 624592.07630184 y = 4335226.39963374 t = 9
bat 3 collision at x = 624592.558094439 y = 4335225.11174247 t = 10
bat 15 collision at x = 623886.292736907 y = 4334816.16815585 t = 33
bat 86 collision at x = 624593.78845343 y = 4335224.3732918 t = 35
bat 90 collision at x = 625444.160215379 y = 4336717.58675178 t = 67
bat 28 collision at x = 624591.438759408 y = 4335225.21817581 t = 248
```

In addition to the panels, the FILE, VIEW, MODEL, and HELP tabs also provide access to important model functionality. Each drop down tab is discussed briefly below:

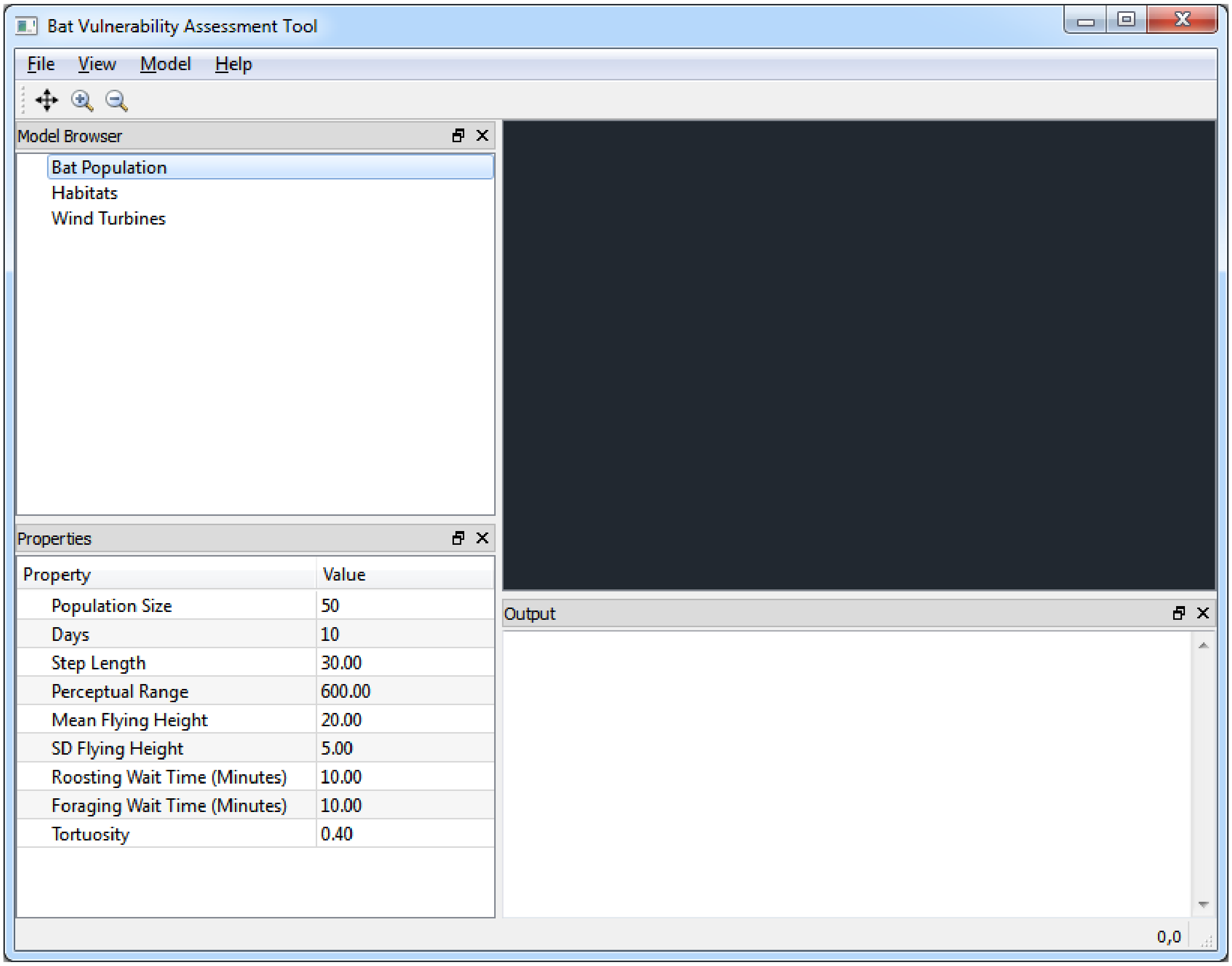
> <u>FILE</u>: Two functions are currently active–Export Map and Exit. Exporting a map allows a user to extract the habitat/turbine map to a bitmap file for use in external reports. Exit is used to close the program. Saving and Opening of project files is not active in this release. All of the model inputs can be saved in external files specific to each section and future releases will include a project file option.
>
> <u>VIEW</u>: Allows a user to display or turn-off the display of any of the three primary home screen tabs.
>
> <u>MODEL</u>: This is the primary access point for adding maps/spatial data; accessing the foraging vs. roosting transition matrix; running the model; exporting bat trajectories; generating a plot of roosting, foraging, turbine locations, and collision points; and clearing the output panel.
>
> <u>HELP</u>: In future releases this tab will be populated with guidance materials and answers to frequently asked questions.

---

[6] Points toward which the bats move – either roosting or foraging

B2. BAT POPULATION INPUTS

In order to model bat behavior using BVAT, a number of important behavior descriptors are required. These inputs are ecological characteristics that are available in the literature (or may be developed based on individual studies), are unique to the species, and may be unique to the location being modeled. They were selected because they most closely describe how the bat moves and thereby might come into contact with the turbines. Figure B-2 is a screen capture of the properties required to describe the modeled bat population. Each input is described briefly below:



Property	Value
Population Size	50
Days	10
Step Length	30.00
Perceptual Range	600.00
Mean Flying Height	20.00
SD Flying Height	5.00
Roosting Wait Time (Minutes)	10.00
Foraging Wait Time (Minutes)	10.00
Tortuosity	0.40

Figure B-2. Bat Population Properties

Population Size: The number of individuals modeled in a single run is the population size. While it is possible to run the model for the actual population size if known, it is not necessary to have an actual measured population size. The model should be run multiple times, with varying sizes in order to more accurately understand sensitivities and threats. The larger the population size, the more computing time will be required to complete a model run. As an alternative, consider running the model multiple times with a smaller population. Because the bats do not influence the behavior of other bats in the model, the results can be compared.

Days: The bat model is run for a user-selected number of days. The greater the number of days, the longer the model running time.

Step Length: The distance a bat moves in one minute is called the step length. The units will depend on the units used in the coordinate system.

Perceptual Range: The radius around each bat's current position that defines the area over which bias points can be detected. A bat cannot move directly to a bias point outside of its current perceptual range.

Mean Flying Height: The mean flying height of the bat defined by a normal distribution.

SD Flying Height: The standard deviation of the flying height based on normal distribution

Roosting Wait Time (minutes): The average wait time at a bias point before selecting a new bias point and resuming movement.

Foraging Wait Time (minutes): The average wait time at a bias point before selecting new bias point and resuming movement.

Tortuosity: Randomness of bat movement as bat moves toward a bias point. The value ranges from 0 to 1. Values closer to 0 tend to cause the bat to move in less directed paths toward the selected point, and paths approach a straight line with values closer to 1.

