ABSTRACT

ROCKHILL, AIMEE PAULINE. The Ecology of Bobcats in Coastal North Carolina. (Under the direction of Drs. Christopher S. DePerno and Roger A. Powell).

We evaluated the effectiveness of medetomidine and butorphanol as a substitute for xylazine in ketamine-based field immobilization protocols for bobcats (Lynx rufus). During 2008 and 2009, 11 bobcats were immobilized with an intramuscular combination of ketamine (10 mg/kg)-xylazine (0.75 mg/kg) (KX) or ketamine (4 mg/kg)-medetomidine (40 mcg/kg)-butorphanol (0.4 mg/kg) (KMB). Time to initial sedation, recumbency, full anesthesia, head up, sternal, standing, full recovery, and total processing times were recorded. The KX combination had a median time to full anesthesia of 10 minutes, a median recovery time of 46 minutes, and a median total processing time of 83 minutes. Alternatively, the KMB combination had a median time to full anesthesia of 21 minutes, a median recovery time of 18 minutes, and a median total processing time of 64 minutes. Median HR, RR, RT, and SpO_2 were within acceptable limits for both protocols. Though both protocols provided safe and reliable sedation, the benefits of using medetomidine and butorphanol to lower ketamine doses and decrease processing time for brief nonsurgical sedation of bobcats in the field are presented.

Monitoring mammals is becoming increasingly important as changing climate and increased urbanization affect populations. We designed and implemented surveys applicable to forested wetlands. Observed species richness, individual detection and cost per species detected were used to evaluate the efficiency of survey techniques. Visual observations produced the highest species richness estimate (14). Trapping was the most expensive

technique ($4,024, $61 per individual) but provided age structure and population estimates through mark-recapture analysis. Camera trapping was relatively expensive ($1,865) and detected the most individuals (n = 673) which resulted in low per individual cost ($3 per individual). Visual observations and camera trapping documented species not detected by any other methods; mink (*Mustela vison*) and feral hog (*Sus scrofa*). Each technique produced different indices and species richness values. Our results indicate that, although camera trapping was a cost effective way to detect mammals, land managers should use a variety of monitoring techniques specific to forested wetlands.

Understanding changes in behaviors of prey and predators based on lunar illumination provides insight into important life history, behavioral ecology, and survival information. The objectives of this research were to determine if bobcat movement rates differed by period of day (dark, moon, crepuscular, day), lunar illumination (< 10%, 10 - < 50%, 50 - < 90%, > 90%), and moon phase (new, full). Bobcats had high movement rates during crepuscular and day periods and low movement rates during dark periods. Bobcats had highest movement rates during daytime when nighttime illumination was low (new moon) and higher movement rates during nighttime when lunar illumination was high (full moon). These behaviors are consistent with prey availability being affected by light level and by limited vision by bobcats during darkness.

The surrogate species approach is being adopted by many organizations that are faced with diminishing budgets and reduced staff. We selected bobcat as a surrogate to guide research on University owned property in North Carolina. We tested the Habitat Suitability Index model developed for bobcats in 1987. Although time consuming, the HSI worked well enough to use as a starting approach for assessing land cover suitability for bobcat throughout the Southeast. Further, we used the synoptic model to simultaneously estimate land cover and space use of bobcats. The top synoptic model included all environmental covariates that were hypothesized to affect bobcat land cover selection. Benefits of the surrogate species approach included: access to information about other mammals, detailed information of land cover structure, and identification of travel corridors used by bobcats and likely other meso-mammals.

The Ecology of Bobcats in Coastal North Carolina

by
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BIOGRAPHY

Aimee Rockhill (formerly Salstead) grew up in Ticonderoga, a small town in the Adirondack Park of upstate New York. Family vacations were usually spent camping at the Schroon Lake camp ground where there was ample opportunity to play in the river, hike on trails, or explore in the woods with her two sisters. It was here that her love and appreciation for the great outdoors began. She received her Bachelor of Arts in Environmental Science from SUNY Plattsburgh in 1998. During her undergraduate degree, she was given the opportunity to study a semester abroad at the University of Queensland, Brisbane, Australia. In 2000, she moved to Raleigh, North Carolina and began work at North Carolina State University in the Genome Research Lab under the direction of Dr. Charles Opperman. After several years of working on the Tobacco Genome Initiative Project, she began to pursue a degree in Forestry. In May 2008, she received a Masters of Science in Forestry from the College of Natural Resources while also pursuing a PhD in Fisheries, Wildlife, and Conservation Biology, both in the Department of Forestry and Environmental Resources at North Carolina State University. During her PhD program, she had the opportunity to teach Natural Resource Management and Mammalogy at North Carolina State University and Mammalogy and Conservation Biology at Virginia Polytechnic Institute. Aimee enjoyed teaching and was fortunate to work with many great students in these courses but wasn’t ready to give up her passion for working in the field. Aimee and her husband, Stephen Rockhill, moved to Galena, Alaska in 2012 where she began working for the USFWS as a wildlife biologist at the Koyukuk/Nowitna National Wildlife Refuge Complex.

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A COMPARISON OF TWO FIELD CHEMICAL IMMOBILIZATION TECHNIQUES FOR BOBCATS (LYNX RUFUS)

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Abstract

Anesthetic protocols that allow quick induction, short processing time, and rapid reversal are necessary for researchers performing minimally invasive procedures (e.g., morphometric measurements or attachment of radio collars). Our objective was to evaluate the effectiveness of medetomidine and butorphanol as a substitute for xylazine in ketamine-based field immobilization protocols for bobcats (Lynx rufus) to reduce recovery and total field times. During 2008 and 2009, 11 bobcats were immobilized with an intramuscular combination of ketamine (10 mg/kg)-xylazine (0.75 mg/kg) (KX) or ketamine (4 mg/kg)-

medetomidine (40 mcg/kg)-butorphanol (0.4 mg/kg) (KMB). Time to initial sedation, recumbency, and full anesthesia were recorded post injection. Time to head up, sternal, standing, full recovery, and total processing times were recorded post reversal. Throughout anesthesia, heart rate (HR), respiratory rate (RR), rectal temperature (RT), and non-invasive hemoglobin-oxygen saturation (SpO_2) were recorded at 5 minute intervals. The KX combination had a median time to full anesthesia of 10 minutes, a median recovery time of 46 minutes, and a median total processing time of 83 minutes. Alternatively, the KMB combination had a median time to full anesthesia of 21 minutes, a median recovery time of 18 minutes, and a median total processing time of 64 minutes. The KX protocol produced a median HR of 129 beats/minute, RR of 25 breaths/minute, RT of 38.3°C, and SpO_2 of 93%. The KMB protocol produced a median HR of 97 beats/minute, RR of 33 breaths/minute, RT of 38.4 °C, and SpO_2 of 92.3%. Though both protocols provided safe and reliable sedation, the benefits of using medetomidine and butorphanol to lower ketamine doses and decrease processing time for brief nonsurgical sedation of bobcats in the field are presented.

Key words: Anesthesia, bobcat, induction rate, ketamine, Lynx rufus, recovery rate.

Introduction

The use of chemical restraint has been used successfully for many years in wildlife research and management.[15] Generally, immobilizing drugs are selected to allow wildlife to be handled in a safe, effective, predictable, and minimally stressful manner.[24] Further, anesthetic protocols that allow quick induction, short processing time, and rapid reversal are necessary for researchers performing minimally invasive procedures (e.g., morphometric measurements or attachment of radio collars). Although bobcats (Lynx rufus) have been studied throughout the United States, reports on doses of anesthetic agents, response, and effectiveness are limited. Doses have been reported as 10-22 mg/kg of ketamine [11,12,19] or 8-11 mg/kg of ketamine combined with 0.71-1.7 mg/kg xylazine.[3,25,28,33] The use of a ketamine-medetomidine-butorphanol (KMB) drug combination compared to the ketamine-xylazine (KX) combinations previously used for bobcats was evaluated as part of a study that analyzed micro-habitat use, movement, and genetic relatedness of bobcats at Bull Neck Swamp Research Forest, North Carolina (A. P. Rockhill, North Carolina State University, unpublished data).

For carnivores, KX has been widely used and typically results in stable cardiovascular function and good muscle relaxation.[15] Ketamine is a dissociative anesthetic that generates rapid immobilization and has been widely used in carnivores.[10,24] Also, ketamine is non-reversible and the margin of safety is high when used alone.[6,27] Advantages of using ketamine for field sedation of small carnivores include safety, intramuscular administration, rapid effect, availability, affordability, and compatibility with other anesthetic agents.[4,32,38] Side effects of ketamine may include increased heart rate, blood pressure and muscle rigidity, convulsions, and catatonia.[2,4,6,38] Xylazine is often used in combination with ketamine to reduce the amount of ketamine needed for anesthesia and mitigate the negative effects of both drugs.[4,8,23] Xylazine is an alpha$_2$ adrenoreceptor agonist that produces moderate sedation, analgesia, and muscle relaxation, and is reversible in carnivores with the antagonist yohimbine.[4,8,27,35] Also, xylazine can decrease heart rate and cardiac output and induce vomiting in felids.[4]

Medetomidine, an $alpha_2$ adrenoreceptor agonist, has been used in combination with ketamine for Canada lynx (Lynx canadensis),[1] tigers (Panthera tigris),[7] European wildcats (Felis silvestris),[20] cougars (Puma concolor),[21] and domestic cats (Felis catus) [34] but has not been reported for bobcats. Medetomidine has a much higher $alpha_2$/$alpha_1$ selectivity ratio than xylazine,[13] resulting in greater potency and more complete reversal with the antagonist, atipamezole.[24,29] However, bradycardia has been reported as a side effect of medetomidine-ketamine combinations used in cats.[13,34] Butorphanol is a kappa-opioid agonist and mu-opioid antagonist with relatively weak analgesic properties, a wide margin of safety, and when combined with medetomidine provides additional sedation and improved muscle relaxation.[8,30] Combinations of KMB have been reported for European badgers (Meles meles),[22] patas monkeys (Erythrocebus patas),[14] ring-tailed lemurs (Lemur catta),[36] red wolves (Canis rufus),[18,30] and ferrets (Mustela putorius furo);[17] but not for free-ranging, wild felids.

The study required large trapping effort (up to 85 traps per night over 2,400 hectares) with the possibility of numerous non-target species, including gray fox (Urocyon cinereoargenteus), Virginia opossum (Didelphis virginiana), and northern raccoon (Procyon lotor). Therefore, the goal was to reduce field time by reducing the overall processing time of anesthetized bobcats, allowing for safe and quick trap release. Specifically, the effectiveness of KMB as a substitute for KX in field procedures with bobcats that required nonsurgical, brief anesthesia was evaluated.

Methods

During 01 March 2008 – 09 March 2008 and 07 March 2009 – 22 March 2009, bobcats were captured at Bull Neck Swamp Research Forest, North Carolina using foot hold traps (#1.5 Victor Softcatch, Minnesota Trapline Products, Inc., Pennock, Minnesota 56279, USA) with a 1.81 kg pan tension. Between 37 and 85 traps were set per night in locations with high bobcat activity based on preliminary data from camera and scent station surveys (A. P. Rockhill, North Carolina State University, unpublished data). Once captured, bobcats were randomly assigned to an immobilization protocol of 10 mg/kg ketamine (Ketaset®, Fort Dodge Animal Health, Fort Dodge, Iowa 50505, USA) and 0.75 mg/kg xylazine (Xyla-ject ® 20mg/mL, Phoenix Pharmaceutical Inc., St. Joseph, Missouri 64506, USA) (KX) or 4 mg/kg ketamine, 40 mcg/kg medetomidine (Domitor®, Pfizer Animal Health, Exton, Pennsylvania 19341, USA), and 0.4 mg/kg butorphanol (Torbugesic®, Fort Dodge Animal Health, Fort Dodge, Iowa 50505, USA) (KMB). Immobilization doses were developed from similar protocols used on captive Pallas' cats (Felis manul) at the North Carolina State University's College of Veterinary Medicine.[26] Doses were calculated based on estimated body weight and the drugs were administered via intramuscular injection. The time to initial sedation, recumbency, and anesthesia were monitored. Time to initial sedation was recorded at first signs of anesthetic effect (e.g. ataxia and disorientation) and time to anesthesia was recorded when animals were no longer responsive to a noxious stimulus (e.g., ear pinch). During anesthesia, heart rate (HR), respiratory rate (RR), rectal temperature (RT), non-invasive hemoglobin-oxygen saturation (SpO_2), and capillary refill time were recorded at 5 minute intervals. SpO_2 was measured with a pulse oximeter (V3402 Handheld Pulse Oximeter, Smiths Medical, Dublin, Ohio 43017). Bobcats were weighed, measured, ear-tagged, sexed, aged based on tooth wear and eruption,[5] and fitted with a global positioning system (GPS)/very high frequency (VHF) radiocollar weighing 250 g (Tellus GPS System, Followit, Lindesberg 711 34, Sweden). Blood samples were collected from the jugular vein for disease surveillance and a tissue sample was collected from an ear punch for genetic analysis. Anesthesia was reversed with 0.2 mg/kg yohimbine (Yobine ®, Lloyd Laboratories, Shenandoah, Iowa 51601, USA) or 0.2 mg/kg atipamezole (Antisedan ®, Pfizer Animal Health, Exton, Pennsylvania 19341, USA) for KX and KMB, respectively. Bobcats were placed in a 2x1 meter transportable animal cage post-reversal and we recorded time to initial raising of the head (i.e., head-up), sternal recumbency, standing, and full recovery (i.e., when no signs of sedation were present). Release time was documented and total processing time was calculated as the time from initial injection of the anesthetic agent to time of release. Bobcats were released at the capture site and monitored with GPS/VHF for up to 9 months post-release.

Data was not normally distributed and sample sizes were low therefore medians were used for analysis.[31,32] Differences were compared for anesthesia time (sedation, recumbency, and complete anesthesia), HR, RR, RT, SpO2, recovery times (head up, sternal, standing, full recovery), and total processing times between KX and KMB with a Mann-Whitney U-test;[37] alpha was set at $P < 0.05$.

All procedures were approved by the Institutional Animal Care and Use Committee at North Carolina State University (Protocol # 08-012 O) and the North Carolina Wildlife Resources Commission (Statues GS113-261 & GS113-272.4, Rules NCAC 10B.0119), and followed guidelines provided by the American Society of Mammalogists.[9]

Results

A total of 11 captures (8 females, 3 males; at time of capture, 5 adults, 6 juveniles) were recorded. Two juvenile female bobcats captured in 2008 were recaptured in 2009 as adults; resulting in 11 anesthetizations of 9 bobcats. Median weights of bobcats were similar for individuals treated with KX (7.1 kg) compared to KMB (6.9 kg; P = 0.855). Bobcats anesthetized under KX received 9.61 – 13.89 mg/kg ketamine (median = 13.46) and 0.71 – 1.05 mg/kg xylazine (median = 0.89). Bobcats anesthetized under KMB received 3.29 – 9.91 mg/kg ketamine (median = 4.80), 0.03 – 0.05 mg/kg medetomidine (median = 0.05), and 0.33 – 0.52 mg/kg butorphanol (median = 0.45). The median time to initial sedation was similar between protocols (P = 0.169; Table 1). However, time to recumbency and anesthesia for bobcats anesthetized with KX were 6 and 11 minutes faster, respectively, than bobcats anesthetized under KMB (recumbency: P = 0.027; anesthesia: P = 0.028; Table 1). The median heart rate differed between protocols (P = 0.018); heart rates for bobcats receiving KMB (median = 97.0 beats/minute) were lower for the first 20 minutes of anesthesia than heart rates for bobcats receiving KX (median = 129 beats/minute) (Figure 1a). Differences in heart rates were statistically significant to the 0.05 level at 5 (P = 0.033), 10 (P = 0.025), 15 (P = 0.036), and 20 (P = 0.046) minute intervals (Figure 1a). Median respiratory rates were similar between KX (25 breaths/minute) and KMB (33 breaths/minute; $\underline{P} = 0.645$; Figure 1b). Rectal temperatures were within the accepted range throughout anesthesia and similar between protocols ($\underline{P} = 0.670$; Figure 1c). Oxygen saturation was similar between protocols ($\underline{P} = 0.480$; Figure 1d).

Bobcats anesthetized under KX received 0.18 – 0.28 mg/kg yohimbine (median = 0.24) and bobcats anesthetized under KMB received 0.20 – 0.26 mg/kg atipamezole (median = 0.25) for reversal. Time to head up and time to sternal were similar between protocols (head-up: $\underline{P} = 0.099$; sternal: $\underline{P} = 0.098$). Standing time, full recovery time, and total processing time, however, differed between protocols (standing: $\underline{P} = 0.017$; full: $\underline{P} = 0.011$; total: $\underline{P} = 0.018$). Bobcats anesthetized with KX had longer times to standing, full recovery, and total processing time compared to the KMB protocol times to standing, full recovery, and total processing time (Table 1). No signs of paddling, vomiting or convulsions were observed with either drug combination during anesthesia; although a pregnant bobcat had convulsions approximately 29 minutes after the reversal for KMB was administered.

Discussion

The results indicate that KMB is a safe and suitable drug combination for brief non-surgical field sedation of bobcats. In general, bobcats anesthetized under KMB exhibited smooth sedation and immobilization along with quicker recovery than KX (Table 1). Although induction times of KMB were on average 11 minutes longer than KX, the total processing times of KMB were on average 19 minutes shorter than KX. Lower doses of ketamine have been reported to result in longer induction times and quicker recovery times.[27]

The addition of medetomidine and butorphanol allowed for lower ketamine doses and overall significantly shorter processing times. Bobcats anesthetized under KMB appeared to be more responsive to surrounding noises or motions and induction time can be reduced by minimizing disturbance at the field site (e.g. reduce noise and visibility). Importantly, trapped bobcats should be approached with caution and can inflict severe injury if not immobilized properly.[24] Although KX provided rapid induction along with acceptable heart rates, respiratory rates, rectal temperature, and oxygen saturation, recovery was long and variable (33 - 103 minutes). During this study, bobcats under KX took, on average, 28 minutes longer to recover fully and exhibited signs of swaying or trembling at some point during recovery. Only one bobcat under KMB exhibited negative signs during recovery; a female bobcat had a seizure 29 minutes after the reversal, atipamezole, was administered. This bobcat received 4 mg/kg more ketamine than necessary and had an abnormally long recovery time (37 minutes). She was monitored for 8 months following initial capture and movement activities were consistent with activities of other bobcats in the study.

Decreases in heart rate with KMB were consistent with previous reports.[14,22,30] Bradycardia was likely a reflex due to peripheral vasoconstriction associated with medetomidine administration.[17] Field conditions precluded reliable blood pressure measurement, and hypertension could not be confirmed. Some bobcats exhibited less than optimal oxygen saturation, and we recommend providing supplemental oxygen when possible.

Most bobcat studies that require the collection of blood, standard measurements, and application of a radiocollar and ear tags can be performed in 20-30 minutes. The effective dose of ketamine begins to wear off in this period.[15] Although no surgical procedures were performed for this project, ear tags were inserted which required taking a 1mm punch biopsy of cartilage from the ears. The biopsy punch was performed last and typically resulted in partial arousal in bobcats sedated with KMB. Reducing the ketamine dose by adding medetomidine and butorphanol may result in partial arousal in bobcats; therefore, appropriate safety precautions should be taken when using KMB. Although a speedy arousal is desirable when a quick return to normal function is important, for processing times that extend beyond 30 minutes the KX combination may be necessary.

Although ketamine or ketamine-xylazine combinations are widely accepted in the literature as appropriate immobilizing protocols for bobcats, field anesthesia of bobcats with a combination of KMB followed by atipamezole for reversal is recommended as an alternative for brief, non-surgical field sedation. Though both protocols provide safe and reliable sedation, the benefits of using KMB for faster recovery and decreased processing time are presented. This protocol is appropriate for non-surgical, brief procedures and we recommend that researchers minimize disturbance by reducing field crew and noise, especially during initial sedation. To the knowledge of the authors, there are no other studies on chemical immobilization of bobcats and further research is needed to analyze the possible effects of age, sex, ambient temperature, and disturbance when anesthetizing bobcats.