B3. ACCESSING ADDITIONAL INPUTS

In order to use the Habitat and Wind Turbine inputs, a user first must add the respective layers to the program. The Model Menu includes options to:

Add Habitat Layer
Add Wind Turbine Layer
State Transition Matrix

The tab also is the access point for the following functions:

Run Model
Export Trajectories
Export Roosting Points
Export Foraging Points
Generate Plot
Clear Output

These will be discussed in the sections that follow.

B4. HABITAT LAYER AND HABITAT LAYER PROPERTIES

The habitat layer and associated properties allow a user to characterize the landscape from the perspective of suitability for bats. Although BVAT will operate with any georeferenced habitat map, we recommend the use of a thematic map like National Land Cover Database (NLCD) maps[7]. These maps are set on a 30m x 30m grid with a standardized habitat type catalog. If you are not using a thematic map like NLCD 2006, the program can automatically generate a colormap using equal interval classification.

Once imported the BVAT habitat layer properties are viewed by right-clicking on habitat layer under Habitat in the Model Browser. The screen that will open is similar to that in Figure B-3. On the colormap tab, the value, color, and label are specific to NLCD maps. Both Roost Density and Forage Density are entered by the user specific to the site and the bats. Each cell in the habitat layer with an original value (i.e., specific habitat type) is assigned an average number of roost points and foraging points per grid cell (density). Those numbers are entered on this screen. Alternatively, a user may create the colormap in a spreadsheet and import it as a comma separated value (CSV) file. Also, colormaps created or edited within BVAT may be saved for future (re)use and/or editing in Excel.

Establishing the Roost and Forage densities can be challenging. In some cases, modelers may have direct knowledge of the roosting density in a specific habitat type and will likely have some knowledge about the habitat preference for foraging. Modelers decide how attractive different habitats found on a site are to bats; in addition, modelers provide a breakdown as percent of time by the hour spent either roosting or foraging (see discussion that follows). The absolute density of each is not as important as the relative density although a density that is too small will lead to very little bat movement.

We are developing a tool that will assist in distributing the total density across habitats based on habitat preference of specific bats. Ultimately, a user should experiment with varying total densities and distribution of roosting and foraging points to understand sensitivity and exposures.

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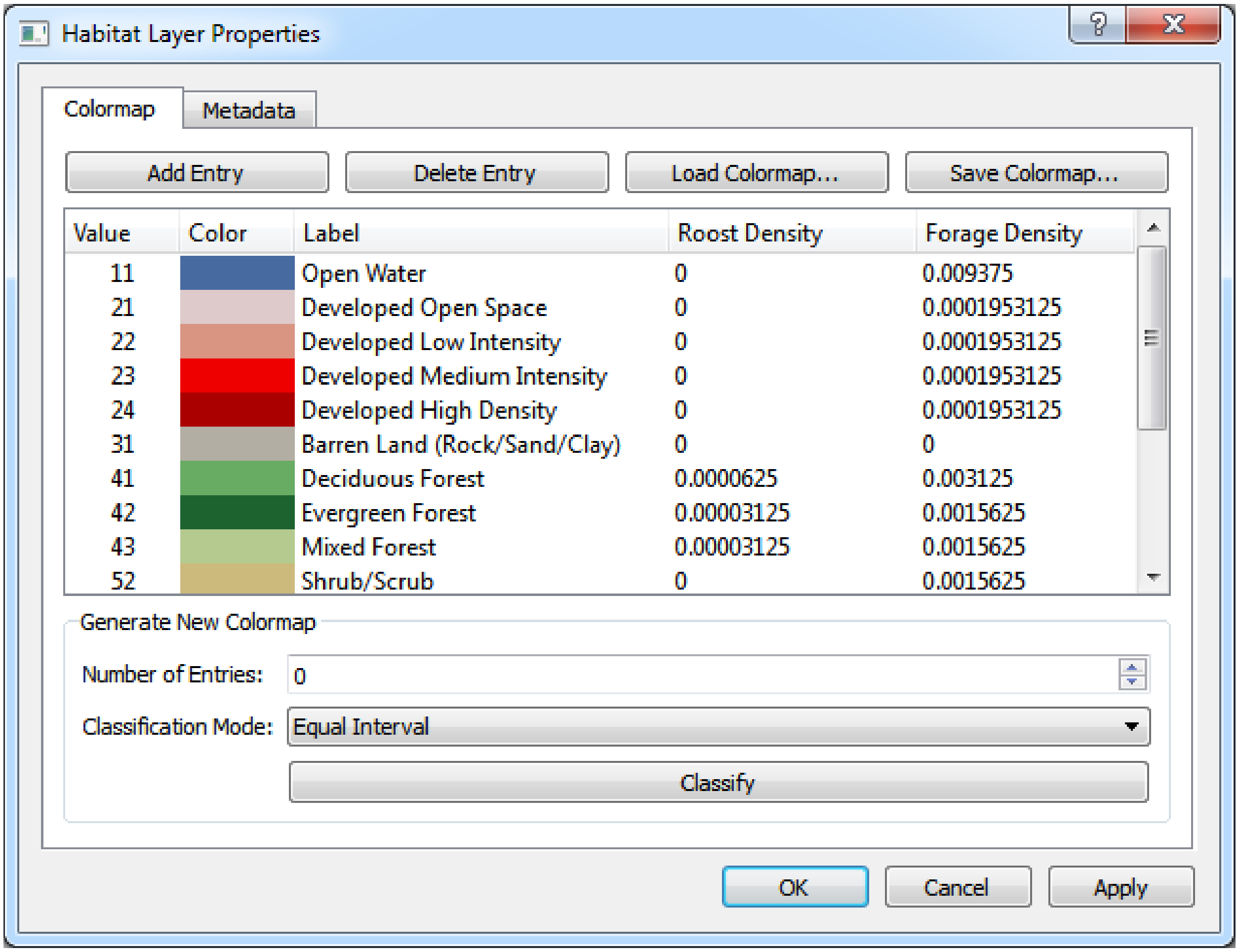
[7] U.S. Geological Service and U.S. Department of the Interior. 2006. http://www.mrlc.gov/nlcd2006.php



Value	Color	Label	Roost Density	Forage Density
11	🟦	Open Water	0	0.009375
21	⬜	Developed Open Space	0	0.0001953125
22	🟧	Developed Low Intensity	0	0.0001953125
23	🟥	Developed Medium Intensity	0	0.0001953125
24	🟥	Developed High Density	0	0.0001953125
31	⬜	Barren Land (Rock/Sand/Clay)	0	0
41	🟩	Deciduous Forest	0.0000625	0.003125
42	🟩	Evergreen Forest	0.00003125	0.0015625
43	🟩	Mixed Forest	0.00003125	0.0015625
52	🟨	Shrub/Scrub	0	0.0015625

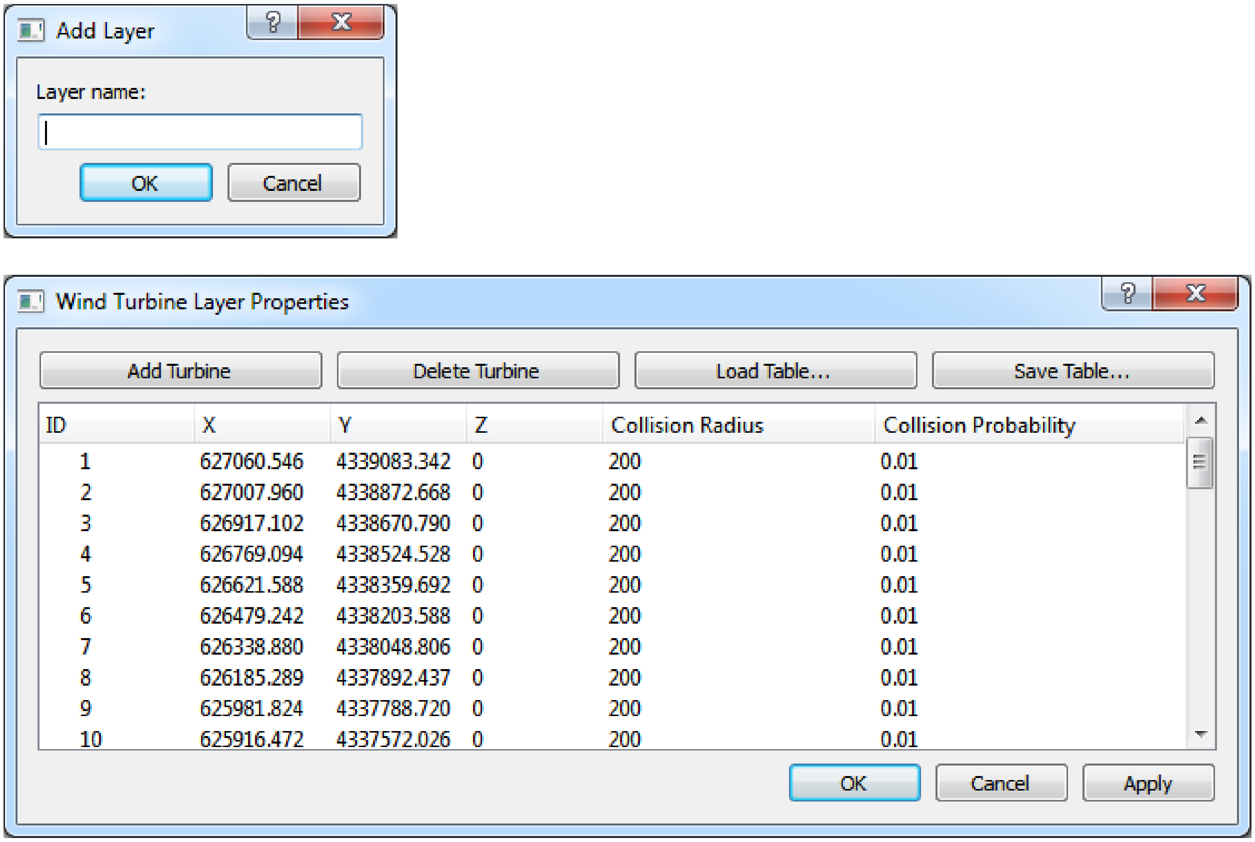
Number of Entries: 0

Classification Mode: Equal Interval

Figure B-3. Habitat layer properties

B5. WIND TURBINE LAYER

The wind turbine layer is the final important component of the BVAT model. To add this layer, click Add Layer under the Model Tab. A pop-up box will appear (Figure B-4). In the dialog box, enter a name for the Wind Turbine Layer. After the layer is created, right-click on the wind turbine layer name in the model browser and choose Wind Turbine Layer Properties (Figure B-4). From this window, users may add or delete individual turbines using known X, Y, Z coordinates. A user cannot actually draw turbines on a map within BVAT. More commonly, users will have a spreadsheet of turbine IDs, and X, Y, Z coordinates external to BVAT. This table is easily imported into BVAT using the Load Table button and any changes made within the model can be saved by clicking Save Table. Two other turbine descriptors are entered on this screen. The collision radius defines the distance (circular) around a turbine in which a bat may be adversely affected. For this screening model, an adverse interaction is assumed to either be a direct hit with the structure or barotrauma–both are recorded as a collision. The collision probability is a modifier of the radius that reflects characteristics about the turbines or bats that might change the collision risk. For example, if some sort of deterrence equipment was used, the probability might be reduced even if the collision radius remained the same. In many cases, just because a bat enters a collision radius, a death or injury is not guaranteed. Records of historic collisions might be helpful in selecting a realistic probability within the collision radius. The model has been designed to be flexible such that users can ask and answer a number of different questions about the interactions with turbines. Both values can vary by individual turbine.

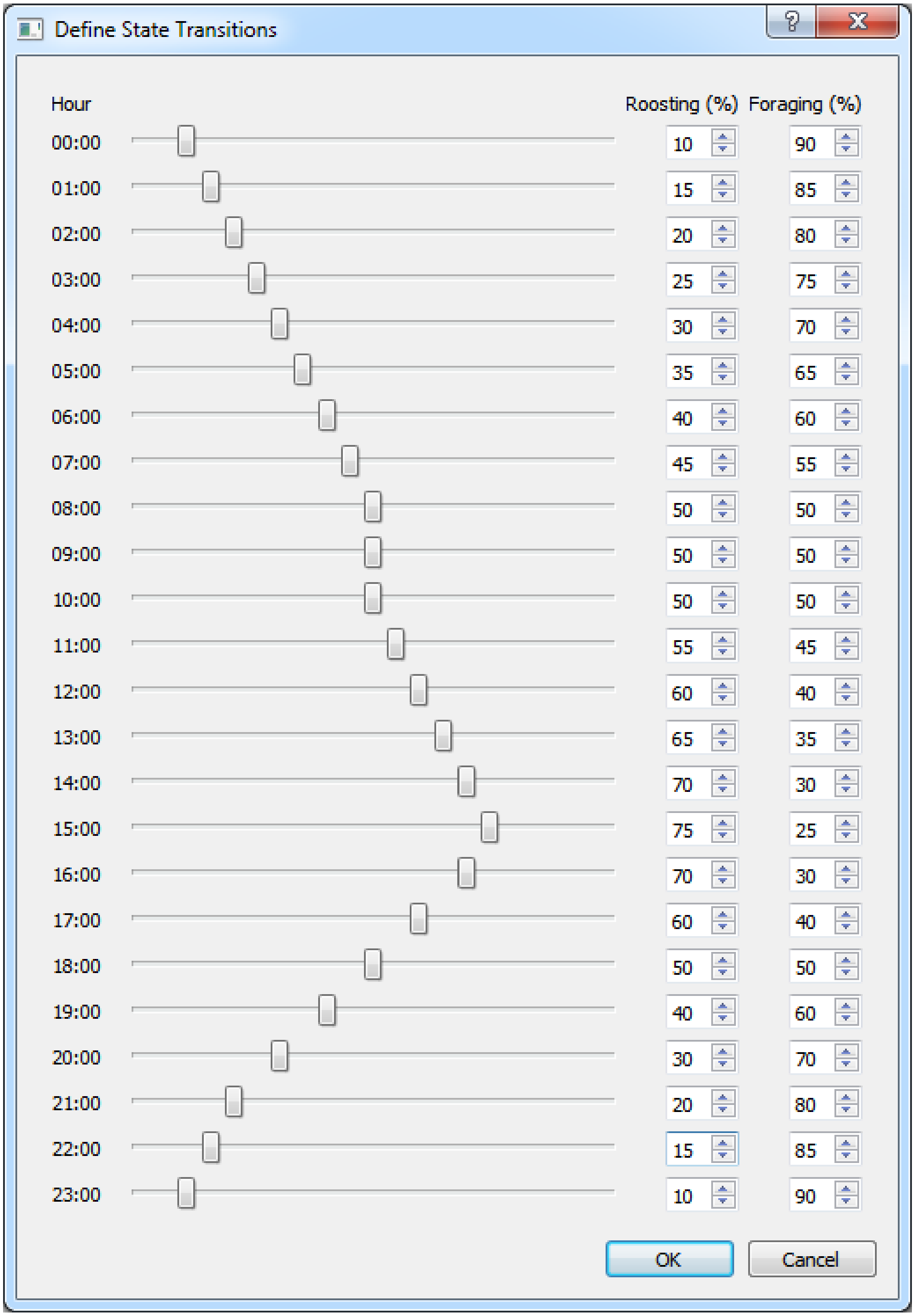


ID	X	Y	Z	Collision Radius	Collision Probability
1	627060.546	4339083.342	0	200	0.01
2	627007.960	4338872.668	0	200	0.01
3	626917.102	4338670.790	0	200	0.01
4	626769.094	4338524.528	0	200	0.01
5	626621.588	4338359.692	0	200	0.01
6	626479.242	4338203.588	0	200	0.01
7	626338.880	4338048.806	0	200	0.01
8	626185.289	4337892.437	0	200	0.01
9	625981.824	4337788.720	0	200	0.01
10	625916.472	4337572.026	0	200	0.01

Figure B-4. Wind turbine layer properties

B6. TRANSITION MATRIX

The transition states are either foraging (feeding or seeking food) and roosting (resting or caring for young). The potential for a collision is very different depending on whether a bat is roosting or foraging. By clicking on the Model Tab and State Transition Matrix option a user can tweak the relative percent of each state by hour of the day (Figure B-5). The percent equals the probability that a selected bias point for any given hour will be a roosting versus a foraging point. In the Bat Population Properties window, users are able to set the Step Length between points and a unique hold time for roosting and a different holding time for foraging. This ability to fine-tune the bat behaviors allows for great flexibility depending on specific knowledge about the bat species.