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TABLES

Table 1: Median, range, and comparison of monitored parameters for ketamine-xylazine (KX) and ketamine-medetomidine-butorphanol (KMB) in immobilized bobcats captured at Bull Neck, N.C., 2008 - 2009.

	KX (n = 5)		KMB (n = 6)		
Parameter	Median	Range	Median	Range	Mann-U
Sedation time [a, b]	3.0	(2.0 - 7.0)	6.5	(1.0 - 13.0)	7.5
Recumbency time [a, b]	8.0	(3.0 - 10.0)	14.0	(9.0 - 28.0)	3.0*
Anesthesia time [a, b]	10.0	(3.0 - 21.0)	20.5	(13.0 - 38.0)	3.0*
Heart rate	128.6	(112.0 - 186.7)	97.0	(82.8 - 120.0)	28.0*
Respiratory Rate	24.6	(16.0 - 38.0)	33.2	(15.0 - 41.3)	11.0
Rectal Temperature (°C)	38.3	(37.6 – 38.8)	38.4	(36.5 – 39.2)	10.0
Oxygen Saturation	93.0	(90.0 - 95.0)	92.3	(82.0 - 94.1)	8.0
Head-up time [a, c]	5.0	(3.0 - 14.0)	1.5	(-5.0 - 6.0)	24.0
Sternal time [a, c]	8.0	(7.0 - 23.0)	5.0	(0.0 - 10.0)	24.0
Standing time [a, c]	29.0	(11.0 - 103.0)	9.5	(5.0 - 15.0)	28.0*
Full Recovery time [a, c]	46.0	(33.0 - 103.0)	17.5	(9.0 - 37.0)	29.0*
Total Process Time [a, b]	83.0	(74.0 – 140.0)	64.0	(49.0 - 77.0)	28.0*

[a] Time in minutes.
[b] Time calculated from immobilization injection.
[c] Time calculated from reversal injection.
* Indicates the drug combinations (i.e., KX and KMB) differed; alpha was set at P = 0.05.

FIGURES

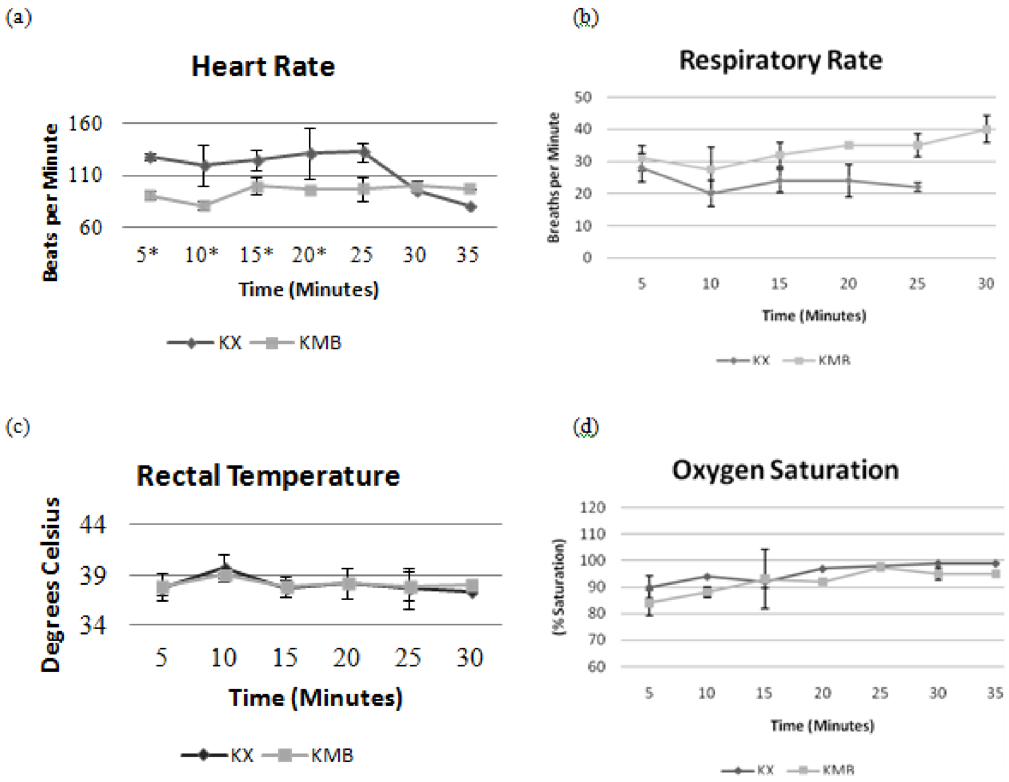

Figure 1: Median values and standard deviations for ketamine-xylazine (KX) vs. ketamine-medetomidine-butorphanol (KMB) at 5 minute intervals for heart rate (a), respiratory rate (b), rectal temperature (c), and oxygen saturation (d). An * indicates a statistically significant difference ($\underline{P} < 0.05$).

A COMPARISON OF SURVEY TECHNIQUES FOR OCCUPANCY MODELING OF MAMMALS IN FORESTED WETLANDS.

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Key words: camera, detection, live-trap, mammal, occupancy, predator call, scent-station, spotlight.

Abstract

Monitoring mammals is becoming increasingly important as changing climate and increased urbanization affect populations, forcing state agencies to develop wildlife action plans. The development of occupancy modeling gives land managers an additional tool to implement long-term monitoring plans for mammals in forested wetlands. We designed and implemented surveys applicable to forested wetlands to 1) assess detection rates and species richness estimates of 6 survey techniques (visual, predator calling, spotlighting, scent stations, camera trapping, and foothold trapping), 2) compare distribution estimates of detected mammals across survey techniques, and 3) assess cost verses success among the techniques. For spatial correlation between techniques, the study site was divided into 9 - 2.6

km^2 grid cells. Observed species richness, individual detection and cost per species detected were used to evaluate the efficiency of survey techniques. Visual observations produced the highest species richness estimate (14) and were the least expensive (opportunistic, $0). Trapping was the most expensive technique ($4,024, $61 per individual) but provided age structure and population estimates through mark-recapture analysis. Camera trapping was relatively expensive ($1,865) and detected the most individuals (n = 673) which resulted in low per individual cost ($3 per individual). Visual observations and camera trapping documented species not detected by any other methods; mink (*Mustela vison*) and feral hog (*Sus scrofa*). Each technique produced different indices and species richness values. Our results indicate that, although camera trapping was a cost effective way to detect mammals, land managers should use a variety of monitoring techniques specific to forested wetlands.

Introduction

Monitoring mammals is becoming increasingly important as changing climate and increased urbanization impact their populations (Bradley and Altizer 2007, Lawler et al. 2009). Many medium to large sized mammals (e.g., black bear [*Ursus americanus*], bobcats [*Lynx rufus*], white-tailed deer [*Odocoileus virginianus*], raccoon [*Procyon lotor*], etc.; hereafter "mammals") can serve as indicators of ecosystem health and biodiversity but are difficult to monitor due to their cryptic habits and/or low population densities, resulting in few long-term monitoring efforts (Boddicker et al. 2002, Sanderson and Trolle 2005, Gaidet-Drapier et al. 2006). The lack of information on many animal assemblages and reliable estimates of population size restricts managers from conservation and from planning, implementing, and evaluating land management strategies (Caughley and Sinclair 1994, Sutherland 2000, Desbiez et al. 2010). Hence, many state agencies have recently developed wildlife action plans that focus on mammals. Adversely, time and cost constraints of mammalian survey techniques in forested wetland habitats may discourage managers and landowners from implementing surveys on their properties (Sheil 2001). Therefore, landowners need information that allows them to weigh the costs and benefits of implementing surveys.

The Southeast region of the United States contains many large tracts of unique, forested wetlands that are important for wildlife conservation. Although the National Wildlife Refuges encompass over 12,000 km^2 of forested wetlands in the Southeast, the United States Fish and Wildlife Service (2009) reported a loss of over 650 km^2 of forested wetlands in 2004-2009. The difficulties in working in forested wetlands make traditional survey design inapplicable and may limit monitoring efforts across a property. Therefore, little is known about the abundances, species richness, and distributions of mammals in these habitats. Generally, forested wetland systems are characterized by systems of raised roads bordered by 5-10 m-wide canals, making access to interior tracts of land difficult and time consuming. Further, seasonal flooding and changing water levels prohibit the use of random survey locations that are off a road system and have stable water levels. Hence, forested wetlands provide unique challenges for land managers who aim to develop long-term monitoring techniques for mammals.

Non-invasive survey techniques commonly implemented to study mammals include scent stations, camera trapping, spotlighting, and scat surveys. Live-trapping, an invasive technique, is not commonly used but provides data on animals’ physical conditions, allows study of physiology and morphology, and permits population estimation if animals are tagged. Zielinski and Kucera (Zielinski and Kucera 1995) reported that standardizing large scale, multi-species monitoring is necessary. Since then, a number of survey techniques have been reviewed, compared, and critiqued (e.g., (Foresman and Pearson 1998, Gese 2001, Wilson and Delahay 2001, Harrison 2002, Gompper et al. 2006) and most studies conclude the need for more than one survey type to detect multiple species (Harrison 2002, Gompper et al. 2006, Lyra-Jorge et al. 2008, Hutchens and DePerno 2009). Further, different techniques allow for the collection of different data, and the use of one technique alone may limit analyses. For example, spotlight surveys can be used for abundance indices or density estimates where distance sampling is possible (McCullough 1982, Naugle et al. 1996, Edwards et al. 2000, Ruette et al. 2003), whereas automatic cameras can provide data for calculating abundance estimates when animals are individually marked (Karanth 1995, Karanth and Nichols 1998, Carbone et al. 2001, Silver et al. 2004, Heilbrun et al. 2006, Kelly 2011). Recent developments in analyses allow estimating species distribution and occupancy, while correcting for imperfect detection using noninvasive surveys practical for carnivore conservation and management (McAninch 1995, MacKenzie et al. 2002, 2006, MacKenzie and Bailey 2004, Long et al. 2010).

We developed our project out of a need for baseline data for land-use planning in forested wetlands. Land managers need better information to help monitor the impact of harvest and habitat manipulation to ensure that stable populations of wildlife are being maintained. The implementation of a cost effective, long-term, spatially explicit monitoring protocol for mammal populations in forested wetlands is necessary to manage property effectively. Therefore, our objectives were to 1) acquire baseline data on the distribution of mammals in forested wetland habitats , 2) assess the efficiency of 6 presence/absence survey techniques (visual, predator calling, spotlighting, scent stations, camera trapping, and foothold trapping) for use in forested wetland habitats, 3) compare detection estimates for applicable techniques for black bear, bobcat, gray fox (*Urocyon cinereoargenteus*), Virginia opossum (*Didelphis virginiana*), raccoon, and white-tailed deer to understand which survey technique was best suited in forested wetland habitats.

Methods

We conducted surveys at Bull Neck Swamp Research Forest (hereafter ‘Bull Neck’, Figure 1), a 25 km^2 wetland located on the southern side of Albemarle Sound in Eastern North Carolina (35° 56´– 35° 59´ S, 76° 23´ – 76° 28´ E). Bull Neck is a self-sustaining, working forest with active, small-scale timber harvests, prescribed burning, and hunting activities. The property was used as a model for forested wetlands and is characteristic of most wetland reserves in the Southeast, containing large tracts of forested wetlands with secondary and tertiary dirt roads bordered by canals. Bull Neck has 5 land cover types; non-riverine swamp forest, peatland Atlantic white cedar (*Chamaecyparis thyoides*) forest, mesic mixed hardwood forest, tidal cypress gum swamp, and tidal freshwater marsh. Monthly mean temperatures range from 10.4 C° to 21.7 C° and rainfall averages 126.5 cm/yr based on 50 year climate normals (NOAA National Weather Service).

We followed survey design suggestions by Zielinski and Kucera (Zielinski and Kucera 1995) and used Arc GIS to overlay 2.59 km^2 (1 mi^2) grid cells onto the research property (Figure 2). Each cell (n = 9) was assigned 2 scent stations, one camera station, and one predator calling station on the roads within that cell (Figure 2). Live-trap locations ranged from 6-16 traps per cell, based on areas with increased sign of movement from animals. Spotlight surveys were conducted across the property on drivable roads and detections were recorded and placed in the appropriate cell post-hoc (Figure 2). For all techniques we assessed the total number of individual animals detected, number of detections per species, total monthly cost of performing the survey, and total monthly cost per detection per survey. We were unable to analyze data from spotlight surveys, predator calling, and visual encounters due to small numbers of detections. We used scent station surveys, camera trapping, and foothold trapping data to estimate detection rate, distribution, and occupancy for animals across the property. We indexed density by dividing the number of records (photo, track, or capture) by the number of days of exposure and multiplying by 1,000 (Rice et al. 2001). We then compared the density index for each species by each technique across 9 cells on the property to assess distribution. We combined detection data from scent stations, camera surveys and trapping to estimate occupancies and technique-specific detection probabilities using occupancy models (MacKenzie et al. 2006). Further, we tested for differences in detection probabilities between baited (scent stations running) and non-baited (scent stations not running) days within camera trap occasions. For each of these survey methods, we used 3-day sampling periods so that detection probabilities for all methods refer to the same temporal scale. Given our relatively small study site and standardized sampling, we assumed spatially and temporally constant detection and constant occupancy probability. We conducted the analyses in program R (Team 2012) using the package unmarked (Fiske et al. 2011).

During scent station and camera check survey periods, we recorded opportunistic visual encounters of animals. To prevent double counting, we assigned animals to one survey technique and did not record sightings as opportunistic during spotlighting, predator calling, and trapping surveys. At each visual encounter we recorded the species, date, time, GPS location, and number of individuals. We did not quantify equipment and labor costs for this technique because we recorded observations, while researchers performed other survey techniques; which required no additional cost. We made the assumption that a majority of land managers spend a considerable amount of time on their property and could record observations at no additional cost.

We conducted predator calling surveys at dawn and dusk in 1 location per cell twice per month (Figure 2) in June, July, and August of 2007. We concealed observers in a portable hunting blind and used a rabbit (*Sylvilagus spp.*) distress call (Primos Ki-Yi™, Flora, MS) as a lure and called at 5 minute intervals, monitoring the area with binoculars for 45 minutes. Predator calling equipment included a hunting blind, binoculars, distress caller, and ATV fuel and mileage. Labor costs included 2 technicians working 10 hours per month.

We conducted spotlight surveys on a fixed 19.3 km route every two weeks for 2 consecutive nights from June, 2007 until September, 2007. If rain was forecasted, we performed the survey on the next rain-free night. We repeated counts to reduce estimate variability (McAninch 1995) and randomized the start time between 20:30 and 2:30 to ensure independence. We surveyed all secondary roads on the property (Figure 2) by driving 5 mph with 2 observers standing in the back of the vehicle with a 2,000,000 candlepower spotlights connected to 12 volt battery. We used binoculars as needed to assist in identifying the mammals observed and recorded observer names, species observed, date, time, location, overnight temperature, visibility, precipitation, and comments (e.g., eyeshine color, number of individuals). Presence of canals along the roads prevented accurate distance measures for some sightings. Equipment costs included fuel, mileage, and spotlights. Labor costs included 3 technicians working 4 hours per night, 4 nights per month.

We trapped mammals with #1.5 Victor Softcatch foothold traps (Minnesota Trapline Products, Inc., Pennock, Minnesota 56279, USA), set with a 0.91 kg pan tension, from 01 March to 09 March, 2008. The foothold was selected to target medium-sized mammals (e.g., gray fox). We set up to 85 traps per night in locations with animal sign (e.g., trails through vegetation, latrines) and activity based on preliminary data from camera and scent station surveys (Figure 2). USDA-APHIS provided trapping equipment, which included foothold traps, a variety of baits and lures, trowels, sifters, shovels, catch poles, and hatchets. We included fuel and mileage for 2 trucks and 3 ATVs in equipment costs and labor costs for 3 technicians working 8 hour days for 10 days.

We conducted scent stations in June, July, and August of 2007. To minimize misdetections and maximize visitations, we used a 0.6 m wide strip to connect 2 1x1-m^2 scent-stations placed 3 m apart on opposite sides of secondary and tertiary roads. We cleared the stations and strip of all vegetation and used a mixture of play sand and mineral oil to preserve tracks temporarily. We secured a 0.8 m stake in the center of each station equipped with a visual attractant (fake feathers and silver tassels) stapled approximately 0.1 m from the top of the stake. Cotton balls were stapled to the top of each post and baited with grey fox urine on one station and sardine oil on the opposite station. Stations were set and checked for 4 consecutive days each month. When not in use, we removed stakes and bait from the stations. Lures used were tested for similarity using a paired t-test and the frequencies of species detected with the center strip are reported. To be consistent with standard methodologies, we randomly selected results from one of each paired scent station to estimate a density index for comparison with other survey techniques. Scent station equipment costs included sand, mineral oil, bait, lures, stakes, cotton balls, rulers, camera, and ATV fuel and mileage. For labor costs, we included 2 technicians working an average of 8 hours per day for 4 days per month.

We placed 1 digital camera (Capture 3.0, Cuddeback Digital, DePere, WI) equipped with an infrared sensor triggered by temperature and movement at 9 of the 18 scent stations (Figure 2). Although cameras were monitored continuously for 3 years, data presented in this report are from June, July, and August of 2007 so that results across techniques were comparable. We programmed cameras to run 24 hours a day with pictures taken once per minute when activity was detected. If battery failure occurred, we reduced the number of camera days accordingly. Equipment costs for this survey included cameras, USB cards, replacement batteries, download accessories, and ATV fuel and mileage. Labor costs included 1 technician to check all cameras, download, and record images and were estimated at 7 hours per month.

All animal handling techniques were approved by the Institutional Animal Care and Use Committee at North Carolina State University (08-012-O) and followed guidelines provided by the American Society of Mammalogists (Gannon and Sikes 2007) and ASAB/ABS Guidelines for the Use of Animals in Research.

Results

During the surveys, we recorded a total of 1,010 individual mammals of 15 species (Table 1). Visual observations accounted for the highest number of species (n = 14) and predator calling detected the least number of species (n = 2). No technique detected all species that were identified through the combination of surveys (Table 1). Mink (*Mustela vison*) were only detected by opportunistic visual observations and feral hogs were only detected with the camera survey. Gray fox was the only species detected by all surveys. Predator calling was successful in attracting bobcat and gray fox, but this technique accounted for the least number of species and individual detections. Spotlight surveys were best suited for black bear (n = 12, density index = 69) and white-tailed deer (n = 34, density index = 196). We detected 59 individuals of 7 species (47% of all species) with the spotlight survey (Table 1). Spotlight survey estimates for nutria (*Myocastor coypus*) and Virginia opossum (density index = 23), gray fox (density index = 17), raccoon and rabbit (density index = 6) were low. No techniques were consistent with producing high and low estimates for all species in the same cells (Table 2).

Trapping was successful in providing sex ratio data for 4 species. We had 10 total captures of 7 individual bobcats; 2 male (1 adult, 1 juvenile) and 5 female (1 adult, 4 juvenile). We captured and marked gray fox (7 male, 10 female), raccoon (14 male, 3 female, 4 unknown), and Virginia opossum (7 male, 4 female, 6 unknown) but recaptures were low. Scent stations were best for detecting black bear, gray fox, Virginia opossum, and raccoon and detected the least number of white-tailed deer. Cameras recorded the second highest number of species (n = 12) and the highest number of individuals (n=653) but 63% of the detections were of black bear.

At scent stations, we detected black bear more than any other species (Figure 3). Over half of the detections were in the center strip only and would have been missed with a standard scent station design. Black bear was the only species detected more at the sardine station and bobcat had twice as many detections at urine stations than at sardine stations. Gray fox, Virginia opossum, and raccoon tended to investigate urine stations at a higher rate than sardine stations but presence at one of the sections often resulted in presence at all 3 sections of the station (Figure 3).

Recording visual observations provided only presence/absence data, but had no costs and documented 1 species (mink) that was not detected with any other technique (Table 1). Trapping had the highest overall cost ($4,024), highest cost per species ($805; Table 3), and the highest number of species detected per month. However, due to high equipment and labor costs the total cost per capture was $61. Trapping targeted specific mammals, which resulted in low species diversity (n = 5), and was labor intensive, requiring a high number of hours (1.21) per species. Scent station surveys were relatively inexpensive ($369/month), had the second lowest cost per species detected ($34, Table 3), and the second lowest total cost per individual ($8) and hours of labor needed per species observed (0.68). Of all techniques that allowed for relative density estimates, camera trapping had the lowest cost per individual observed ($3, Table 3). Most of the cost accrued for this survey was in equipment and initial setup ($1,865) which resulted in a cost per species observed of $56. Monthly maintenance and data processing was inexpensive ($51) compared to other techniques and required only 0.01 hours of labor per detection.

Scent stations were successful at detecting raccoons across the entire property (i.e., tracks were documented on each grid). Otherwise, detection of species across the entire property was only possible by combining techniques (Table 4). Combining data from scent stations, cameras and live traps, cell occupancy was 1 (i.e., species were detected in all cells) for black bear, gray fox, Virginia opossum, and raccoon. We compared detection probability at baited versus non-baited camera traps for black bear, gray fox and Virginia opossum; however, data were too sparse for the remaining species. All three species had similar detections between baited and non-baited camera traps (Table 5). However, detection probability per 3-day period was highest at scent stations and lowest at cameras for all species except white-tailed deer. Differences were detected between cameras and scent stations for all species except white-tailed deer and differences were detected between trapping and cameras for all foothold trapped species (Table 5). Detection probabilities from foothold trapping and scent stations differed (the confidence interval of the former did not include the estimate of the latter and vice versa) for raccoon and Virginia opossum (Table 5).

Discussion

Through various survey techniques, we obtained baseline data for mammal diversity and distribution at Bull Neck. Prior to the survey, 9 mammal species had been documented on the property and this study resulted in the documentation of 6 additional species (bobcat, domestic cat (*Felis catus*), domestic dog (*Canis lupus familiaris*), feral hog, mink, and nutria. Relative density estimates are typically used to demonstrate large scale trends in populations over a specified period of time. Although it is not possible to compare relative density for a species across all survey techniques, it is possible to compare relative density estimates across the property within a survey technique, assuming no spatial variation in detection probability. Interestingly, no techniques were consistent with producing high and low estimates for all species in the same cells which indicates that spatial pattern of detection varied by technique and a combination of techniques would be necessary to accurately record presence and distribution of species on a property (Table 4). Conveniently, occupancy modeling gives managers the ability to account for imperfect and temporally and spatially varying detection.

Camera and scent station surveys proved to be the most feasible techniques for surveying mammals in forested wetlands; both techniques recorded the majority of mammals and when used together they detected all but one species (i.e., mink). We detected few aquatic mammals with 2 techniques and surveys designed specifically for their detection would be an ideal inclusion to mammal monitoring protocols. Spotlight surveys were ideal for monitoring white-tailed deer but were not a realistic option for distance sampling due to low detection rates and extensive canals posing logistic difficulties. Because distance sampling is a benefit of spotlight surveys and roads bordered by canals are characteristic of managed coastal wetlands, this survey technique is not recommended in forested wetlands. Although, predator calling served as a quick means for detecting elusive carnivores, it produced unacceptable detection rates. Trapping was the only technique that allowed for population estimates using mark/recapture analyses. While implementing this technique may be too expensive for annual use, it increased our knowledge of the abundance and distribution of furbearers and we recommend including trapping surveys when feasible or supporting local trapping and obtaining data through trapper efforts.

An increasing number of managers rely exclusively on camera surveys for monitoring species and their distributions (O'Connell et al. 2011). By implementing intensive monitoring and combining survey techniques, we were able to compare detection probabilities of mammals for camera, scent station, and live trapping techniques. Interestingly, similarities between camera detections during scent station days (when bait was in use) and camera detections during non-scent station days (no bait in use) (Table 5) suggests higher detections at scent stations are a result of the methodology and not solely a result of baiting. Similarly, detection probabilities for trapping were significantly higher than detection probabilities for cameras for all mammals captured with live traps (Table 5). Placing traps in areas with increased sign of movement by animals likely increased our trapping efficiency and increased detection probabilities for all species. While detection was high in comparison to other techniques, standardizing trapping by selecting a set number of random locations per grid cell could result in a loss of detection. Further, low detection probability of camera surveys was a function of an increased number of days in the survey and not due to poor camera function. Where scent stations were run at 3 day increments, cameras were run continually. Therefore, detection at a given occasion was low and the overall probability of detection was still high.

Our results are consistent with previous studies that report the need for a number of survey techniques to monitor species richness and composition accurately (Harrison 2002, Gompper et al. 2006, Lyra-Jorge et al. 2008, Hutchens and DePerno 2009). Nonetheless, studies increasingly rely solely on cameras for non-invasive surveys (Ahumada et al. 2011, O'Connell et al. 2011). While this approach may be appropriate for monitoring the distribution or populations of some species, we caution against depending solely on this technique to make inferences on mammal presence or absence, distribution, and richness; we suggest that a number of techniques be used for maximum accuracy.

Management Implications

A lack of information on the time and cost constraints associated with monitoring mammals in forested wetlands has limited land managers from implementing surveys on their property. We urge land managers to implement a combination of survey techniques to provide the greatest amount of information regarding mammals on a property. If unlimited by funds and resources, we recommend a combination of all survey techniques to produce the greatest amount of information about mammals on a property. Realistically, budget and time constraints will limit land managers from implementing all survey techniques reported. Therefore, we suggest combining camera trapping and recorded visual observations to monitor species richness of medium to large mammals and their distribution in a relatively inexpensive manner. If management objectives include monitoring long-term trends of indices and distributions, we recommend including scent stations in survey efforts.

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TABLES

Table 1: Total number of detections (relative density) for each species by survey technique at Bull Neck Swamp Research Forest, North Carolina, 2007. The total number of techniques that were successful at detecting each species is denoted in the far right column.

Mammal	Visual	Spot-lighting	Trapping	Scent Station	Camera Trapping	Predator Calling	Total Techniques
bear, black (*Ursus americana*)	13	12	-	35	408	-	4
beaver, American (*Castor canadensis*)	1	-	-	1	-	-	2
bobcat (*Lynx rufus*)	1	-	10	8	17	1	5
cat, domestic (*Felis catus*)	1	-	-	3	1	-	3
deer, white-tailed (*Odocoileus virginiana*)	43	34	-	1	43	-	4
dog, domestic (*Canis familiaris*)	3	-	1	1	15	-	4
fox, gray (*Urocyon cinereoargenteus*)	4	3	19	29	122	1	6
hog, feral (*Sus scrofa*)	-	-	-	-	1	-	1
mink (*Mustela vison*)	1	-	-	-	-	-	1
muskrat (*Ondontra zibethica*)	3	-	-	4	-	-	2
nutria (*Myocastor coypus*)	4	4	-	-	5	-	3
opossum, Virginia (*Didelphis virginiana*)	1	4	17	26	14	-	5
otter, river (*Ondontra zibethica*)	3	-	-	-	1	-	2
rabbit (*Sylvilagus spp.*)	1	1	-	1	1	-	4
raccoon, northern (*Procyon lotor*)	9	1	19	33	25	-	5
Total captures	88	59	66	142	653	2	
Total species	14	7	5	10	12	2	

Table 2: Percentage of animals that were recorded in each cell by trapping (n = 5), camera surveys (n = 12), scent stations (n = 11), and all techniques combined (n = 12) at Bull Neck Swamp Research Forest, North Carolina, 2007.

Grid Cell	Trapping	Camera Surveys	Scent Stations	Combined Techniques
1	25	58	58	67
2	33	33	42	58
3	25	42	42	58
4	17	33	33	42
5	33	25	25	42
6	25	50	50	75
7	0	17	33	42
8	33	50	50	75
9	8	50	42	58

Table 3: Hours of labor and monthly costs needed for each survey technique to detect species at Bull Neck Swamp Research Forest, North Carolina, 2007 – 2008.

Survey Technique	Total Equipment Cost (USD, $)	Total Labor Cost (USD, $)	Total Monthly Cost (USD, $)	Number of Species Observed	Number of Captures per Month	Hours Labor per Detection
Visual	0	0	0	14	29	0.00
Spotlighting	166	1044	403	7	20	0.81
Trapping	2284	1740	4024	5	66	1.21
Scent Station	411	696	369	11	47	0.68
Camera Trapping	1865	152	672	12	224	0.01
Predator Calling	268	435	234	2	1	15.00

Table 4: Percentage of cells (n = 9) that each species was detected by trapping, camera surveys, scent stations, and all techniques combined at Bull Neck Swamp Research Forest, North Carolina, 2007. Where detection was calculated, it is denoted by ( ).

Mammal	Trapping	Camera Surveys	Scent Stations	Combined Techniques
beaver	0	0	11	11
bear, black	0	89 (0.470)	89 (0.830)	100
bobcat	44 (0.284)	56 (0.090)	56 (0.423)	78
cat, domestic	0	0	22	22
deer, white-tailed	0	67 (0.14)	0 (0.06)	67
dog	11	33	11	44
fox, gray	78 (0.500)	78 (0.263)	78 (0.722)	88
muskrat	0	0	33	33
nutria	0	22	0	22
opossum, Virginia	67 (0.375)	44 (0.042)	89 (0.778)	100
rabbit spp.	0	11	11	22
raccoon	67 (0.417)	67 (0.075)	100 (0.833)	100

Table 5: Occupancy and detection estimates for 6 mammals at Bull Neck Swamp Research Forest, North Carolina, 2007.

Mammal	occupancy (se)	trap	detection	se	lower	upper	p-value
bobcat	0.79	camera (bait)	0.09	0.02	0.05	0.14	-
	(0.14)	camera (no bait)	-	-	-	-	-
		scent station	0.42	0.13	0.20	0.68	0.001
		live trap	0.28	0.10	0.13	0.51	0.01
bear	1.00	camera (bait)	0.47	0.03	0.41	0.54	-
		camera (no bait)	0.56	0.12	0.32	0.78	0.491
		scent station	0.83	0.09	0.59	0.95	0.008
		live trap	-	-	-	-	-
deer	0.89	camera (bait)	0.14	0.02	0.10	0.19	-
	(0.11)	camera (no bait)	-	-	-	-	-
		scent station	0.06	0.06	0.01	0.33	0.406
		live trap	-	-	-	-	-
fox	1.00	camera (bait)	0.26	0.03	0.21	0.33	-
		camera (no bait)	0.25	0.11	0.10	0.51	0.906
		scent station	0.72	0.11	0.48	0.88	<0.001
		live trap	0.50	0.10	0.31	0.69	0.018
opossum,	1.00	camera (bait)	0.04	0.01	0.02	0.07	-
Virginia		camera (no bait)	0.13	0.08	0.03	0.39	0.107
		scent station	0.78	0.10	0.54	0.91	<0.001
		live trap	0.38	0.10	0.21	0.58	<0.001
raccoon	1.00	camera (bait)	0.08	0.02	0.05	0.12	-
		camera (no bait)	-	-	-	-	-
		scent station	0.83	0.09	0.59	0.95	<0.001
		live trap	0.42	0.10	0.24	0.62	<0.001

FIGURES

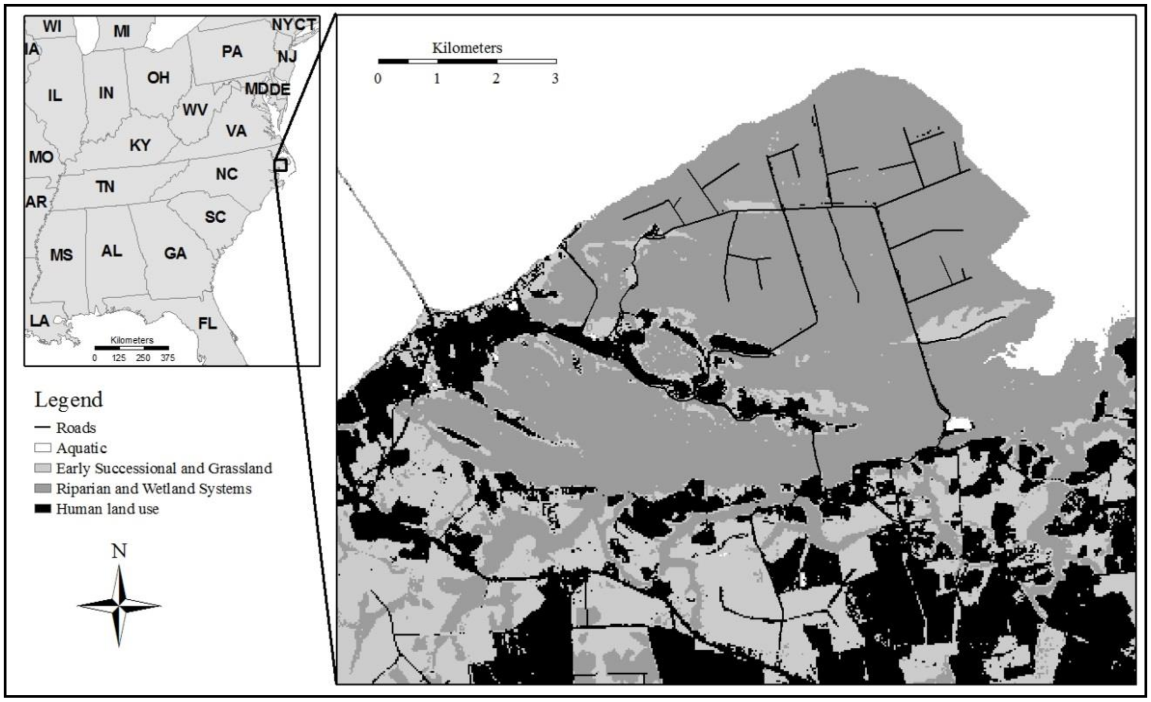

Figure 1: Four major land cover types on and surrounding Bull Neck Swamp Research Forest, North Carolina, 2007.

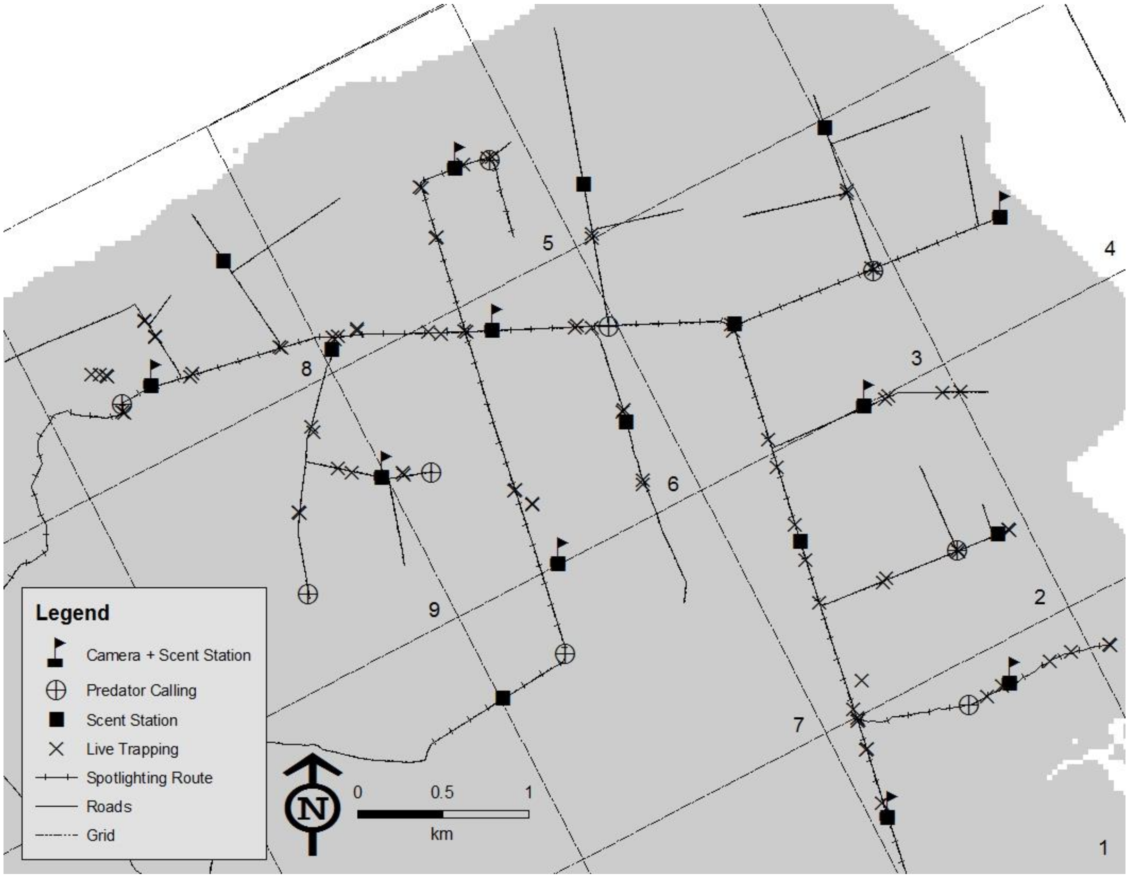

Figure 2: Grid overlay with selecting locations for scent station, camera, predator calling, trapping, and spotlight surveys at Bull Neck Swamp Research Forest, North Carolina, 2007. The assigned grid number is marked in the bottom right hand corner of each cell.

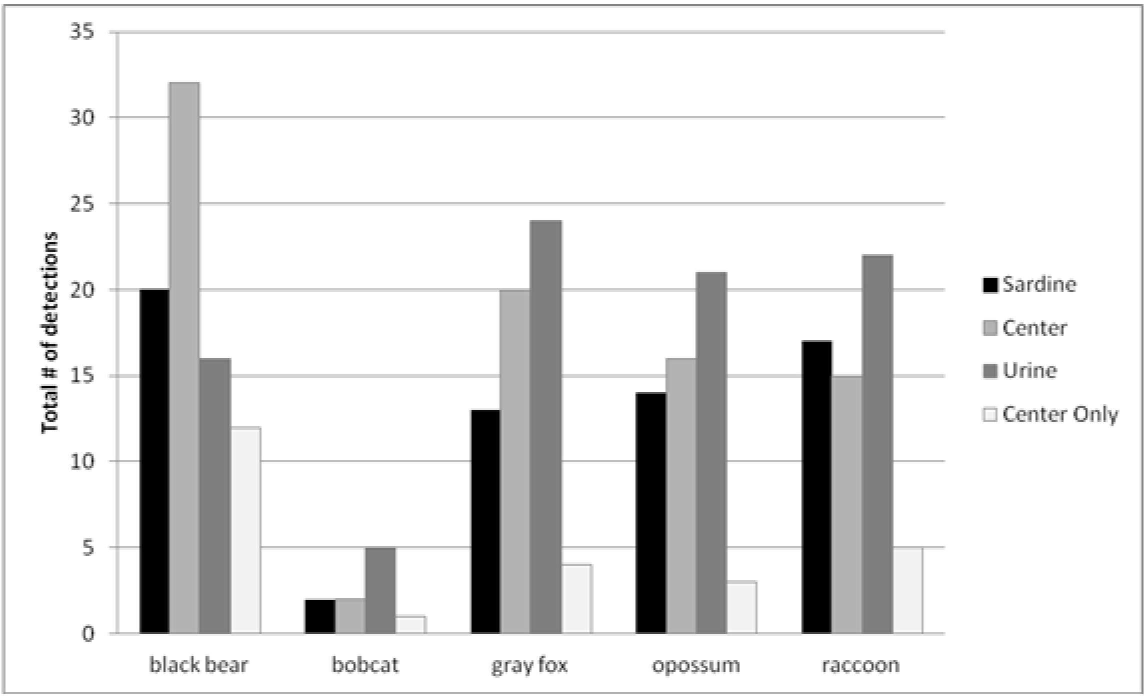

Figure 3: Total number of individuals detected at sardine, center, urine, and center strip only of scent stations at Bull Neck Swamp Research Forest, North Carolina, 2007.