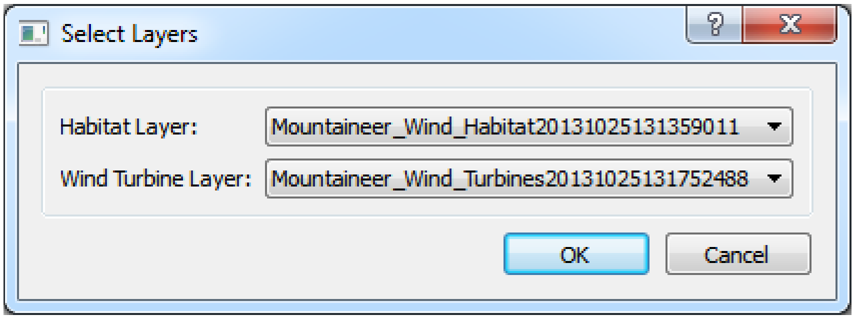


Hour	Roosting (%)	Foraging (%)
00:00	10	90
01:00	15	85
02:00	20	80
03:00	25	75
04:00	30	70
05:00	35	65
06:00	40	60
07:00	45	55
08:00	50	50
09:00	50	50
10:00	50	50
11:00	55	45
12:00	60	40
13:00	65	35
14:00	70	30
15:00	75	25
16:00	70	30
17:00	60	40
18:00	50	50
19:00	40	60
20:00	30	70
21:00	20	80
22:00	15	85
23:00	10	90

Figure B-5. Define state transitions

B7. RUNNING THE MODEL

Once all of the inputs have been entered, select Model and Run Model. If a user entered multiple habitat and turbine layers, the model will ask the user to select the preferred combination for the present run (Figure B-6).

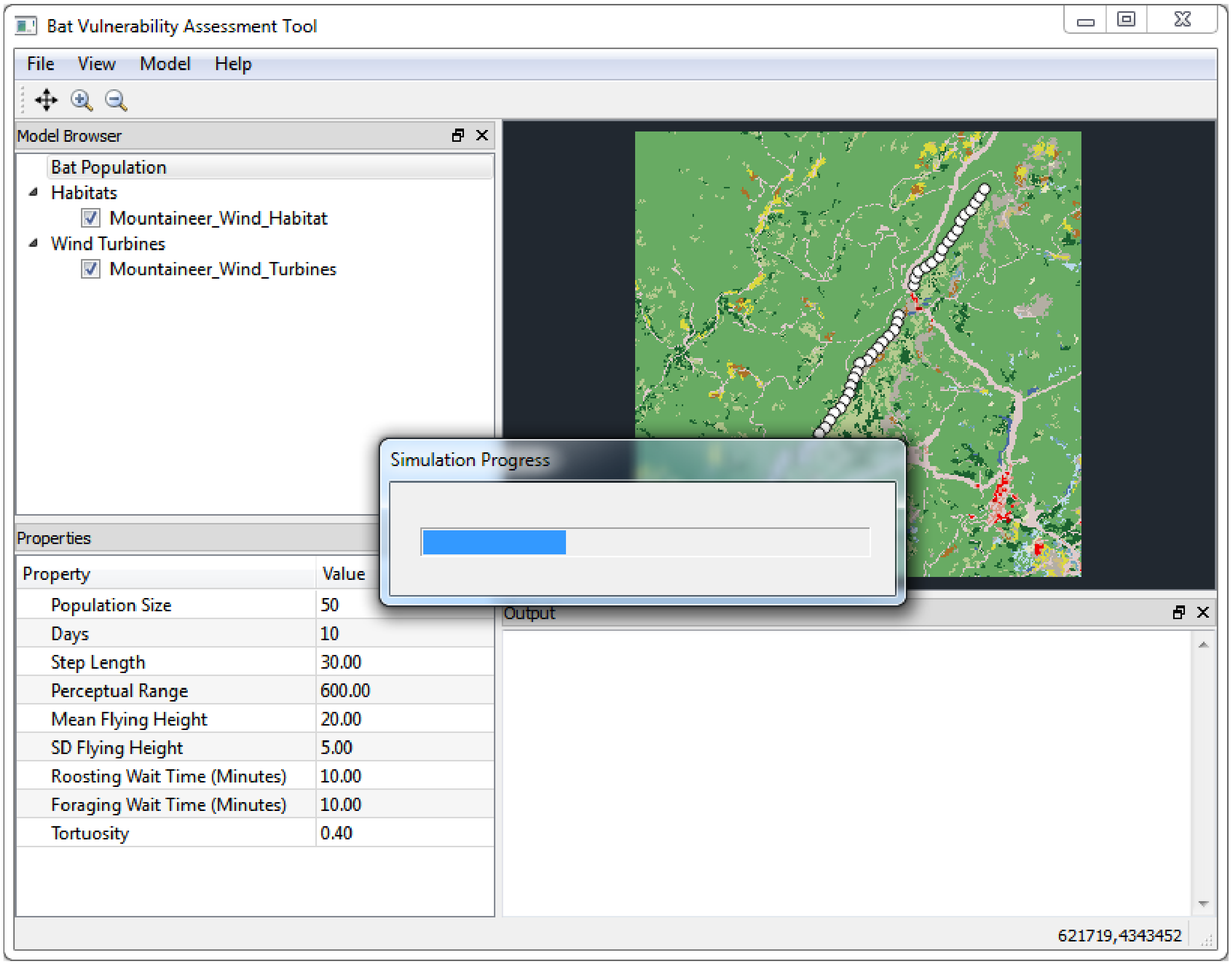


Habitat Layer: Mountaineer_Wind_Habitat20131025131359011

Wind Turbine Layer: Mountaineer_Wind_Turbines20131025131752488

Figure B-6. Selecting layers for a model run

When the model is running a Simulation Progress bar will appear (Figure B-7).



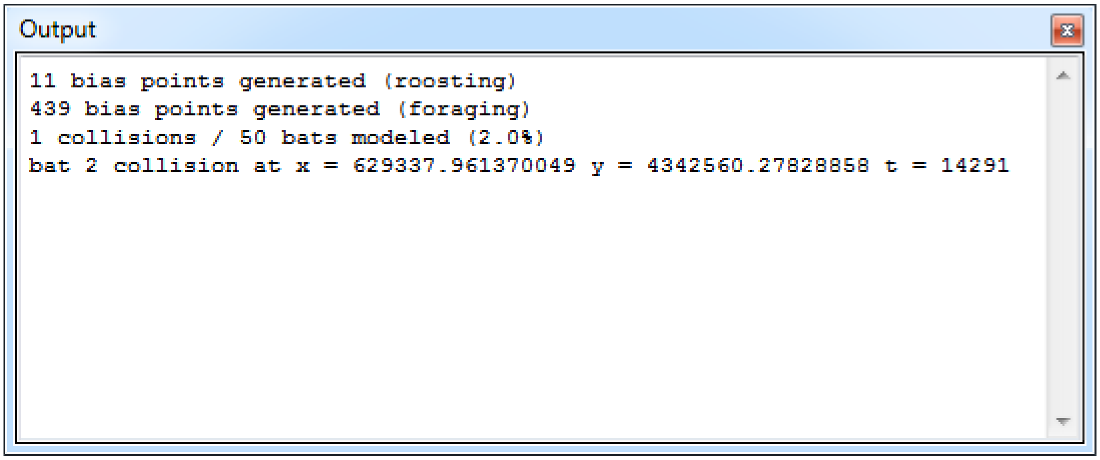
Property	Value
Population Size	50
Days	10
Step Length	30.00
Perceptual Range	600.00
Mean Flying Height	20.00
SD Flying Height	5.00
Roosting Wait Time (Minutes)	10.00
Foraging Wait Time (Minutes)	10.00
Tortuosity	0.40

Figure B-7. Model run progress bar

B8. MODEL OUTPUTS

There are three primary output types from BVAT. In its current form, users can take the outputs and create summary maps outside of the BVAT model. Capabilities to create custom outputs within BVAT are being considered for future releases.

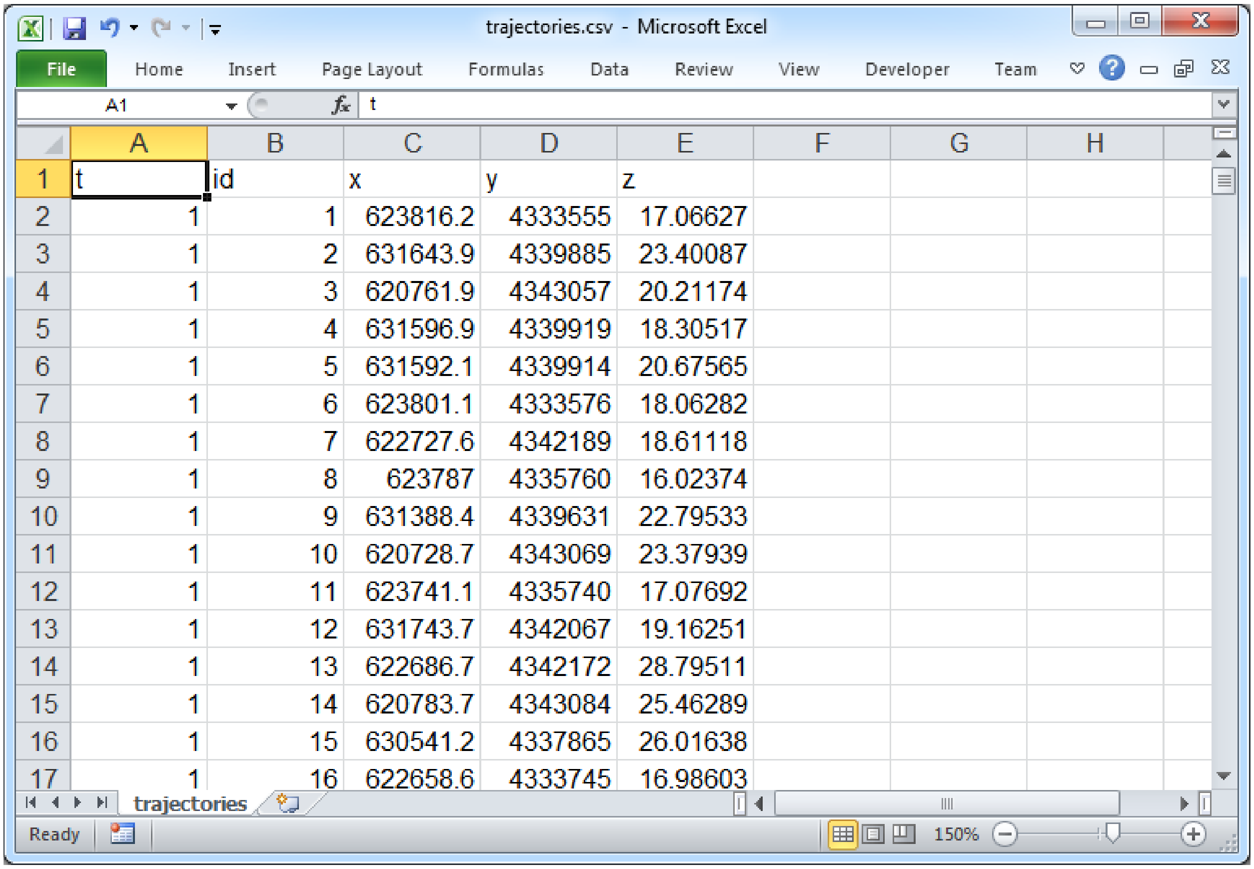
The first output type is presented in Figure B-8. This is a summary of the number of bias points generated and the number of collisions that occurred. Where a collision has occurred, the bat number and the coordinates and time of the collision are presented. The output from each subsequent run is added below the previous runs unless the user chooses to clear the output.



```
11 bias points generated (roosting)
439 bias points generated (foraging)
1 collisions / 50 bats modeled (2.0%)
bat 2 collision at x = 629337.961370049 y = 4342560.27828858 t = 14291
```

Figure B-8. Model summary output

A user may also export the trajectory the bats follow as a .csv file (choose Export Trajectories from the Model tab). Figure B-9 illustrates what the exported trajectory table looks like. The ‘t’ represents the time step, ‘id’ is the bat, and X, Y,z is the position. The table presents all of the locations for all bats at all time steps and can be plotted on a GIS map outside of the program (see Figure B-9).