THE EFFECT OF ILLUMINATION AND TIME OF DAY ON MOVEMENTS OF BOBCATS (*LYNX RUFUS)*

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Key words: bobcat, hunting, illumination, *Lynx rufus*, moon, movement

Abstract

Understanding changes in behaviors of prey and predators based on lunar illumination provides insight into important life history, behavioral ecology, and survival information. The objectives of this research were to determine if bobcat movement rates differed by period of day (dark, moon, crepuscular, day), lunar illumination (< 10%, 10 - < 50%, 50 - < 90%, > 90%), and moon phase (new, full). Bobcats had high movement rates during crepuscular and day periods and low movement rates during dark periods with highest nighttime movement rates at 10- < 50% lunar illumination. Bobcats had highest movement rates during daytime when nighttime illumination was low (new moon) and higher movement rates during nighttime when lunar illumination was high (full moon). These behaviors are consistent with prey availability being affected by light level and by limited vision by

bobcats during darkness.

Introduction

In 1929, John Alden Knight postulated the solunar theory on periodic behavior of fishes and developed tables predicting optimal times for hunters and anglers to take their quarry [1]. Today, many hunters and anglers use these tables to try to increase success. In the 1940s, researchers began investigating the impact of moon phase and lunar illumination on animal movements, habitat use, and predator-prey relationships [2–4]. Many mammalian prey studies focused on illumination effects on foraging strategies, and optimality models predicted that prey species would shift habitat use and alter movement rates to minimize predation risk [3,5–9]. Likewise, predators should optimize foraging by shifting habitat use, movement rates, and foraging time to maximize hunting success [10,11].

Generally, small mammals have low predation risk during new moons and high predation risk during full moons [2,5,6,8,9,12–18]. Therefore, to reduce risk, nocturnal prey should behave in ways that reduce vulnerability to predators during high nighttime illumination. During full moon periods, prey reduce movement rates, shift activity periods, reduce food consumption, forage for short periods, spend more time in dense habitat compared to open habitat, and reduce sizes of their foraging areas compared to during new moon periods [3,5,6,8,9,12–15,17–25]. Although extreme behavioral changes are documented in prey, few studies have investigated the effects of lunar illumination on predator behavior [26–28].

Changes in foraging behavior by prey to reduce detection by predators decrease hunting success for predators [3,26]. Moon phase can have the second largest effect, after prey species, on hunting success of predators [26,28]. Further, a study on red foxes (*Vulpes vulpes*) reported individual foxes selected the same prey species during the same moon phases and shifted prey selection when moon phase changed [27]. To counteract changes in activity of prey and to increase hunt success, predators should concentrate hunting efforts during low illumination nights [29]or shift prey selection during high illumination nights towards prey species that may not offer as high of reward (i.e. smaller size) but may be easier to catch.

Although bobcats are commonly thought to be nocturnal or crepuscular, their eyes are proportionately smaller and less well adapted to low light compared to strictly nocturnal cats, allowing bobcats to hunt during day and night [30–34]. A majority of bobcat movement studies report peaks in crepuscular activity with highest movement rates at dusk [35–38]. Factors affecting bobcat movement rates include temperature, age, sex, and season [35–38]. Further, laboratory studies suggest that bobcats may be inhibited by low light and darkness [39]. Thus, hunting may be difficult for bobcats if prey are most active and likely to use open areas during low lunar illumination. Previous reports of bobcats' limited night vision, combined with changes in prey movement, present an interesting trade-off for bobcats between their ability to see, prey availability, and their own hunger. Throughout their range, bobcats' diets include a variety of prey that are active throughout different times of the day including; birds (day), cotton rats (*Sigmodon hispidis*; late afternoon to midnight), eastern gray squirrels (*Sciurus carolinensis*; day), rabbits (*Sylvilagus* spp.; night, dawn, dusk), and white-tailed deer (*Odocoileus virginianus*; various) [40–42].

Bobcats are solitary hunters adapted for short bouts of speed and either stalk and ambush or actively search their home ranges for prey [31]. Active home range searches often occur when prey densities are low and result in high movement and activity rates by bobcats [43]. Given depressed activity of small prey during high lunar illumination, the abilities of bobcats to hunt throughout the day, and reports that bobcat are most active when prey are active, we hypothesized that bobcats should shift movement rates with changes in illumination. Therefore, we tested 3 hypotheses: 1) movement rates of bobcats increase with increases in lunar illumination but decrease with increases in solar illumination; 2) movement rates of bobcats increase with increasing percentages of lunar illumination (< 10, 10 - < 50, 50 - < 90, and > 90); and 3) bobcats have low movement rates during new moon nights and high movement rates during full moon nights.

Methods

We studied bobcats at Bull Neck Swamp Research Forest (henceforth ‘Bull Neck’, Figure 1), a 25-km^2 wetland located on the southern side of Albemarle Sound in Eastern North Carolina (35° 57´ S, 76° 25´ E). The property was one of the largest remaining tracts of undeveloped waterfront on North Carolina's Albemarle Sound, containing more than 11 km of undisturbed shoreline, 10 km^2 of preserve, and 15 km^2 of forested and early successional habitat managed through prescribed burning and timber harvesting. Bull Neck had 5 land cover types: non-riverine swamp forest, peatland Atlantic white cedar (*Chamaecyparis thyoides*), mesic mixed hardwood forest, tidal cypress gum swamp, and tidal freshwater marsh. Possible prey that exhibit nocturnal or crepuscular behavior included marsh rabbits

(*Sylvilagus palustris*), eastern cottontails (*Sylvilagus floridanus*), cotton rats, white-tailed deer, eastern gray squirrels, northern raccoons (*Procyon lotor*), Virginia opossums (*Didelphis virginianus*), feral pigs (*Sus scrofa*), American beavers (*Castor canadensis*), nutrias (*Myocastor coypus*), voles (*Microtus spp.*), and numerous land birds. Mean monthly temperatures ranged from 6.5 C° in January to 26.6 C° in July and rainfall averaged 126.5 cm per year [44]. The property was managed by the Fisheries, Wildlife, and Conservation Biology Program at North Carolina State University, Raleigh, North Carolina.

During 1 – 11 March 2008 and 8 – 22 March 2009, we live-trapped bobcats using #1.5 Victor, padded-jaw, foot-hold traps. We immobilized bobcats with an intramuscular injection of Ketamine (10 mg/kg) and Xylazine (0.75 mg/kg) or Ketamine (4 mg/kg), Medetomidine (40 mcg/kg), and Butorphanol (0.4 mg/kg) [45]. We fitted each bobcat with a GPS collar weighing 250 g (Televilt, Lindesberg, Sweden). Also, the collars broadcast in the VHF range so that bobcats could be located from the ground. Immobilized bobcats were reversed with Yohimbine (0.2 mg/kg) or Atipamezole (0.2 mg/kg), depending on the anesthetizing protocol. All animal handling techniques were approved by the Institutional Animal Care and Use Committee at North Carolina State University (08-012-O) and followed guidelines provided by the American Society of Mammalogists [46] and ASAB/ABS Guidelines for the Use of Animals in Research. All efforts were made to minimize suffering.

Each GPS collar collected a location every 2 h beginning at 18:00 and ending at 06:00 with an additional location taken at 12:00 each day. Also, on the 1st and 15th of each month, the collars collected a location every hour from 1:00 – 24:00. To ensure that collars functioned properly and that study animals were still alive; we monitored bobcats weekly using VHF telemetry equipment. We used Hawth's Tools in ArcGIS to calculate linear distances moved by bobcats between consecutive locations and divided distances by times between locations to estimate movement rates (n = 5,924). Movement rates can be used to estimate general patterns of daily activity accurately with results similar to analysis using net activity time and percent locations with activity [47].

Initial regression tests with independent variables produced significant effects of temperature and standardized time and we blocked by these variables to meet assumptions of independence. Temperature and time were grouped to the nearest degree and hour and treated as discrete variables. Further, sex or individual bobcats did not have a significant effect but we treated the latter variable as a random effect to correct for the lack of independence. We blocked by these variables when testing our 3 hypotheses. We used analysis of covariance (ANCOVA) with logarithmically transformed movement rates (hereafter "rate", to meet assumptions of normality) as our dependent variable. We used Tukey's Studentized Range (HSD) mean comparison tests with a Tukey-Kramer adjustment for multiple comparisons to compare mean rates for all analyses. All analyses were conducted using SAS (Cary, North Carolina) and alpha level was set at P = 0.05.

To quantify illumination levels throughout each 24-hour day, we acquired daily sunrise, sunset, moonrise and moonset times from the Naval Oceanography Portal (http://www.usno.navy.mil/). We partitioned each 24-hour day into day (1 h post sunrise – 1 h pre sunset), crepuscular (2 h periods surrounding sunrise and sunset), and nighttime (1 h post sunset – 1 h pre sunrise) periods. We further grouped nighttime locations into moon (hours between moonrise and moonset) and dark (new moon or nighttime hours before moonrise and after moonset) categories. Rates between day, crepuscular, moon, and dark were compared using ANCOVA (n = 5,924).

We assigned each nighttime location a lunar illumination value based on the fraction of the moon that was illuminated and on moonrise and moonset times (http://www.usno.navy.mil/). Lunar illumination values ranged from 0.1 to 1 and hours of the night with no moon received a moon illumination value of zero. For example, if moonrise was at 08:20, moonset at 23:08, and 16% of the moon was illuminated then hours 09:00 – 23:00 were assigned an illumination value of 0.16. We then grouped illumination levels into 4 categories that included < 10%, 10 - < 50%, 50 - < 90%, and > 90% [19]. We tested the subset of data consisting of nighttime only locations (n= 3,073) using ANCOVA. Previous research has noted variation in lunar illumination based on moon angle and cloud cover and suggests illumination could be increased with high, thin clouds and bias would be added to analysis by making assumptions of decreased illumination based on cloud cover alone [48,49]. Further, consistencies were lacking between local weather at Bull Neck and weather conditions recorded at the 2 closest weather stations. Often, Bull Neck had rain when surrounding areas had clear skies. Therefore, we did not include cloud cover to avoid adding bias to assigned illumination values.

To test for temporal shifts in movement rates, we compared hourly rates between new and full moon periods. Using a subset of the nighttime only data (n = 2,246), we assigned each hourly location as either new (n = 1,103) or full (n = 1,143) moon for 5 days surrounding each period. For example, if a new moon occurred on 08 March, then all hourly rates from 01:00 on 06 March – 24:00 on 11 March were assigned the new moon period. Because locations were acquired throughout the year, we transformed times of each day so that sunrise occurred at 06:00 and sunset at 18:00 and included this information as a standardized time variable. Standardized time allowed us to analyze hourly movement rates based on illumination instead of time of day.

Results

We trapped 9 individual bobcats in 2008 (4 females, 3 males) and 2009 (3 females, 1 male) during 725 and 1,291 trap nights, respectively. Of the 9 bobcats, 2 adult females were recaptured in 2009. We collected 6,647 GPS locations from 5 (2008; 3 females, 2 males) and 2 (2009; 2 females) bobcats between March and October of 2008 and 2009. Movement rates differed by period (daytime, crepuscular, moon, no moon; $n = 5,924$, $F_3 = 2.78$, $P = 0.03$) with highest movement rates during crepuscular (153 m/hr) and day (144 m/hr) periods and lowest movement rates during the dark period (no moon; 120 m/hr, Table 1). On average, bobcats moved more during crepuscular periods than during dark periods ($P < 0.001$, Table 1).

Movement rates during night differed by lunar illumination period ($n = 3,073$; $F_3 = 5.26$, $P = 0.001$). Bobcats had higher movement rates (+42 m/hr) when illumination was 10 - < 50% than when illumination was < 10% ($P < 0.0001$, Table 1). Illumination levels < 10% and 50 - < 90% ($P = 0.8617$) and 50 - <90 % and > 90% ($P = 0.7848$) were similar and no difference was detected between low (< 10%) and high (> 90%) illumination ($P = 1.0000$, Table 1).

Standardized time affected bobcat movement rates ($n = 2{,}246$, $F_1 = 38.93$, $P < 0.001$) and bobcats had high movement rates from 9:00 - 12:00 (late morning) and again from 14:00 - 19:00 (mid-afternoon through dusk; Figure 2). On average, bobcats moved 17 m/hr more during full moon nights than during new moon nights ($n = 2{,}246$, $F_1 = 3.884$, $P = 0.028$). During new moon periods, bobcats exhibited low movement rates (< 40 m/hr) during nighttime hours and high movement rates (> 80 m/hr) during most daytime hours (Figure 2). Conversely, during full moon periods bobcats had low movement rates (< 40 m/hr) during the early daytime hours with increases to 166 m/hr in the afternoon hours (Figure 2).

Bobcat was not a significant variable (df = 1, $F = 0.39$, $P = 0.53$). Temperature ($n = 5{,}924$, df = 1, $F = 148.68$, $P = <0.0001$) was the best predictor of bobcat movement rates; bobcats moved < 10 m/hr below 14°C and > 50 m/hr between 15 - 25°C (Figure 3) and interacted with period of the day (df = 3, $F = 9.63$, $P = < 0.0001$).

Discussion

Bobcats can be flexible in their circadian rhythms and can adjust foraging time to track their prey, as can other mammalian predators who can fast longer than several hours [10,11]. During our study, bobcats adjusted their movement rates with changes in illumination associated with moon phase and time of day. Bobcats had 44% higher movement rates during crepuscular periods compared to moon periods and our results support the hypothesis that if prey move and forage less during high lunar illumination [2,3,24], then bobcats must search larger areas to meet energy requirements during such periods. The high movement rates of bobcats during high illumination implies bobcats are not able to take advantage of increased prey movement during dark periods and may hunt prey that are available during crepuscular or daylight hours to compensate for poor night vision. Analysis based on period indicated that bobcats moved more during moonlit periods than during dark periods. Further analysis revealed the higher movement rate during moon periods was driven by periods of lunar illumination of 10 to 49%. We hypothesize that 10 to 49% lunar illumination represents an optimal nocturnal hunting time when small prey have high movement rates [3] yet illumination is enough to facilitate efficient hunting.

Movement peaks at dusk are similar to those previously reported [35–38]. We hypothesize that bobcats have high movement rates during early evening because prey are available and diverse, and because illumination levels are still high enough for bobcats to see well [34]. It is important to understand the physiological limitations of predators in different systems and, perhaps more importantly, how predators compensate for limitations. Clearly, bobcat vision is well suited for diurnal foraging [30,32,33] and a high daytime movement rate during dark nights suggests compensation for poor night vision when no lunar illumination is available. Analyzing the movement rates by illumination and lunar cycles allowed us to identify diel shifts where movement peaks occurred during mid-day. Zezulak and Schwab [38] reported diel shifts, with crepuscular bobcat activity during winter and nocturnal bobcat activity during spring, and hypothesized the shift was due to high temperature (>26ºC) or reduced prey activity. Our data limited us from investigating changes in movement related to illumination by season; however we did detect a decrease in activity around the same temperature (25ºC). Accounting for the effect of temperature in our analysis suggests that illumination and prey activity drive bobcat movement rates which highlight the importance of incorporating temperature and seasonal variation in future lunar phase and illumination analysis of bobcat movement.

We hypothesize that predators shift habitat use based on lunar illumination to compensate for shifts reported in habitat use by prey [3,5,8,13,15,18,21,29]. Our results support the hypothesis that prey species should forage less in open areas during high lunar illumination to decrease the risk of predation [3,8,14]. Further, if prey species are more likely to be detected by predators during high lunar illumination [2,3,24], predators should be more vulnerable to visual detection by their prey. We hypothesize that an increased risk of visual detection combined with decreased prey use of open areas during high lunar illumination would cause a shift in habitat use to interior forests. Our research indicates that illumination and the population dynamics of prey should be built into habitat models, leading to 4 dimensional (or more) habitat maps (the 4th dimension being lunar phase or illumination). Including movement dynamics of predators and prey, will provide the insights needed to understand why and when predators use habitats [50–53].

That bobcat match activity within the combination of solar and lunar cycles to availability of prey may make bobcats appear cathemeral. Their circadian behaviors, however, are hardly random. Predation is a multispecies dynamic incorporating predators and prey; the hunting strategy of a predator undoubtedly guides the prey response to risk, while prey foraging behavior undoubtedly guides the hunting strategy of the predator. Our study highlights the importance of incorporating illumination into movement analysis of all animals. Averaging movement rates over a daily or seasonal period will cause researchers to miss important insights to predator hunting strategies.

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TABLES

Table 1: Mean movement rates (m/hr), standard deviation (SD), and Tukey pairwise comparison groupings for bobcats at Bull Neck Swamp Research Forest, North Carolina from 2008 – 2009. Movement rates are shown for Period analysis and Lunar Illumination analysis.

		Movement Rate (m/hr)	SE	Tukey Grouping
Period	Dark	120	6	A
	Moon	140	5	A,B
	Crepuscular	153	5	B
	Day	144	7	B
Lunar	< 10%	119	6	B
	10 - < 50%	161	11	A
	50 - < 90%	145	8	A,B
	> 90%	122	8	B

FIGURES

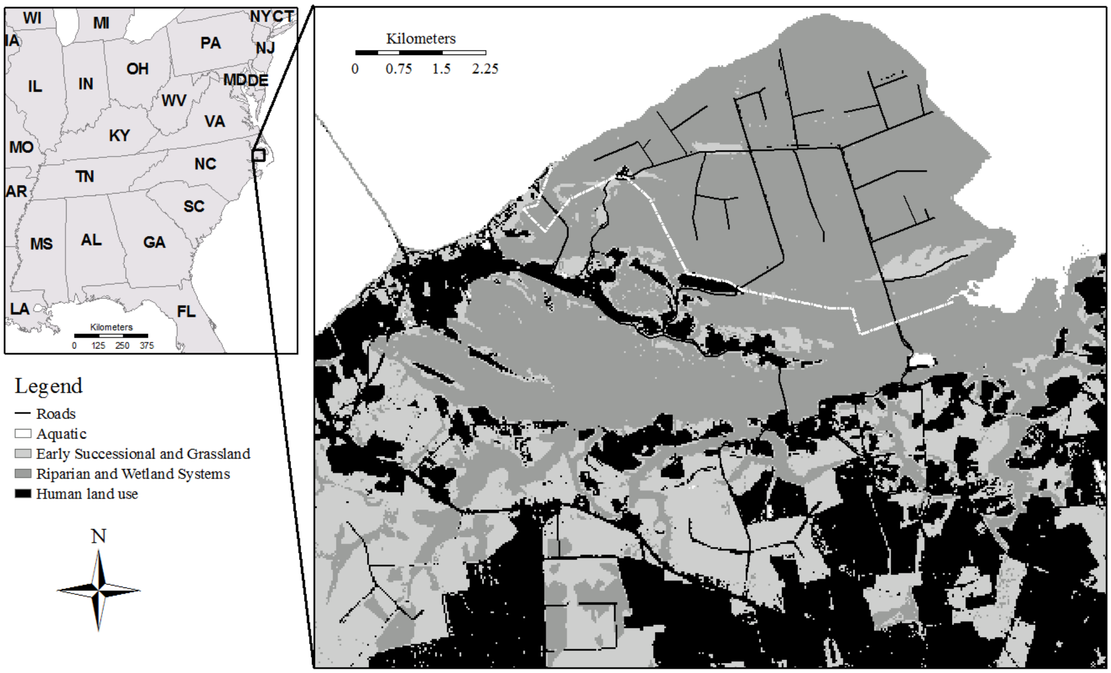

Figure 1: Bull Neck Swamp Research Forest, North Carolina, 2009. The white dashed line represents the property boundary; however, bobcat GPS locations were acquired on the surrounding property as well as on Bull Neck Swamp Research Forest.