	A	B	C	D	E
1	t	id	x	y	z
2	1	1	623816.2	4333555	17.06627
3	1	2	631643.9	4339885	23.40087
4	1	3	620761.9	4343057	20.21174
5	1	4	631596.9	4339919	18.30517
6	1	5	631592.1	4339914	20.67565
7	1	6	623801.1	4333576	18.06282
8	1	7	622727.6	4342189	18.61118
9	1	8	623787	4335760	16.02374
10	1	9	631388.4	4339631	22.79533
11	1	10	620728.7	4343069	23.37939
12	1	11	623741.1	4335740	17.07692
13	1	12	631743.7	4342067	19.16251
14	1	13	622686.7	4342172	28.79511
15	1	14	620783.7	4343084	25.46289
16	1	15	630541.2	4337865	26.01638
17	1	16	622658.6	4333745	16.98603

Figure B-9. Trajectory output table

Finally, BVAT has basic capability to visualize the results of the model as a static plot, by clicking Model > Generate Plot after a simulation. This will generate a CSV file for visualization in GIS. Figure B-10 presents an example of BVAT Plot. The plot symbols and colors are defined as follows:

Red Squares are roosting bias points
Blue Circles are foraging bias points
Green Triangles are wind turbines

Each bat trajectory is shown in a different color and collisions are shown as an "X" in that color.

Future iterations of the program may integrate this output into the dynamic map and allow for custom symbols[8].

---

[8] Advanced users can customize the plot by modifying R code in "R/bvatPlot.R" in the BVAT home directory and restarting the program

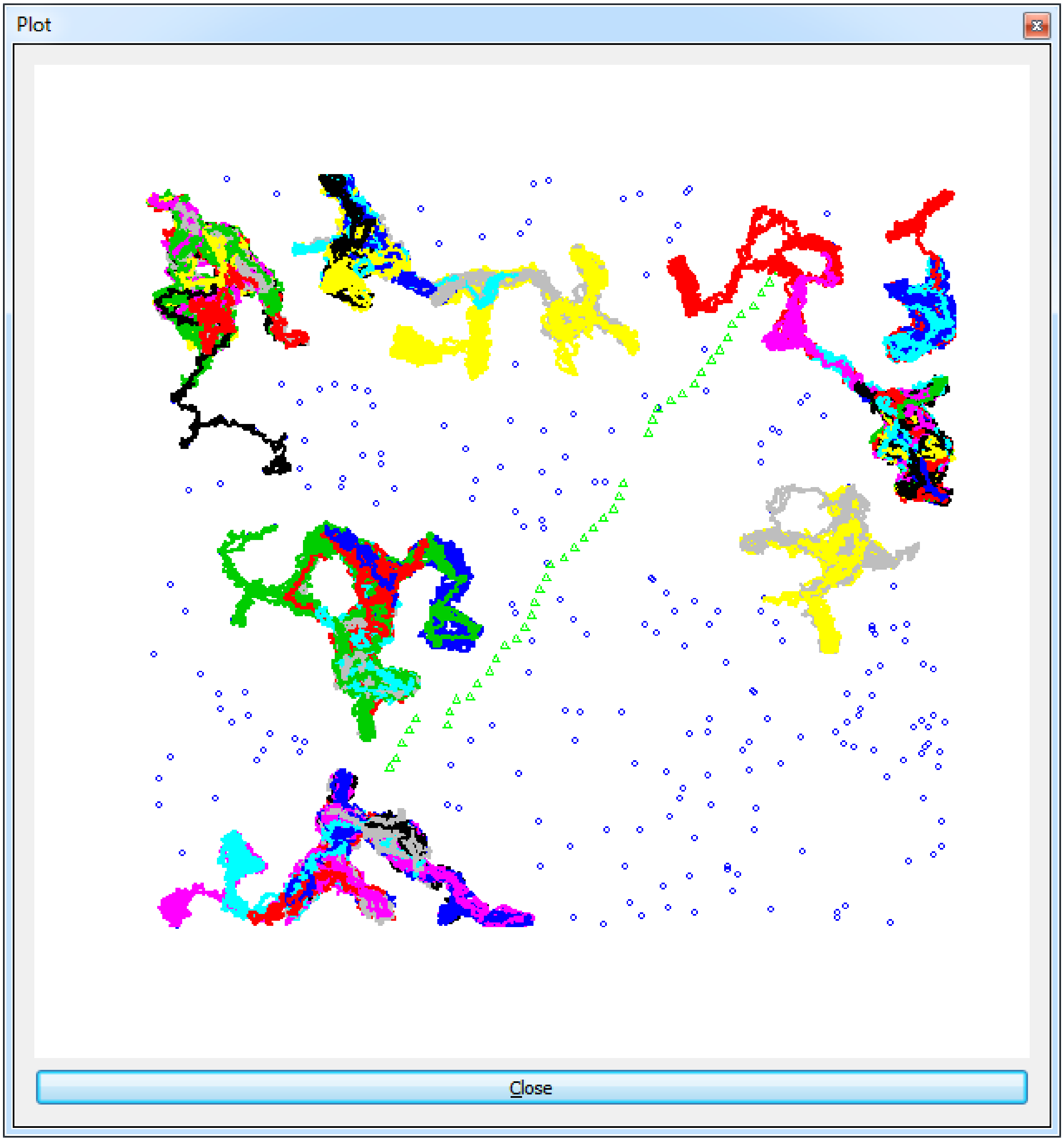


Figure B-10. Model Output plot

The model output (trajectories) can be combined with the habitat map and the turbine layer to create a summary figure in GIS external to BVAT. Figure B-11 provides an example. The colored lines are recorded trajectories of different individual bats modeled in the program. The numbered circles are wind turbines.

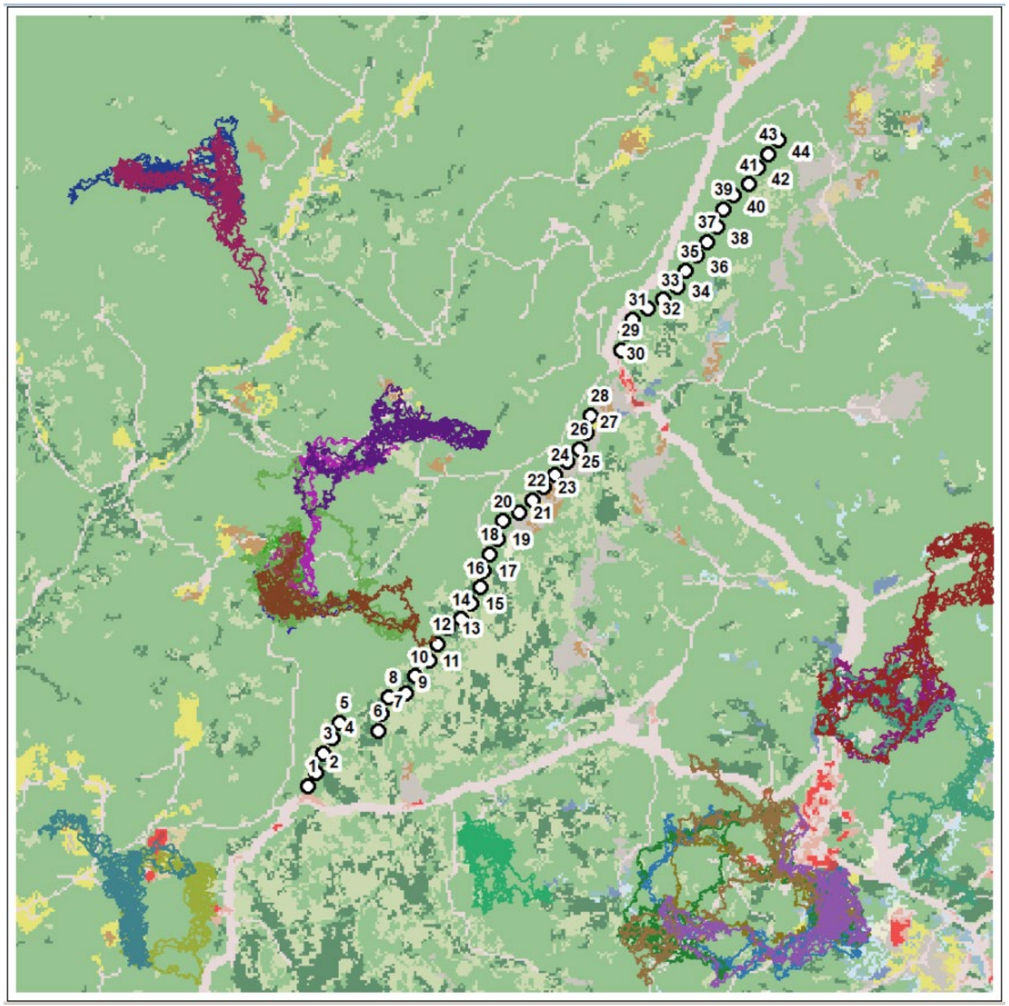


Figure B-11. BVAT outputs (colored tracks of bat movement) combined with habitat map and turbine locations in GIS external to the program

B9. NOTES ON DATA PREPARATION FOR USE IN BVAT

When using BVAT it is important that all of the spatial data are in the same projection. Below, we provide a brief introduction to the concepts that underlie map/data projections and how to work with spatial data.