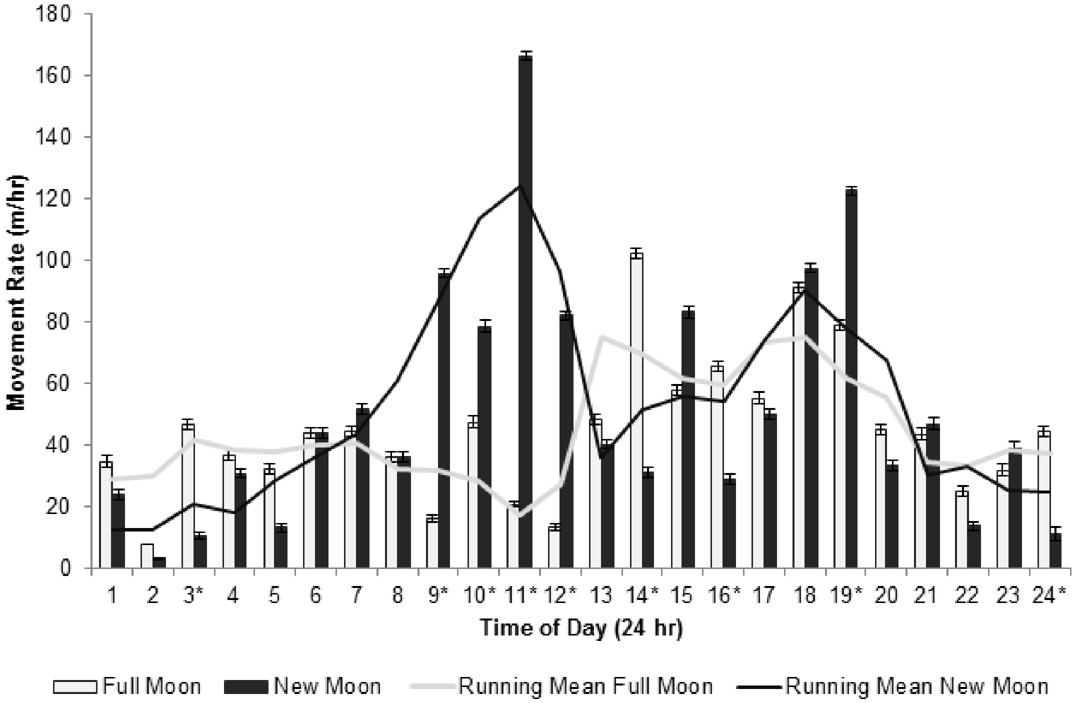

Figure 2: Mean hourly movement rates (± standard error) by bobcats during full and new moon periods. Movement rates were averaged for 5 bobcats at Bull Neck Swamp Research Forest, North Carolina from March 2008 and October 2009 and include 5 days surrounding new moon or full moon periods for each month. Lines indicate the running average mean for movement rates during new (gray line) and full (black line) moon periods. An * above the Time of Day indicates a significant difference ($P < 0.05$) in movement rates between new and full moon periods.

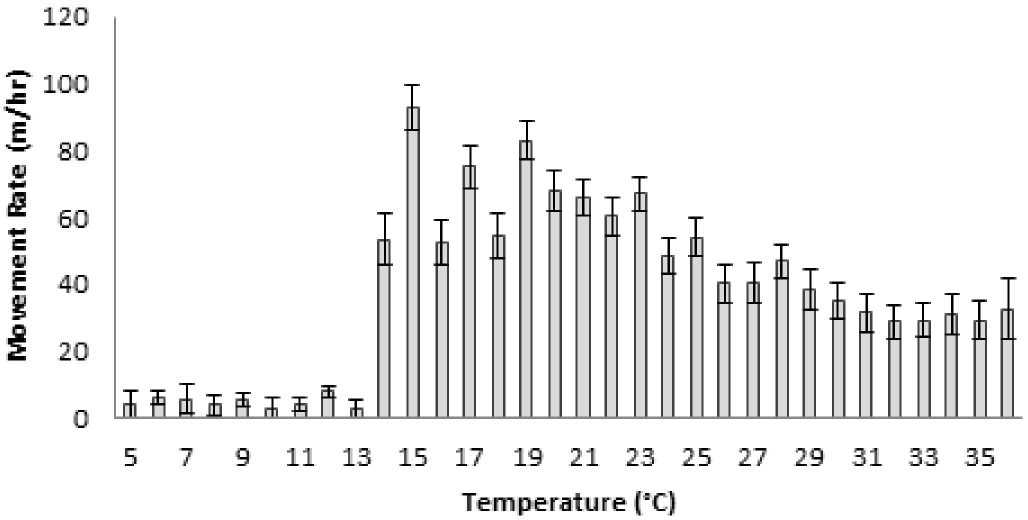

Figure 3: Mean movement rates (m/hr) per 1° change in temperature by bobcats at Bull Neck Swamp Research Forest, North Carolina, March 2008 – October 2009. Temperature was averaged using the temperature at start and end points used to calculate mean movement rates.

IS THE SURROGATE SPECIES APPROACH FEASIBLE FOR SMALL SCALE MANAGEMENT? AN EVALUATION USING BOBCATS IN COASTAL NORTH CAROLINA.

Introduction

Limited resources and economic instability are causing many organizations to combine forces and focus management on few select species (Caro and Doherty 1999). The surrogate species approach is being adopted by many organizations (e.g., US Fish and Wildlife Service) as a means of managing lands by focusing research and monitoring efforts on a single species or a suite of species that are thought to represent entire ecosystems (US Fish and Wildlife Service 2012). We used the surrogate species approach to guide short-term land management and conservation activities at Bull Neck Swamp Research Forest, North Carolina (hereafter 'Bull Neck'). Our study was multi-faceted and included a comparison of mammal survey techniques; but we focus here on land cover use and home range of our selected surrogate species, the bobcat (*Lynx rufus*).

Management strategies that protect ecosystem function and connectivity are becoming increasingly important with human population growth (Simberloff 1998). Identifying critical conservation areas that ensure connectivity of ecosystems and the persistence of species has become a focus for many conservation biologists (Hess and King 2002). Pressed by human expansion but limited by funds and resources, conservation biologists are using surrogate species to represent entire communities (Fleishman et al. 2000, Hess and King 2002, Lewandowski et al. 2010). In theory, the surrogate species approach to land management reduces the time and financial burden of studying all or most animals in a given area (i.e., National Parks, Refuges) by focusing research efforts on one or few animals. The surrogate approach has been used for various research and management objectives that include tracking population changes (McKenzie et al. 1992), assessing anthropogenic impacts (Burdick et al. 1989, McKenzie et al. 1992), attracting public support (Dietz et al. 1994), locating high biodiversity areas (Ricketts et al. 1999), and acting as an "umbrella" for multiple sympatric species (Berger 1997, Caro and Doherty 1999). Surrogate species can be grouped into three main categories: indicator species, umbrella species, and flagship species (Caro and Doherty 1999). An indicator species is "an organism whose characteristics (e.g., presence or absence, population density, dispersion, reproductive success) are used as an index of attributes too difficult, inconvenient, or expensive to measure for other species or environmental conditions of interest" (Landres 1983). Indicator species can be further grouped into health indicator species (species that can be used to measure environmental pollution), population indicator species (species that have growth rates reflecting those of the species of interest), and biodiversity indicator species (a family or genera whose diversity can be used to predict the diversity of other taxa) (Caro and Doherty 1999). Umbrella species are typically selected to determine the size and shape of a reserve due to their large area and habitat requirements (Wilcox 1984). A major assumption of using an umbrella species is that focusing conservation efforts on the land cover needs of one species will lead to the conservation of a multitude of species that depend on the same land cover but less space

(Noss et al. 1996). Flagship species are charismatic species (e.g., the polar bear, *Ursus maritimus*) that can be used to gain public support and sympathy for conservation of less charismatic species (Caro and Doherty 1999). Mammalian top predators have been used as surrogate species because they typically have low population densities and fecundity, require large areas, and are sensitive to human modified landscapes (Weaver et al. 1996).

Although critics argue the surrogate species approach makes assumptions that are not well tested, the reality is that limited funding and lack of resources to study all animals in detail exists (Lindenmayer et al. 2002). We were faced with a similar situation when trying to develop a management plan for Bull Neck. We wanted to develop a land management plan which incorporated land use and wildlife diversity, but we had limited funds and a lack of information on current wildlife assemblages and wildlife land cover use. We used the surrogate species approach to guide short-term land management and conservation activities at Bull Neck. Bull Neck was a 25-km^2 tract of land owned by North Carolina State University, and managed by the Department for Forestry and Environmental Resources, and the interdepartmental program for Fisheries, Wildlife, and Conservation Biology. Revenue generated on Bull Neck by timber production and hunting and trapping leases was important economically for the Fisheries, Wildlife, and Conservation Biology Program. Further, Bull Necks' limited connectivity to surrounding land made understanding how animals move on and off of Bull Neck a management priority for the University. Bull Neck was surrounded on the North and East by Albemarle Sound and to the South and West by agricultural and developed land with few forested areas. To maintain connectivity to the surrounding land and to ensure sustainable populations of wildlife, we wanted to identify potential travel corridors by assessing land cover use on and near Bull Neck. Until 2007, little research had been completed on Bull Neck and information on species assemblages was lacking. Hutchens (2009) provided information on species richness and diversity of herpetofauna, but the relatively small home ranges of herpetofauna did not allow analyses of land cover connectivity on a large scale. The large home range size, low reproductive output, and territoriality of coastal North Carolina mammalian carnivores make them ideal for studying land cover use and avoidance and analyzing movements to identify critical corridors.

Potential surrogate species on Bull Neck included the black bear (*Ursus americanus*), the gray fox (*Urocyon cinereoargenteus*), and the bobcat (*Lynx rufus*). The bobcat may serve as a good surrogate species at Bull Neck because its distribution reflects population processes on a regional-scale (Carroll et al. 2001). Hess and King (2002) reported 46 vertebrate species' land covers that coincide with bobcat land cover use and 11 species affected by bobcat predation in North Carolina. Also, the bobcat was identified as a potential keystone species that needed large tracts of land with connectivity for dispersal (Hess and King 2002). Currently, the bobcat inhabits every state in the United States except Delaware and has limited ranges in Illinois, Indiana, Iowa, Michigan, Missouri, and Ohio (Nielsen and Woolf 2002). McCord and Cardoza (1982) attribute the limited distribution of bobcat in these latter states on the abundance of intensive agriculture. Reports of land cover use by bobcats varies in the literature (Table 1), which can be explained by lack of consistency with land cover variables. For example, low use of mature pine land cover in one place (Buie et al. 1979, Hamilton 1982, Litvaitis et al. 1986) conflicts with high use of mature pine land cover in other places (Rucker et al. 1989, Lovallo and Anderson 1996, Chamberlain et al. 2003) but may be a reflection of variation in management practices resulting in dissimilar land cover structure (e.g., percent canopy cover, visual obstruction, basal area) within the mature pine stands. Throughout the eastern United States, bobcats inhabit land covers ranging from mature forests to agricultural areas (Lovallo and Anderson 1996, Chamberlain et al. 2003), but relatively little is known about use of wetlands. Lancia (1982) calculated high bobcat use in young pine plantations, bottomland hardwoods, and upland hardwoods and low bobcat use in agricultural, marsh, and pocosin land covers. King *et al.* (1983) suggested that bobcats did not associate with climax land covers but benefitted from early successional land covers. Bull Neck contains numerous wetland land covers and few early successional land covers, suggesting poor suitability for bobcats. Preliminary studies of mammalian assemblages on Bull Neck suggested the bobcat existed on Bull Neck at high density (1 bobcat/km^2, Rockhill et al. 2013). Previous models that describe bobcat land cover use have been based on land cover classification and food availability (Boyle and Fendley 1987, Burch and Nichols 1997) combined with availability of denning sites, interspersion (Lancia et al. 1982), or presence of roads (Larson et al. 2003). Hence, sufficient biological information was available in the literature and through preliminary studies to make the bobcat a potential surrogate species for our study site in coastal North Carolina.

Single-species land cover-relation models may be useful to monitor indicator species and their habitat requirements (Fecske 1994). Further, Morrison *et al.* (1998) advocated using land cover-relation models to test research hypotheses and to update historic models as part of an adaptive management plan. Habitat Suitability Index Models (hereafter, HSI) have been used since the early 1980's and were initially developed by the U.S. Fish and Wildlife Service based on expert opinion and empirical data. The HSI models assigned values to land cover variables (e.g., food, cover, and water) on a scale from 0 = not suitable to 1 = maximum suitability. The values were derived from a number of landscape measurements such as stand age, percent cover, apportionment, and percent of sample area covered by grass/forb and shrub. The HSI for bobcat was developed in 1987 for application in the Southeastern U.S., specifically the Piedmont and Coastal Plains regions (Boyle and Fendley 1987). The model evaluated year round land cover requirements for bobcat in evergreen forest, deciduous forest, evergreen shrubland, deciduous shrubland, deciduous forested wetland, deciduous scrub/shrub wetland, grassland, and forbland (US Fish and Wildlife Service 1981). The model did not include water or cover as factors in land cover suitability for bobcat because food was determined to be the only limiting resource. Although the HSI model was reviewed, it has not been field tested to evaluate relationships between model outputs and bobcat land cover use.

We were interested in how the agricultural and marsh land surrounding Bull Neck affected movement of bobcats on and off of Bull Neck, especially considering the reports of low use by bobcats of these cover types (Lancia et al. 1982, King et al. 1983). The objective of this landscape analyses was to provide a broad-scale examination of Bull Neck land cover related to bobcat suitability that would aid in the long-term conservation and management of wildlife at Bull Neck. Determining potential routes of travel or use of corridors by bobcats will allow land managers to make educated management and conservation decisions. We tested an existing land cover-relation model for the bobcat (HSI) and used bobcat locations acquired from GPS points to test 2nd order land cover selection (Johnson 1980) and identified potential conservation areas that served as high use for movement on and off of Bull Neck. Additionally, we provide a synopsis of using the bobcat as a surrogate species for guidance of land management activities throughout coastal North Carolina.

Methods

Study Area

Bull Neck (Figure 1) was a 25 km^2 wetland located on the southern side of Albermarle Sound in Eastern North Carolina (35° 57´ S, 76° 25´ E). Bull Neck was one of the largest remaining tracts of undeveloped waterfront on North Carolina's Albemarle Sound, containing more than 11 km of undisturbed shoreline, 10 km^2 of preserve, and 15 km^2 of forested and early successional land cover managed through prescribed burning and timber harvesting. Our study area extended 15 km west and east of Bull Neck and 25 km south. Throughout, we refer to Bull Neck when discussing activities that occurred within the confines of Bull Neck itself and coastal North Carolina when referring to activities that extended beyond the boundaries of Bull Neck. Mean monthly temperatures ranged from 6.5 C° in January to 26.6 C° in July and rainfall averaged 126.5 cm per year (50 year climate normal, National Oceanic and Atmospheric Administration 2009, http://www.noaa.gov/).

HSI model

Water and cover were not regarded as limiting factors for survival by bobcats in the Southeast, therefore the HSI was developed based on food suitability (Boyle and Fendley 1987). Given that rabbits (*Sylvilagus* spp.) and cotton rats (*Sigmodon hispidus*) were the main prey for bobcats in the Southeast and grass/forb-shrub vegetation was critical to survival for both prey, food suitability was determined by measuring the percent of grass/forb and shrub in various land covers. Food suitability in the HSI was determined by the measurement of two variables, the percentage of the sample area covered by grass/forb-shrub (SIV1, Figure 2a) and the percentage of the grass/forb-shrub area that is covered by grass/forb (SIV2, Figure 2b). The value of the lowest SIV was used as a food suitability index (hereafter, FSI).

We conducted 160, randomly selected, ground truthing surveys to collect microland cover data in coastal North Carolina. Surveys were conducted during 01 June – 28 August 2009. We collected land cover information from 220 m^2 plots centered on each sampling point in various land cover classes (Figure 3). At each plot center we recorded percent ground cover in a 1m x 1m area for grass, forb, shrub, moss/lichen, fern, water, leaf litter, bare soil, downed woody debris, sapling, and tree. Also, we recorded canopy cover, basal area, distance to nearest snag, and point quarter species. We recorded tall shrub species and frequency of occurrence for a 10 m distance from the center point (Figure 3). At the end of each 10 m transect, we recorded percent ground cover in a 1 m x 1 m area as described above. Also, we recorded visual obstruction from each cardinal direction at 0.0 – 0.5 m, 0.5 – 1.0 m, and 1.0 – 2.0 m heights. We used land cover data from the Gap Analysis Program (hereafter “GAP”, U. S. Geological Survey 2008) to classify land covers. We used the United States Fish and Wildlife Service (USFWS 1981) land cover definitions to group measured variables so they were consistent with those used by Boyle and Fendley (Boyle and Fendley 1987). For example, USFWS (1981) defines grassland as “…dominated by nonwoody plants (including bryoids, e.g. lichens and mosses), of which grasses, native or introduced, are dominant.” therefore we grouped percent ground cover for grass and moss/lichen. Using our ground truthing data, we calculated Suitability Indices (SIV1 and SIV2) based on the HSI guidelines and assigned each land cover with the representative Suitability Index in Arc GIS 10.0 (Boyle and Fendley 1987).

To reflect the degree of interspersion, the HSI guidelines suggest sampling in relatively small dimensions by creating 0.001 ha ‘sample home ranges’ with dimensions 1.9 m x 1.3 m (Boyle and Fendley 1987). We developed a grid of 1.9 km x 1.3 km rectangles in Arc GIS and overlaid the grid onto the GAP land cover data in Arc GIS. For clarification, we will refer to a ‘sample home range’ (e.g., one rectangle in the grid) as a cell. For each cell, we used the Tabulate Area feature in Spatial Analyst Tools (Arc GIS 10.0) to extract the total area of each land cover type. We calculated the percent area in optimal food suitability (PAOFS) for each cell as

$$PAOFS = \sum_{i=1}^{n}\left[FSI_i\left(\left(\frac{A_i}{\sum_{i=1}^{n} A_i}\right)\right) * 100\right] \qquad \text{Equation 1}$$

where *n* = the number of cover types in the cell, FSI = the lowest of SIV1 and SIV2, and A*i* = the area of cover type *i* (Boyle and Fendley 1987). Optimal food suitability was expected to occur when greater than 90% of a cover type supports grass/forb-shrub or 50% - 70% of the grass/forb-shrub area is in grass/forb vegetation (Boyle and Fendley 1987). For each cell, the PAOFS was converted to a final suitability index (SIV3, Figure 2c, Boyle and Fendley 1987) and associated with the appropriate cell in the GIS layer (Appendix A).

Use of bobcat GPS locations to test the HSI model

During 01 – 11 March 2008 and 08 – 22 March 2009, we live-trapped bobcats using #1.5 Victor, padded-jaw, foot-hold traps. We immobilized bobcats with an intramuscular injection of Ketamine (10 mg/kg) and Xylazine (0.75 mg/kg) or Ketamine (4 mg/kg), Medetomidine (40 mcg/kg), and Butorphanol (0.4 mg/kg) (Rockhill et al. 2011). We reversed immobilized bobcats with Yohimbine (0.2 mg/kg) or Atipamezole (0.2 mg/kg), depending on the anesthetizing protocol. We fitted each bobcat with a GPS collar weighing 250 g (Televilt, Lindesberg, Sweden). Also, the collars broadcast in the VHF range so that we could locate bobcats from the ground weekly. The GPS collars collected a location every 2 h beginning at 18:00 and ending at 06:00 each night with an additional location taken at 12:00 each day. Also, on the 1st and 15th of each month, the collars collected a location every hour from 1:00 to 24:00. All animal handling techniques were approved by the Institutional Animal Care and Use Committee at North Carolina State University (08-012-O) and followed guidelines provided by the American Society of Mammalogists (Gannon and Sikes 2007) and ASAB/ABS Guidelines for the Use of Animals in Research.

We used 6,646 bobcat GPS locations to estimate the percent use of each cover type. We used Spatial Analyst Tools (Arc GIS 10.0) to extract the associated cover type to each individual bobcat location. We used the proportion of the total number of locations in each cover type to the total number of locations for each bobcat to calculate the proportional use by cover type. To estimate the total availability, we used second order selection (Johnson 1980) and assumed a minimum convex polygon represented the combined home range of the bobcats based on the high number of locations per bobcat (Roloff and Kernohan 1999, Kolodzinski et al. 2010). We used minimum bounding geometry (Arc GIS 10.0) to create a polygon from the combined bobcat locations. We created a grid of points within the polygon every 90 m and extracted the land cover class at each availability point in the grid. To test the HSI model, we calculated a use index by

$$\frac{(2*use-availability)}{1+use+availability} \qquad \text{Equation 2}$$

and tested for a positive linear relationship between the final SIV value and the proportion of use for each cell and for each bobcat. We used Spearman Rank Correlation analysis (Systat 10) to compare the resultant SIV values for cells with a use index for each bobcat within the same cell (Loukmas and Halbrook 2001). Further, we used Spearman Rank Correlation analysis (Systat 10) to compare SIV values for cover types against a use index for the cover type for each bobcat. Spearman correlation coefficients range from 1 to -1, where 1 represents a strong positive relationship between ranks and -1 represents a strong negative relationship between ranks. We assumed a monotonic relationship between the data and that the data was not linear (Appendix A).

Synoptic model

We used a synoptic model (Horne et al. 2008) to analyze space use of bobcats because there were confounding land cover features in our study area that would be included in home range estimators available in most ("black box") software packages (e.g., minimum convex polygon, kernel density). The ability to simultaneously estimate land cover use and home range allowed us to remove those features (e.g., water bodies) from home range estimates when appropriate. We used ArcMap (10.1) Spatial Analyst to define an initial analysis extent polygon, which contained all edges of a bivariate normal fit, for each individual's location data. We used Arc Map (10.1) to create multiple layers, at 30 m resolution, of land cover covariates that we hypothesized would affect bobcat space use based on our knowledge or previous literature (Millions and Swanson 2005; Donovan et al. 2011; Tucker, Clark, and Gosselink 2008; Woolf et al. 2002, Table 2). Covariate data included: NC-GAP Land Cover Classification (North Carolina GAP Analysis Project, U. S. Geological Survey 2008), canopy height (National Biomass and Carbon Dataset 2000, mapping zone 58/60, Kellndorfer et al. 2012), North Carolina cropland data layer (USDA National Agricultural Statistics Service; http://www.nass.usda.gov/research/Cropland/Release/index.htm, 2008 & 2009), elevation (Digital Elevation Model, U. S. Geological Survey, http://ned.usgs.gov/), and roads (U. S. Geological Survey, http://www.usgs.gov/). Canopy height was included to account for variation in vertical obstruction within land cover classes that was discovered during vegetation surveys. We hypothesized that higher canopy cover would be associated with increased canopy closure and decreased vertical obstruction. Rather than evaluate individual pixels of each layer, we estimated the percentage of each resource within a 500 m and 1000 m buffer surrounding each pixel (Appendix B, Donovan et al. 2011). We created raster layers for low and high road density at the 500 m and 1000 m scale, each. Low density roads included all secondary and tertiary (ATV trails or non-paved) roads and high density roads included all primary roads (major highways) as defined by the USGS data layer. We calculated edge density, patch evenness, and patch richness at the 500 m and 1000 m scales and included each as a raster layer in the analysis. NC GAP landcover classification was grouped into 5 main categories: wet hardwood forest, pine pocosin forest (*Pinus* spp.), oak hardwood forest (*Quercus* spp.), managed pine, and early-successional land cover. We used the North Carolina cropland data layer to define agricultural land because the layer defines specific crops that were planted in each field (30 m resolution), allowing us to associate plant and harvest dates with the layer and therefore better estimate available land cover. Crop field cover types were confirmed in the field during vegetation surveys in 2008 and bobcat monitoring in 2008 and 2009. We defined a minimum available date for each crop type based on the average plant date + the average time for each crop to grow to bobcat height. For example, corn planting was most active in North Carolina beginning 01 April (USDA NASS 2010) and plants typically grow up to 60 cm within 3 weeks post emergence (McWilliams et al. 1999, Boomsma et al. 2006). Peak harvest occurs 10 October; therefore, we classified corn fields as available for all periods when they were above the bobcat average height of 55 cm (29 April - 10 October, Anderson and Lovallo 2003). We recognize that growth rates can vary based on abiotic factors (e.g., soil condition, water availability, fertilization) and assumed that our analysis area was representative of average growth rates across the state.

We estimated within-home range selection (Johnson's second-order) and home range size, simultaneously (Horne et al. 2008, Slaght et al. 2013). We created two files for the synoptic analysis in Program R that represented used and available land cover for bobcats. The used data was created by extracting the value for each of the 14 raster layers described above to each individual bobcat location. The available data was created by overlaying a grid of points within the initial analysis extent at 100 m spacing. Values for each of the 14 raster layers were extracted to each available point. To model bobcat space use, we used i = 1 to 20 environmental covariates in 15 candidate models with the synoptic model

$$s(x) = \frac{f_o(x)\prod_{i=1}^{k}\left(1+\beta_i H_i(x)\right)}{\int_x\left[f_o(x)\prod_{i=1}^{k}\left(1+\beta_i H_i(x)\right)\right]} \qquad \text{Equation 3}$$

where f_o was the null model of space use, H_i was the environmental covariate i, and β_i was the estimated selection parameter for variable i. We used a bivariate normal distribution for our null model of space use (Horne et al. 2008, Slaght et al. 2013). To incorporate the temporal component of crop availability, we created two separate covariates that varied temporally (t), but not spatially. The covariate 'crop not summer' represented fields with little to no vegetation that typically occurred at the beginning or end of the growing season. The covariate 'crop summer' occurred during the growing season but only once plants were estimated to be tall enough to serve as cover for bobcats. For candidate models that incorporated temporally changing land cover covariates, our resulting model was:

$$f_u(x,t) = \frac{f_o(x)\times Exp[\beta_1 CropSummer_t+\beta_2 CropSummer_t\beta_3\ldots]}{\int f_o(x)\times Exp[\beta_1 CropSummer_t+\beta_2 CropSummer_t\beta_3\ldots]dx} \qquad \text{Equation 4}$$

where $f_u(x, t)$ was the probability density of being at location x and time t (Slaght et al. 2013).

We selected the best candidate model based on Akaike's Information Criterion (AIC) corrected for small sample sizes (AIC$_c$; (Burnham and Anderson 2002, Horne et al. 2008, Slaght et al. 2013). We used parameter estimates from the information theoretic best model to estimate the utilization distribution for each bobcat (Horne et al. 2008). Estimates from the selection parameters $\hat{\beta}$ from the information theoretic best model were used to determine the effects of environmental covariates on the space use of each bobcat (Horne et al. 2008). We calculated the magnitude of effect that certain environmental variables had on individual space use with probability ratios estimated with β coefficients from the best model. The probability ratio determined the degree of likelihood that an animal was expected to be at a given location *x* based on a selected change in a covariate by

$$\delta_{a,b} = \frac{exp[H(a)'\beta]}{exp[H(b)'\beta]} \quad \text{Equation 5}$$

where H(*a*) was covariate value 1 and H(*b*) was covariate value 2 (Horne et al. 2008). For example, if we would like to know the increase in likelihood that a bobcat was to occur at locations with 45 m tree heights versus 30 m tree heights, we would convert the tree heights back to the standardized range of 0 to 1 (0.58 and 0.38, respectively) and use the output selection coefficient (e.g., β = 3.45) from our selected model. In this case, exp[0.58×5.62]/ exp[0.38×5.62]≈3. Therefore, bobcats would be approximately 3 times more likely to use locations with tree heights of 45 m versus 30 m. We performed the synoptic model analysis in Program R (v.2.11, R Development Core Team, www.r-project.org) with code written by D. Johnson and J. S. Horne.

Results

HSI model

We sampled 133 vegetation plots and calculated SIV1 and SIV2 values for each plot (Table 3). We classified a total of 898 arbitrary bobcat home ranges and estimated the PAOFS for each home range. The minimum PAOFS was 0 and the maximum PAOFS was 46.27; mean 33.93 ± 13.06. On average, the grid had 56% suitability for bobcats (range = 0 – 1, standard deviation = 36.2%; Figure 4a). A total of 271 and 82 cells had a final suitability index of 1 and 0, respectively (Figure 4a). An SIV3 value equal to 1 signifies enough food optimal area in a cell to sustain a maximum density of bobcats (Boyle and Fendley 1987). Therefore, 30% of our study area had land cover suitability that was able to support a high density of bobcats based on the land cover suitability index.

Bobcat GPS locations used to test the HSI model

We trapped 9 individual bobcats in 2008 (4 females, 3 males) and 2009 (3 females, 1 male) during 725 and 1,291 trap nights, respectively. Of the 9 bobcats, 2 adult females were captured in both years. We collected 6,647 GPS locations from 5 (2008; 3 females, 2 males) and 2 (2009; 2 females) bobcats between March and October of 2008 and 2009. We collected no data from bobcats prior to 01 March or post 26 November in either year.

No land cover classes received a maximum SIV3 = 1. Averaged data from all bobcats illustrated a use of developed, floodplain forest, pine woodland, wet hardwood forest, and early successional land covers that was more than what was available (Figure 5). Conversely, bobcats used open water, managed pine, and dry-mesic oak forest less than what was available (Figure 5). Comparing individual bobcat use, all bobcats used pine woodlands more and open water less than they were available (Figure 6). An adult male bobcat used managed pine more than it was available and a juvenile female bobcat used floodplain forest less than it was available (Figure 6). HSI values for cells in the grid were negatively associated with the calculated bobcat use index for 6 of the 7 bobcats (Table 4). In contrast, cover type selection was positively associated with SIV3 values for all bobcats (Table 4); cover types with higher SIV3 had higher use index values.

Synoptic model

The top model included all environmental covariates that were hypothesized to affect bobcat land cover selection and was ranked the top model for all bobcats (Table 5). Variables included in the top model were time dependent crop, tree height, elevation, and (at the 500 m and 1000 m scale each) percent edge, evenness, richness, secondary road density, and primary road density. The top ranked model carried all the weight in the model set based on Akaike weights (w_i) for all bobcats (Table 5). The environmental covariates that remained in the 2^{nd} best model for all but one bobcat included: time dependent crop, tree height, elevation, and all covariates at the 1000 m level. For a dispersing juvenile male, covariates at the 500 m scale were more informative for describing space use than covariates at the 1000 m scale.

All bobcats had positive responses to tree height, elevation, time dependent crop, and early successional fields (Table 6). On average, bobcats were 7 times more likely to be in locations with 30 m trees as 10 m trees. An adult female and adult male were 37 and 16 times more likely to be in locations with 30 m trees, respectively. Bobcats were 13 times more likely to be in locations with 7 m elevation than 5 m elevation. In general, bobcats were 4, 2, and 2 times more likely to be in early successional fields, pine pocosin forest, and wet hardwood forest compared to their availability. Further, bobcats were 4 times more likely to use crop fields during the summer when they were planted than during times they were barren. One bobcat had a negative response to pine pocosin forest while the other 4 bobcats were nearly 4 times as likely to select this cover type compared to available. Two bobcats had a negative response to wet hardwood forests and, on average, bobcats were 2 times more likely to select this cover type as availability increased. All bobcats had a decreased use of oak hardwood forests given an increase in the cover type (average = -0.5, maximum ratio = 0.8).

Discussion

HSI model

The HSI worked well enough to use as a starting approach for assessing land cover suitability for bobcat throughout the Southeast. We were able to test the HSI with data from bobcats in the study area and our overall conclusion was that the HSI performed well. Cells with low SIV values were typically located over water or agricultural fields and cells with high SIV values were located over areas with sufficient shrub or forested cover. The HSI model allowed us to produce a grid of locations of suitable land cover. The approach of extrapolating vegetation covariates to the representative land cover type was appropriate, even given the high degree of variability between covariates within a cover type. This model could be used successfully throughout the Piedmont and Coastal Plains regions of the southeast. Further, we hypothesize the range of the model could be extended beyond these regions and suggest testing the model elsewhere. Results from the model could be used to guide land management by highlighting areas in conservation need (i.e., increased development). The sampling approach was labor intensive, however, and expensive.

Bobcat GPS locations used to test the HSI model

Although there was a negative relationship between cell values and actual use by bobcats within each cell, a lack of data from non-collared bobcats may have biased our results (Figure 4b). We extended our study beyond Bull Neck to account for cover type selection of 2 dispersing juvenile bobcats. Because of this, part of the sample area lacked data on abundance and distribution of other bobcats. Further, year-round camera monitoring on Bull Neck confirmed the presence of at least 3 uncollared bobcats throughout the 2 year period that GPS data was collected. The potential presence of other bobcats could restrict activity in those areas by the bobcats we monitored and used to test the HSI. When comparing cover type use by bobcats against the cover type use index, we detected a positive relationship further suggesting that we were not accounting for other bobcats in the area (Figure 4b). Alternatively, a number of highly ranked cells with a large percentage of agricultural fields were within or surrounding the home range. Based on the HSI, only 35% of an area in optimum food is necessary to support a maximum density of bobcats (Boyle and

Fendley 1987). These results may hold true for relatively undeveloped areas; however, previous efforts to include juxtaposition and interspersion in land cover suitability models may perform better. Lancia et al. (1982) took this approach, but the model associated 0 scores with marsh and pocosin land covers and since our study area was more than 40% marsh and pine pocosin with known high densities of bobcats we did not test that model.

Synoptic model

We used the synoptic model approach because we were specifically interested in cover type selection on a managed tract of land. We were interested in determining areas of Bull Neck that were used extensively by bobcats and, more importantly, those that were used minimally so we could target our conservation efforts towards those areas. Use of land cover by bobcats has been studied extensively throughout the United States and we had sufficient data and current life history knowledge of bobcats that allowed us to formulate a set of models that would describe land cover selection by bobcats in coastal North Carolina. Our results confirmed that land cover selection by bobcats favored environmental covariates at the 1000 m scale (Donovan et al. 2011). While our best model included all environmental covariates, the 2nd best model included the time dependent crop and all covariates at the 1000 m scale.

We incorporated a temporal covariate for crop fields that allowed us to include planted crop fields in potential land cover. Although crop fields are used infrequently by bobcats, they can provide important dispersal cover (Lancia et al. 1982, King et al. 1983, Tucker et al. 2008, Donovan et al. 2011). During field monitoring, we documented a dispersing juvenile female using corn fields to disperse south of Bull Neck for 3 consecutive days. GPS collar data confirmed over 40 locations in corn fields within the 3 day period and over 50% (321 out of 606) of the bobcats' locations were in crop fields between 09 July and 05 October. We were able to show the importance of incorporating this temporal covariate into future models and hypothesize it would be especially useful in the Midwest where agriculture has been shown to affect bobcat populations. The crop layer we used was available online, free of charge, through the USDA National Agricultural Statistics Service and is updated annually. Some bias exists when selecting crop planting dates and we recommend ground truthing data when possible. Variability in growth rates and planting dates are likely to exist throughout a study area and it was possible that our available dates for crop fields were offset by a few weeks in some fields and ground truthing would have strengthened our model.

We identified areas of Bull Neck that were not included in the utilization distributions of bobcats. Nevertheless, given the levels of variation surrounding our coefficients, we were not confident these areas should be discounted as areas of non-use. We hypothesis that more study is needed and suggest sampling these areas to determine land cover structure and abundance of bobcat prey species (e.g., small mammals).

Bobcat cover type selection

Our overall land cover use results were consistent between approaches. We were able to show similar land cover selection results through a predetermined suitability index that was developed in the 1980s and tested post hoc with bobcat GPS data, as well as with an information theoretic approach that estimated cover type selection through already known GPS data from bobcats. Both approaches showed increased selection with increased availability of pine pocosin, wet hardwood, and early successional land covers and decreased selection with increased availability of oak hardwood forest. The models conflicted on results from managed pine land covers although the synoptic model β coefficient was low with a wide range (0.13±1.6), suggesting large variation in selection. Also, individual bobcat β coefficients showed selection for and against managed pine for 3 and 2 bobcats, respectively. One adult female had high selection for this cover type ($\beta = 2.25 \pm 1.53$) and further investigation highlighted a 13 hectare area of the tract that was harvested 2 years prior. The site had log piles scattered throughout and early successional grasses beginning to emerge that likely provided good cover. The two bobcats that showed a slight increase in managed pine selection were documented using this area. Had the harvested tract been incorporated to the model appropriately as early successional land cover; our results would have been similar to the HSI. Our results highlight the positive affect harvesting can have on bobcat land cover selection. Although our model results were consistent with one another, agreement with previous land cover selection studies was variable. This was due mostly to the high variability in previous studies (Table 1) and was likely a result of different research and analysis approaches, different resources within study areas, and variability within land cover types.

Surrogate approach

Our synopsis of the use of bobcat as a surrogate species in coastal North Carolina is non-statistical and based solely on our interpretation of our ability to answer our management questions for Bull Neck. Our overall conclusion was that the surrogate species approach was appropriate for Coastal North Carolina and the bobcat would be an appropriate surrogate species in the Southeast provided the questions asked were similar to ours.

The benefits of using the surrogate species approach included: access to information about other mammals on Bull Neck, detailed information of land cover structure for various land covers throughout area, and identification of travel corridors used by bobcats and likely other medium to large sized mammals. Although not reported here, our initial phase of the project was designed to monitor our research site and identify an appropriate surrogate species. We accomplished our objective through the comparison of a number of survey techniques (Rockhill et al. 2013). Results from the initial stage allowed us to confirm the presence of bobcats in sufficient density to initiate this broader cover type selection study. Further, results from the initial stage provided us with mammalian species richness, occupancy, and detection rates for up to 13 other mammals on Bull Neck. Acquiring the land cover structure information was labor and cost intensive; the process was necessary, however, to test the HSI and the surveys allowed us to create a dataset that can be used for future studies on Bull Neck.

The HSI results were broad on depicting low suitability indices, but the information theoretic model allowed us to specifically identify travel corridors currently used by bobcats. Currently, the main corridors identified through this study are privately owned and open to harvesting, development, or conversion to agricultural land. Recent shovel logging activity has reduced the width of the corridors to nearly 55% of their original width. This necessitates concern for reduced gene flow across Bull Neck boundary and highlights the potential for sink populations of broad ranging species. Conserving these areas or converting current agricultural land surrounding Bull Neck may be critical for many animals on Bull Neck. Although the surrogate species approach allowed us to answer our management questions, we caution that this should be viewed as a course filter, non-statistical approach. Researchers and managers should be aware that sensitive species (i.e., those that do poorly post timber harvest) may fall through the filter. Although it may be appropriate to say there are enough prey species to support high densities of bobcat on Bull Neck, it is inaccurate to infer anything about what those prey species, or their densities, may be.

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TABLES

Table 1: Reported variations in land cover use by bobcats throughout the United States. The land cover type is reported in the top row and the table lists the reported use by each land cover type by author.