B9.1 INTRODUCTION TO MAP PROJECTIONS

Standard GPS coordinates describe points on the curved surface of the earth, as angles north/south of the equator (latitude) and east/west of the Prime Meridian (longitude). In order to model bat movements in familiar X, Y, Z (linear) coordinates, geographic coordinates on the curved surface of the Earth must be projected onto a flat surface using a suitable technique, called map projection.

There are many map projections, each with advantages and disadvantages: a flat map can show one or more—but never all—of the following: true directions; true distances; true areas; true shapes. At small scales suitable for local habitat mapping, most map projections will be nearly correct in all respects. However, it may be necessary to reproject source data so both the wind turbine coordinates and the habitat map use the same coordinate system.

The native map projection for the National Land Cover Database (NLCD) is Albers Equal Area Conic. This projection is widely used by the USGS and US Census for thematic mapping of the lower 48 states, and ensures that areas are proportional to the same areas on Earth. For small- and medium-scale habitat maps, the NLCD must be clipped to the area of interest, and optionally reprojected to a coordinate system matching the wind turbine coordinates. Generally, wind turbine locations will be listed in Universal Transverse Mercator (UTM) or State Plane coordinates, as “X, Y” or “Easting, Northing” fields. The following sections illustrate reprojection of wind turbine coordinates and the NLCD image from latitude/longitude or Albers Equal Area Conic to UTM Zone 17, covering West Virginia.

B9.2 CONVERTING WIND TURBINE COORDINATES FROM LATITUDE/ LONGITUDE TO UTM ZONE 17 USING CS2CS

CS2CS is an open source program included with the PROJ.4 package, originally developed by the USGS. It is included in the free FWTools package for Windows.[9] To use the program, enter latitudes and longitudes into a text file, with coordinates separated by a space, and each coordinate pair on a separate line. From the FWTools Shell, the following command will perform the reprojection, using a text file located at “C:\Mountaineer_Wind.txt”:

```
cs2cs +proj=latlong +datum=WGS84 +to +proj=utm +zone=17
+datum=NAD83 -r C:\Mountaineer_Wind.txt
```

The `-r` option reverses the order of the expected input from longitude-latitude or x-y to latitude-longitude or y-x.

B9.3 CONVERTING WIND TURBINE COORDINATES FROM LATITUDE/ LONGITUDE TO UTM ZONE 17 USING MSP GEOTRANS

MSP GEOTRANS is another open source program available from the National Geospatial-Intelligence Agency (NGA) which can perform the same conversion.[10] Single coordinate pairs can be converted using the calculator-like user interface, or converted in batch

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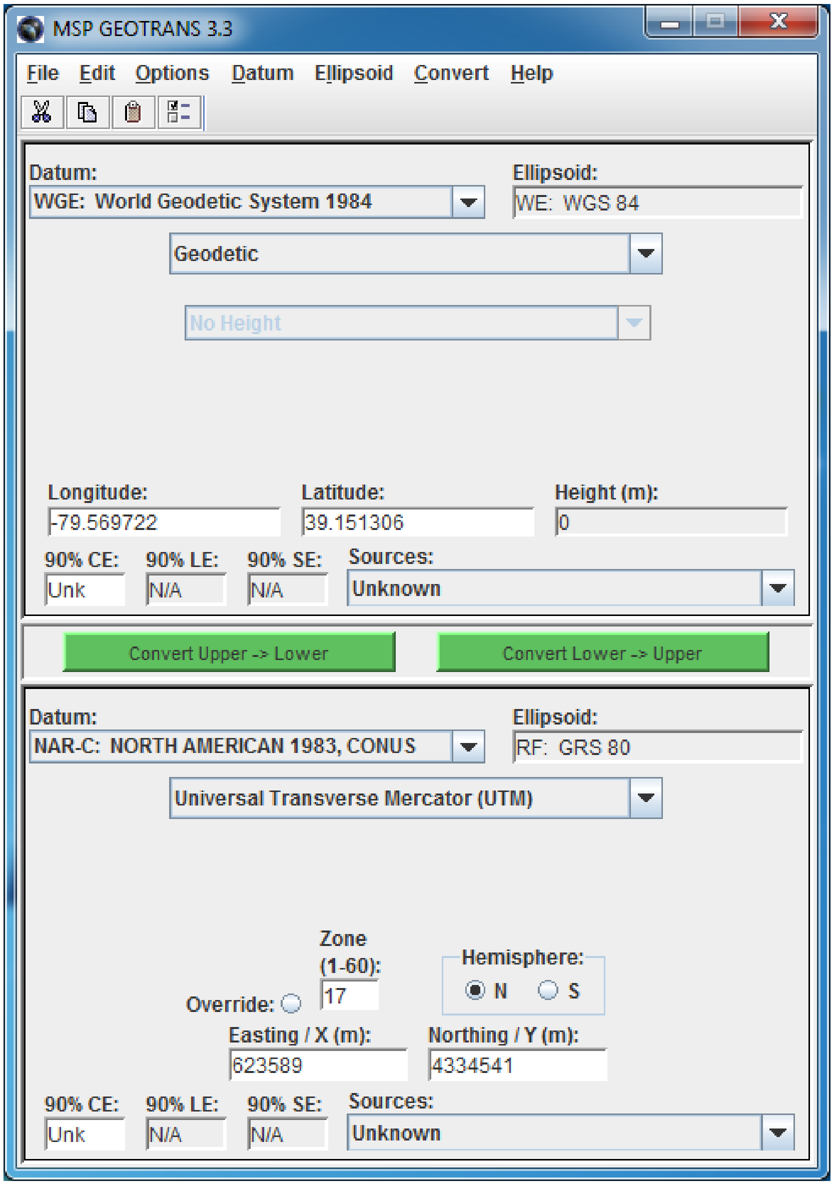
[9] http://fwtools.maptools.org/

[10] http://earth-info.nga.mil/GandG/geotrans/

using a ".DAT" file with a simple header. The program can generate the header for you in the required format using File > Create File Header…