State	Old Field	Ag.	Pocosin	Hardwood	Pine-Hardwood	Lowland	Upland	Young Pine	Mature Pine	Source
MA	Low	N/A	N/A	Low	Low	N/A	N/A	Low	Low	(McCord and Cardoza 1982)
LA	High	N/A	N/A	N/A	N/A	N/A	N/A	High	N/A	(Hall and Newsom 1976)
AL	High	N/A	N/A	N/A	N/A	N/A	N/A	High	N/A	(Miller and Speake 1979)
GA	Seasonal	N/A	N/A	N/A	N/A	High	Seasonal	N/A	Low	(Buie et al. 1979)
NC	Low	Low	Low	N/A	N/A	High	High	High	Moderate	(Lancia et al. 1982)
MO	High	Low	N/A	N/A	N/A	N/A	Moderate	High	Low	(Hamilton 1982)
AZ	N/A	N/A	N/A	N/A	N/A	High	N/A	N/A	N/A	(Lawhead 1984)
OK	Seasonal	N/A	N/A	Seasonal	Moderate	N/A	N/A	Seasonal	Seasonal	(Rolley and Warde 1985)
ME	N/A	N/A	N/A	High	Low	N/A	N/A	Low	Low	(Litvaitis et al. 1986)
AR	N/A	N/A	N/A	High	Low	High	Moderate	Moderate	High	(Rucker et al. 1989)
WI	N/A	Low	N/A	Low	N/A	High (conifer)	Low (conifer)	Low	High	(Lovallo and Anderson 1996)
IL	Moderate	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	(Nielsen and Woolf 2002)
MS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Moderate	High	(Chamberlain et al. 2003)
MI	Low	Low	High	N/A	N/A	High	Moderate	N/A	N/A	(Preuss and Gehring 2007)

* N/A = not applicable due to lack of land cover type

Table 2: List of models used for synoptic analysis in coastal North Carolina, 2008-2009. All models include land cover classes wet hardwood forest, pine pocosin forest, oak hardwood forest, managed pine, and early succession.

Model	Model Summary	Added Variables
1	crop (unavailable year round)	crop
2	time dependent crop (available only when planted and high enough for cover)	crop summer, crop not summer
3	tree height	tree height
4	elevation	elevation
5	percent edge within 500 m and 1000 m of each 30 m pixel	edge 500, edge 1000
6	percent evenness within 500 m and 1000 m of each 30 m pixel	evenness 500, evenness 1000
7	percent richness within 500 m and 1000 m of each 30 m pixel	richness 500, richness 1000
8	percent of low density roads within 500 m and 1000 m of each 30 m pixel	road low 500, road low 1000
9	percent of high density roads within 500 m and 1000 m of each 30 m pixel	road high 500, road high 1000
10	crop, tree height, elevation, all 1000 m variables	crop, tree height, elevation, edge 1000, evenness 1000, richness 1000, road low 1000, road high 1000
11	time dependent crop, tree height, elevation, all 1000 m variables	crop summer, crop not summer, tree height, elevation, edge 1000, evenness 1000, richness 1000, road low 1000, road high 1000
12	crop, tree height, elevation, all 500 m variables	crop, tree height, elevation, edge 500, evenness 500, richness 500, road low 500, road high 500
13	time dependent crop, tree height, elevation, all 500 m variables	crop summer, crop not summer, tree height, elevation, edge 500, evenness 500, richness 500, road low 500, road high 500
14	time dependent crop, all variables	crop summer, crop not summer, tree height, elevation, edge 500, edge 1000, evenness 500, evenness 1000, richness 500, richness 1000, road low 500, road low 1000, road high 500, road high 1000
15	time dependent crop, tree height, elevation	crop summer, crop not summer, tree height, elevation

Table 3: Variation in SIV1 and SIV2 values for cover types in coastal North Carolina, 2008 - 2009.

		SIV1		SIV2	
Cover Type	N	Mean	StDev	Mean	StDev
Floodplain Forest	37	37	17.15	77	19.88
Dry-Mesic Oak Forest	7	47	26.37	63	33.56
Wet Hardwood Forest	38	39	11.93	77	20.93
Peatland Pocosin	20	40	19.60	62	25.89
Pine Woodland	7	33	13.44	54	19.68
Cultivated Cropland	14	63	27.10	94	20.05
Developed	2	27	19.09	65	8.49
Successional	6	57	28.52	82	27.25
Managed Pine	2	45	11.31	36	50.91

Table 4: Spearman rank correlation results comparing final SIV values for cells with a use index for each bobcat within the same cell and final SIV values for cover types against a use index for the cover type for each bobcat in coastal North Carolina, 2008 - 2009. Spearman correlation coefficients range from 1 to -1 where 1 represents a strong positive relationship between ranks and -1 represents a strong negative relationship between ranks.

Bobcat	ρ cells	ρ cover type
juvenile female	0.441	0.545
juvenile female	-0.191	0.359
juvenile female	-0.236	0.548
juvenile male	-0.053	0.587
adult female	-0.548	0.444
adult female	-0.639	0.060
adult male	0.038	0.331

Table 5: Akaike's Information Criterion ranking for *a priori* candidate models used to estimate the utilization distribution of 5 individual bobcats in coastal North Carolina, 2008 - 2009. The number of telemetry locations (*n*), model number (Table 2), number of estimated model parameters (K), AIC$_c$, difference between each models' AICc and the model with the lowest AIC$_c$ (ΔAIC$_c$), and the Akaike weight (w_i) given.

Bobcat (*n*)	Model #	K	AIC$_c$	ΔAIC$_c$	w_i
BL01	14	14	115178	0	1.00
(1517)	10	8	115513	335	0.00
	11	9	115513	335	0.00
	12	8	115839	661	0.00
	13	9	115839	661	0.00
	15	4	115908	730	0.00
	8	2	116350	1172	0.00
	4	1	116429	1251	0.00
	3	1	116431	1253	0.00
	5	2	116734	1556	0.00
	7	2	116753	1575	0.00
	9	2	116776	1598	0.00
	1	1	116780	1601	0.00
	2	2	116780	1601	0.00
	6	2	116783	1605	0.00
GR33	14	14	143853	0	1.00
(1815)	13	9	143879	27	0.00
	12	8	143941	89	0.00
	11	9	143958	106	0.00
	10	8	144020	168	0.00
	15	4	144119	267	0.00
	3	1	144228	375	0.00
	5	2	146565	2712	0.00
	7	2	146682	2829	0.00
	2	2	146692	2839	0.00
	9	2	146716	2864	0.00
	4	1	146747	2894	0.00

Table 5 Continued

	6	2	146750	2898	0.00
	1	1	146754	2901	0.00
	8	2	146757	2905	0.00
OR77	14	14	125883	0	1.00
(1704)	10	8	126571	688	0.00
	11	9	126573	690	0.00
	13	9	127133	1250	0.00
	12	8	127151	1268	0.00
	15	4	127266	1383	0.00
	3	1	127306	1423	0.00
	5	2	128844	2961	0.00
	8	2	128886	3003	0.00
	6	2	128947	3064	0.00
	7	2	128962	3079	0.00
	9	2	129094	3211	0.00
	1	1	129142	3259	0.00
	4	1	129144	3261	0.00
	2	2	129144	3261	0.00
RE51	14	14	75804	0	1.00
(1001)	10	8	75870	66	0.00
	11	9	75870	66	0.00
	12	8	75900	96	0.00
	13	9	75900	96	0.00
	15	4	75997	194	0.00
	3	1	76402	598	0.00
	4	1	77179	1375	0.00
	8	2	77342	1538	0.00
	5	2	77375	1571	0.00
	7	2	77389	1585	0.00
	1	1	77395	1591	0.00
	2	2	77395	1591	0.00
	9	2	77395	1591	0.00
	6	2	77400	1596	0.00
YE105	14	14	46724	0	1.00
(610)	11	9	46851	127	0.00
	10	8	46860	136	0.00

Table 5 Continued

13	9	46876	152	0.00
12	8	46885	161	0.00
8	2	47220	496	0.00
5	2	47337	613	0.00
15	4	47370	646	0.00
3	1	47468	744	0.00
9	2	47478	753	0.00
6	2	47509	785	0.00
7	2	47526	802	0.00
4	1	47528	804	0.00
2	2	47553	829	0.00

Table 6: Parmeter estimates (β) and associated standard errors (SE) for the top model used to construct utilization distributions for individual bobcats in coastal North Carolina, 2008 - 2009.

Model Parameters	Adult Female[a]			Juvenile Male[b]			Adult Female[a]			Adult Male			Juvenile Female[b]		
	β	SE	SD	β	SE	SD	β	SE	SD	β	SE	SD	β	SE	SD
Wet Hardwood Forest	2.12	0.22	7.56	-0.61	0.09	2.53	0.33	0.14	5.26	1.02	0.19	5.24	-0.33	0.34	2.90
Pine Pocosin Forest	2.03	0.23	3.72	-1.14	0.12	1.31	1.09	0.17	1.81	1.23	0.21	2.64	1.13	0.31	3.77
Oak Hardwood Forest	-0.23	0.47	1.15	-1.12	0.16	1.16	-0.94	0.29	1.16	-1.10	0.50	1.12	0.05	0.34	2.01
Managed Pine	2.25	0.32	1.53	-1.86	0.35	1.05	-0.99	0.72	1.02	0.56	0.39	1.23	0.71	0.31	4.87
Early Successional Fields	1.68	0.31	1.32	1.06	0.11	1.61	1.72	0.20	1.50	1.63	0.27	1.27	0.38	0.35	1.82
Crop Planted	NA	NA	NA	1.96	0.12	2.15	0.58	0.74	1.05	NA	NA	NA	1.36	0.36	2.04
Crop Barren	NA	NA	NA	0.98	0.15	1.45	0.56	0.74	1.05	NA	NA	NA	0.48	0.35	2.10
Tree Height	7.16	0.33	12.85	5.72	0.15	6.39	18.34	0.48	19.81	14.28	0.50	15.82	2.48	0.26	6.42
Elevation	14.79	0.48	18.70	1.43	0.29	12.35	8.18	0.47	19.40	14.96	0.58	18.35	5.17	0.36	8.89
Percent Edge (1000 m)	1.64	0.62	24.15	-0.79	0.41	17.47	14.33	0.56	23.12	1.29	0.72	22.78	-9.11	0.86	21.24
Percent Edge (500 m)	-1.88	0.45	17.53	2.27	0.32	13.63	-6.50	0.40	16.51	2.16	0.55	17.40	3.07	0.59	14.57
Percent Evenness (1000 m)	1.58	0.39	15.19	-0.53	0.17	7.24	1.75	0.26	10.73	-0.76	0.45	14.24	0.59	0.29	7.16
Percent Evenness (500 m)	-2.07	0.40	15.58	-1.61	0.22	9.37	-2.57	0.33	13.62	-1.43	0.50	15.82	1.30	0.31	7.66
Percent Richness (1000 m)	-0.65	0.18	7.01	-0.15	0.14	5.96	0.93	0.14	5.78	0.98	0.20	6.33	2.54	0.44	10.87
Percent Richness (500 m)	1.20	0.21	8.18	0.87	0.16	6.82	0.69	0.16	6.60	-1.15	0.27	8.54	-1.40	0.24	5.93
Secondary Roads (1000 m)	-12.30	0.55	21.42	1.66	0.43	18.32	-13.66	0.52	21.47	-5.08	0.62	19.62	4.99	1.07	26.43
Secondary Roads (500 m)	9.44	0.56	21.81	-0.66	0.52	22.15	11.59	0.52	21.47	2.48	0.66	20.88	5.93	1.02	25.19
Primary Roads (1000 m)	NA	NA	NA	-0.44	0.62	26.41	NA	NA	NA	NA	NA	NA	-0.75	0.67	16.55
Primary Roads (500 m)	NA	NA	NA	3.41	0.87	37.06	NA	NA	NA	NA	NA	NA	-2.47	1.15	28.40

[a] Female bobcats that were captured in 2008 as Juveniles and recaptured in 2009 as adults

[b] Juvenile bobcats that dispersed off of Bull Neck in 2008

FIGURES

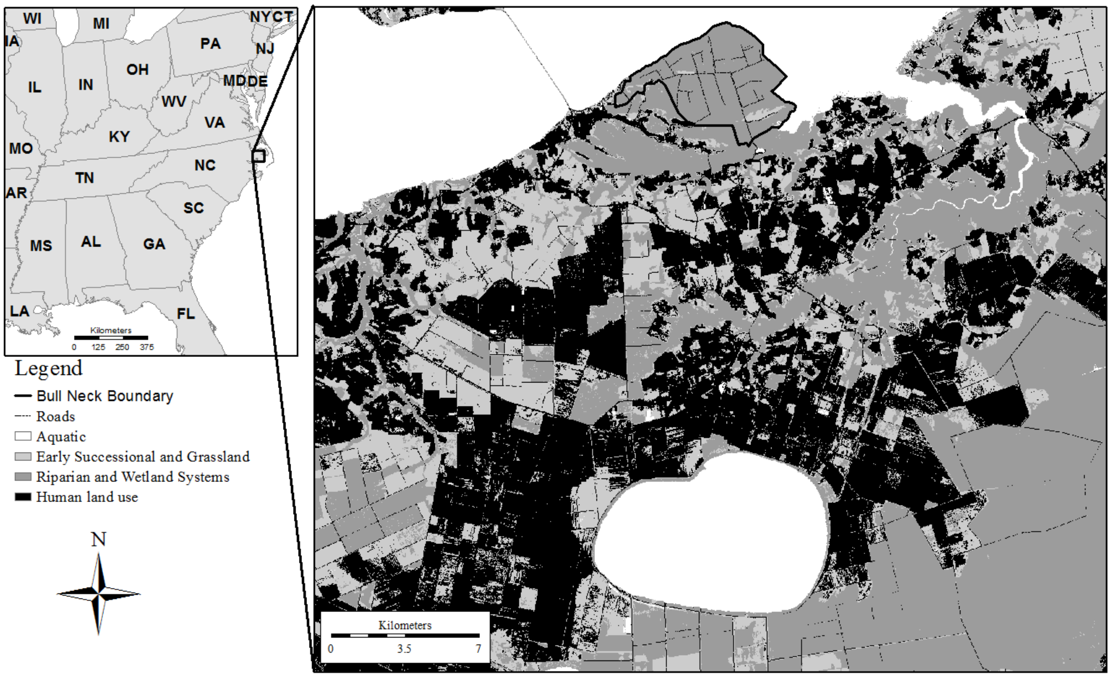


Figure 1: Major land cover classification in coastal North Carolina. Bull Neck is outlined on the northern tip of the map with a solid black line, 2008-2009.

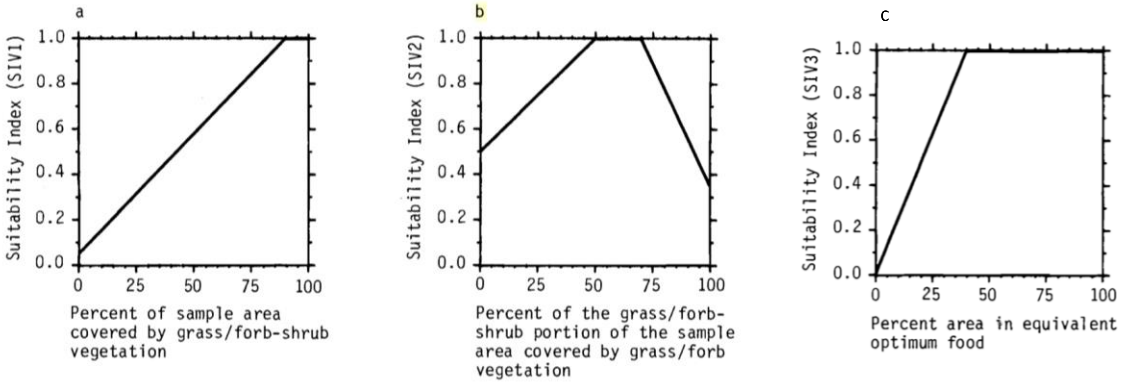


Figure 2: Suitability Index measures used for analysis from Boyle (1987). Figure 2a reflects a linear increase in suitability as the percentage of the sample area covered by grass/forb-shrub increases. Figure 2b reflects changes in suitability as the percentage of the grass/forb-shrub area that is covered by grass/forb increases. Suitability begins to decline once grass/forb vegetation exceeds 70%. Figure 2c reflects a linear relationship between suitability and the percent of an area in optimum food (PAOFS, Equation 1). Suitability reaches a maximum of 1.0 when 40% or more of an area is determined to be in optimum food coverage.

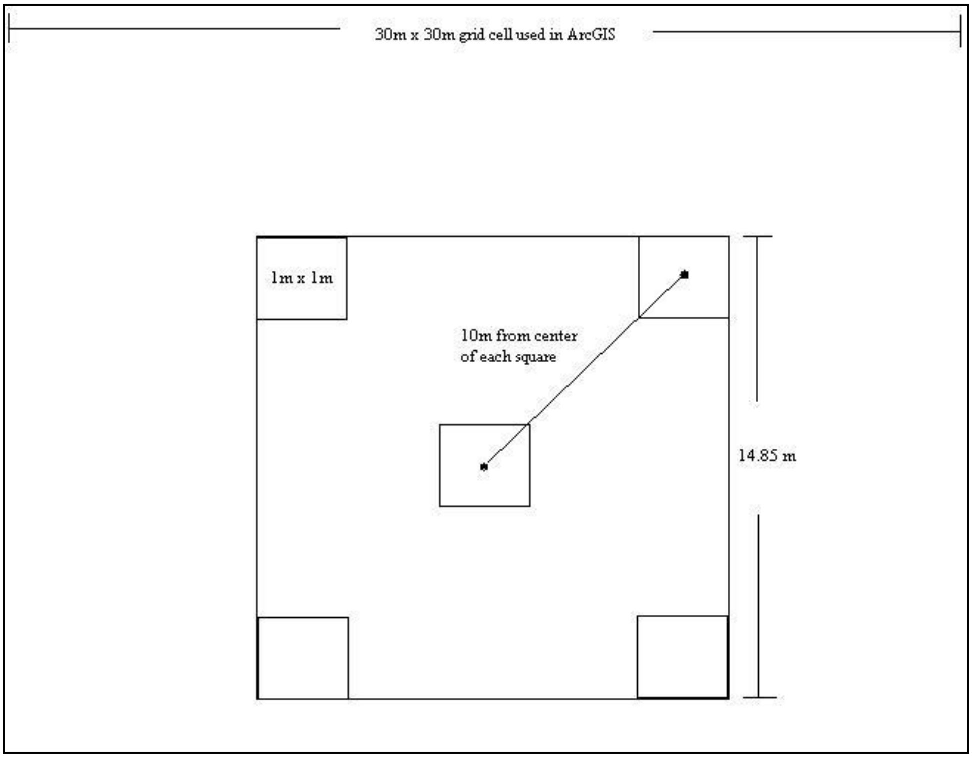


Figure 3: Vegetation sampling design. Percent ground cover was taken in each 1m x 1m plot (n=5) at each site. Stem density was collected in 10 m transects from the center point to each corner ground cover point.

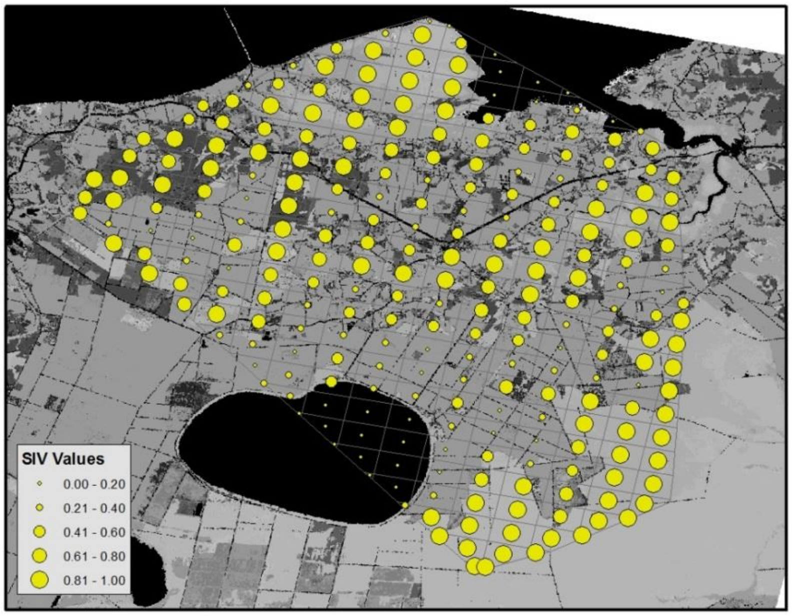


Figure 4a: Output SIV3 cell values for study area in coastal North Carolina, 2008-2009.