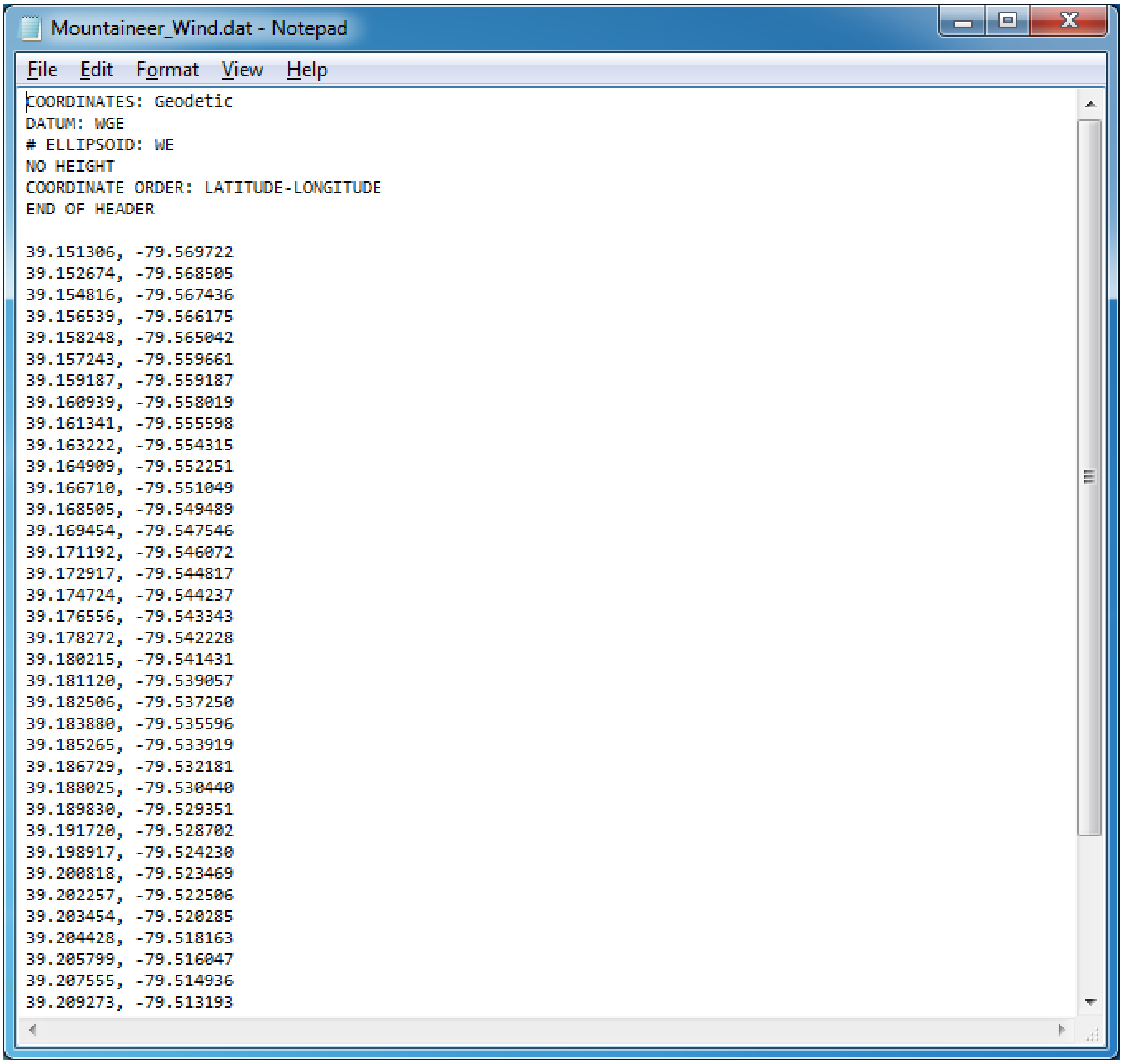
The conversion process is illustrated in figures B-12 and B-13.



Datum: WGE: World Geodetic System 1984
Ellipsoid: WE: WGS 84
Geodetic
No Height
Longitude: -79.569722
Latitude: 39.151306
Height (m): 0
90% CE: Unk
90% LE: N/A
90% SE: N/A
Sources: Unknown

Datum: NAR-C: NORTH AMERICAN 1983, CONUS
Ellipsoid: RF: GRS 80
Universal Transverse Mercator (UTM)
Override: ○
Zone (1-60): 17
Hemisphere: ● N ○ S
Easting / X (m): 623589
Northing / Y (m): 4334541
90% CE: Unk
90% LE: N/A
90% SE: N/A
Sources: Unknown

Figure B-12. Single coordinate conversion using MSP GEOTRANS



```
COORDINATES: Geodetic
DATUM: WGE
# ELLIPSOID: WE
NO HEIGHT
COORDINATE ORDER: LATITUDE-LONGITUDE
END OF HEADER

39.151306, -79.569722
39.152674, -79.568505
39.154816, -79.567436
39.156539, -79.566175
39.158248, -79.565042
39.157243, -79.559661
39.159187, -79.559187
39.160939, -79.558019
39.161341, -79.555598
39.163222, -79.554315
39.164909, -79.552251
39.166710, -79.551049
39.168505, -79.549489
39.169454, -79.547546
39.171192, -79.546072
39.172917, -79.544817
39.174724, -79.544237
39.176556, -79.543343
39.178272, -79.542228
39.180215, -79.541431
39.181120, -79.539057
39.182506, -79.537250
39.183880, -79.535596
39.185265, -79.533919
39.186729, -79.532181
39.188025, -79.530440
39.189830, -79.529351
39.191720, -79.528702
39.198917, -79.524230
39.200818, -79.523469
39.202257, -79.522506
39.203454, -79.520285
39.204428, -79.518163
39.205799, -79.516047
39.207555, -79.514936
39.209273, -79.513193
```

Figure B-12. DAT file for batch conversion using MSP GEOTRANS

B9.4 REPROJECTING NLCD FROM ALBERS EQUAL AREA CONIC TO UTM ZONE 17 USING GDALWARP

GDALWARP is an open source program for cropping and reprojecting raster files included with the FWTools package. From the FWTools Shell, the following command will reproject the NLCD raster located at “H:\nlcd2006_landcover_4-20-11_se5.img” and create a local habitat map at “H:\Mountaineer_Wind_Habitat.img”

```
gdalwarp -of hfa -t_srs "+proj=utm +zone=17 +datum=NAD83" -
te 620000 4332000 632000 4344000 -tr 30 30
"H:\nlcd2006_landcover_4-20-11_se5.img"
"H:\Mountaineer_Wind_Habitat.img"
```

The options are as follows:

`-of hfa` specifies that the output format should be an ERDAS IMAGINE .img file, which is the same format as NLCD 2006. This option should be used whenever working with the NLCD 2006.

`-t_srs` specifies the target spatial reference system (projection), which can be written in the same format as shown for the CS2CS utility. The source projection is automatically determined from the input file.

`-te` specifies the output extent of the image as “xmin ymin xmax ymax” in the target projection (UTM Zone 17N, meters). These boundaries were selected to encompass a 12 km × 12 km surrounding the wind turbines.

`-tr` specfies the target resolution (pixel size) of the image. The pixel size of the NLCD 2006 is 30 m × 30 m, and this can be smaller or larger. Roosting and foraging densities are relative to this value.