Larger circles represent higher suitability (SIV3) for bobcats.

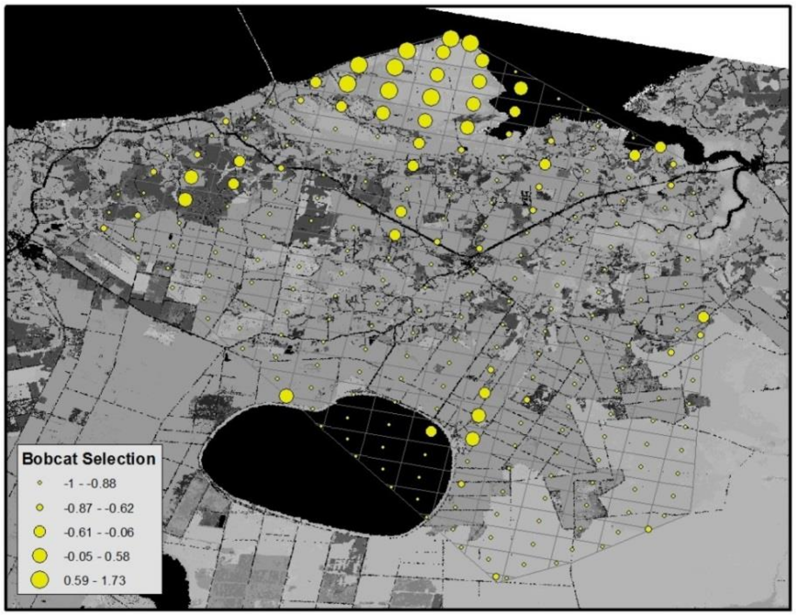


Figure 4b: Output use index values for bobcats in coastal North Carolina, 2008-2009. Larger circles represent higher use of a cell by bobcats.

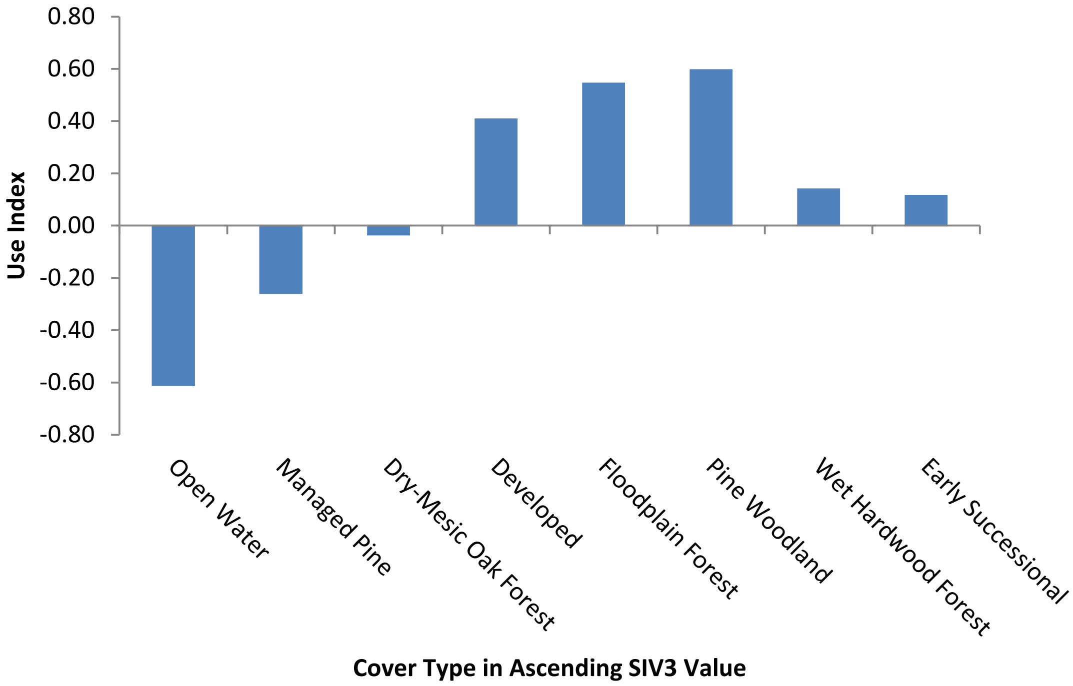


Figure 5: Output use index by land cover type. Negative values represent lower use than availability. Positive values represent higher use than availability. Data represent the average use index for all bobcats combined, coastal North Carolina, 2008 – 2009.

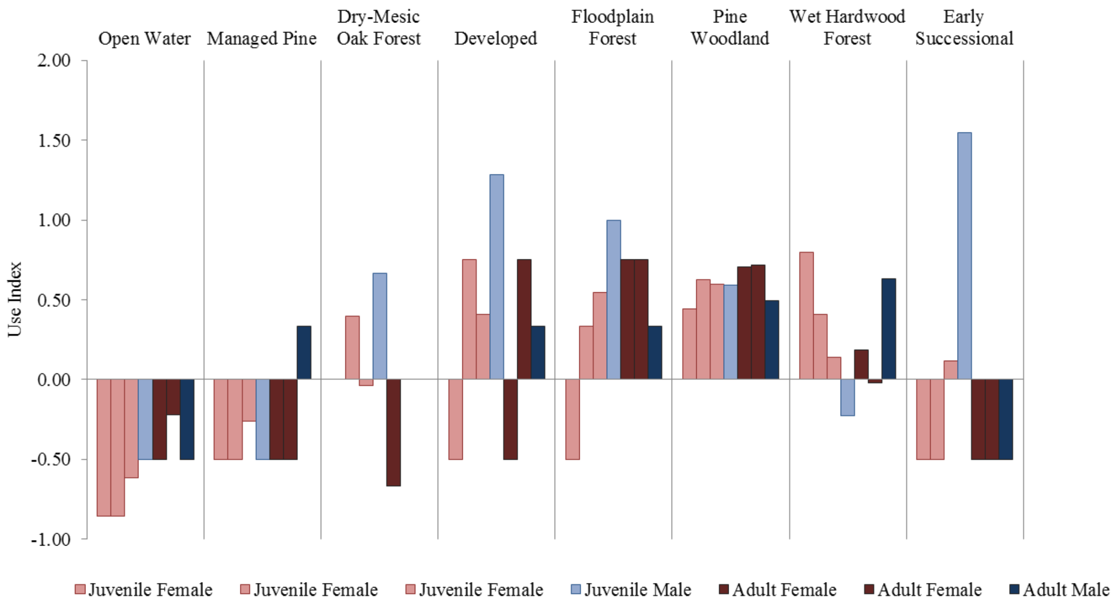
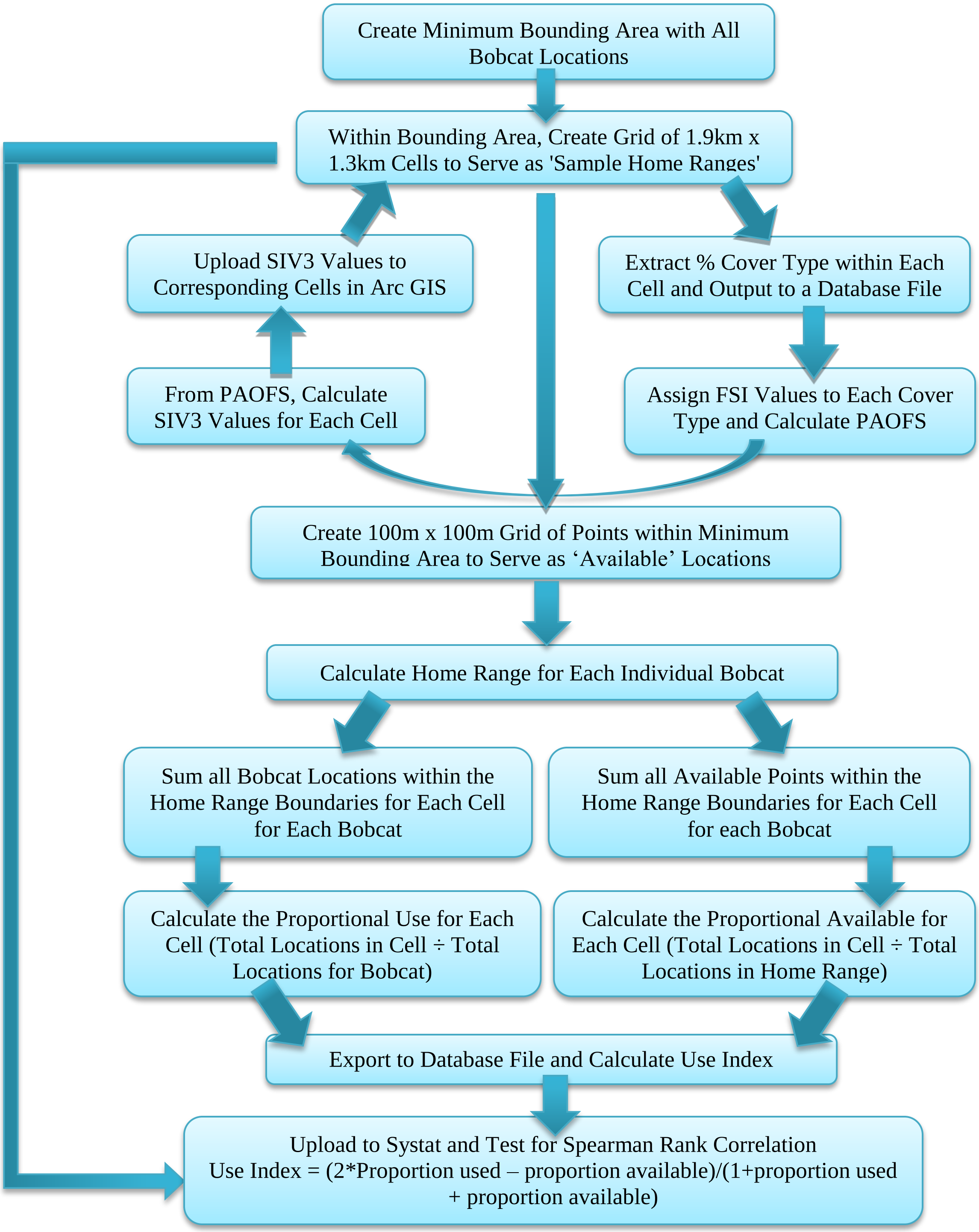


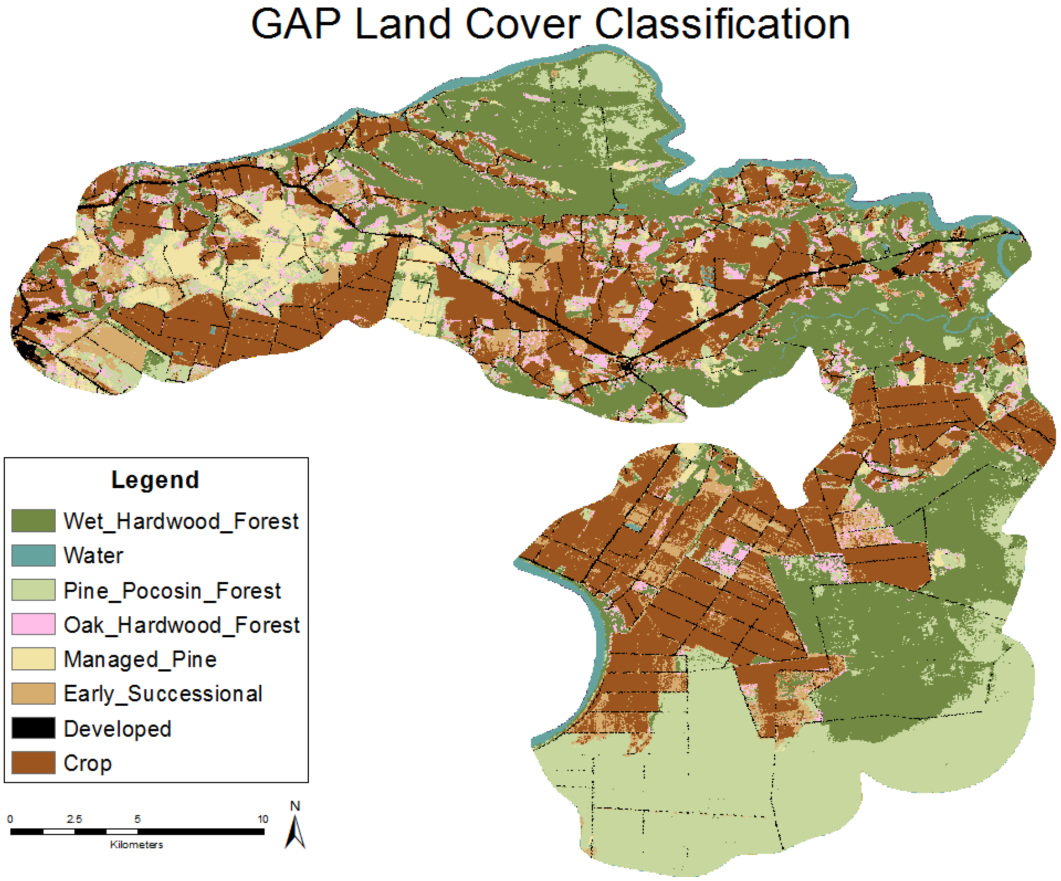
Figure 6: Output use index by land cover type for individual bobcats. Individuals are identified by age (juvenile vs. adult) and sex (female vs. male). Negative values represent lower use than availability. Positive values represent higher use than availability. Data were collected from bobcats in coastal North Carolina, 2008 – 2009.

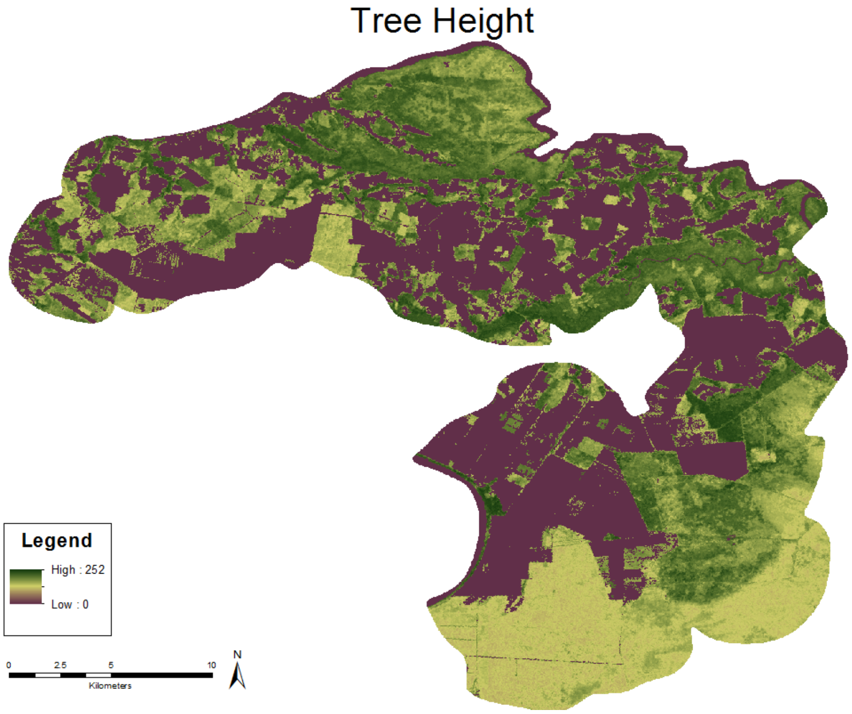
APPENDICES

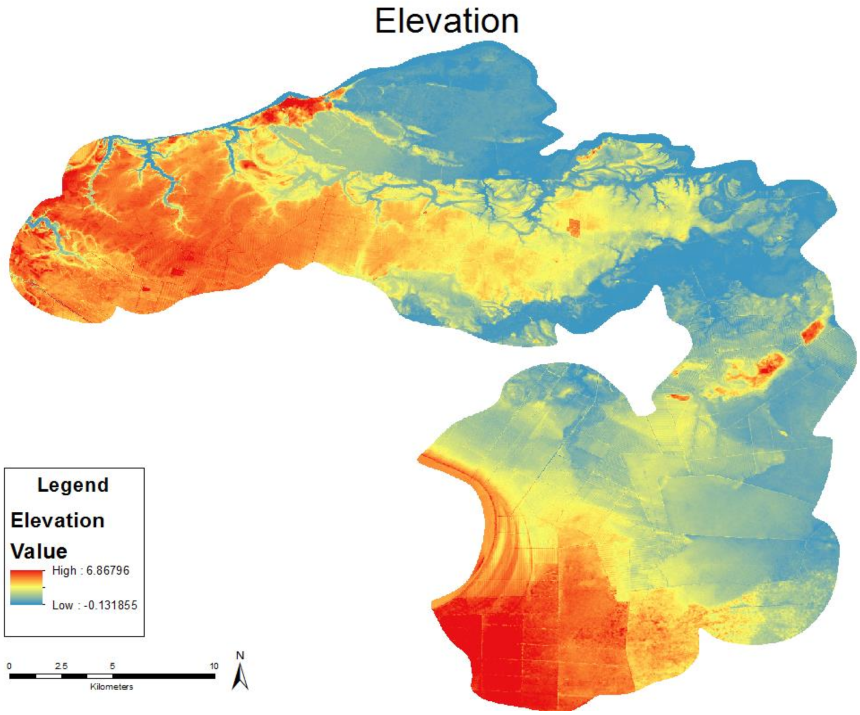
Appendix A - Flow chart for the steps involved with HSI model testing.



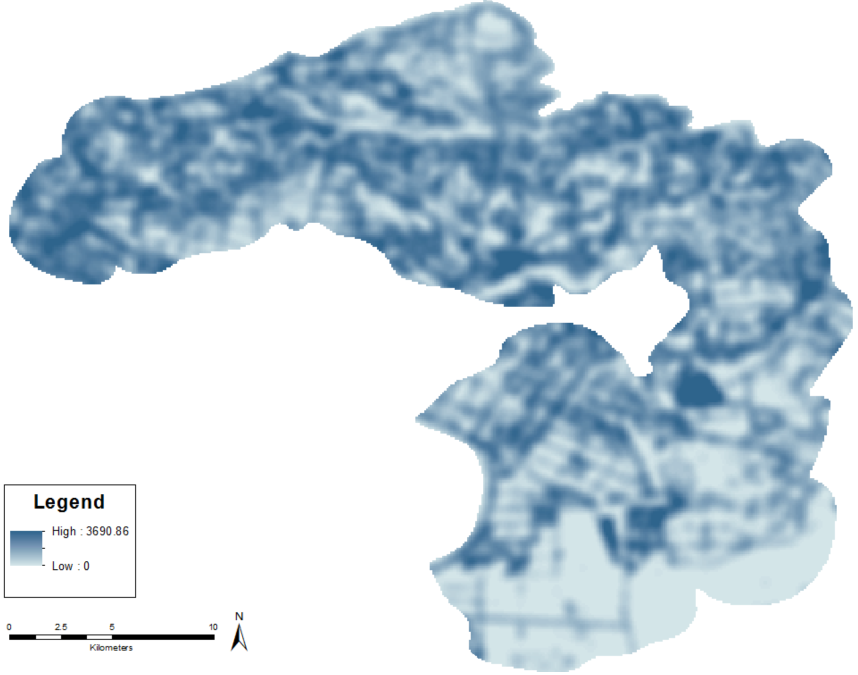
Appendix B – GIS Layers used for synoptic analysis. The classification outline contained all edges of a bivariate normal fit, for each individual’s location data. The primary roads layer was clipped to the minimum extent of the layer.



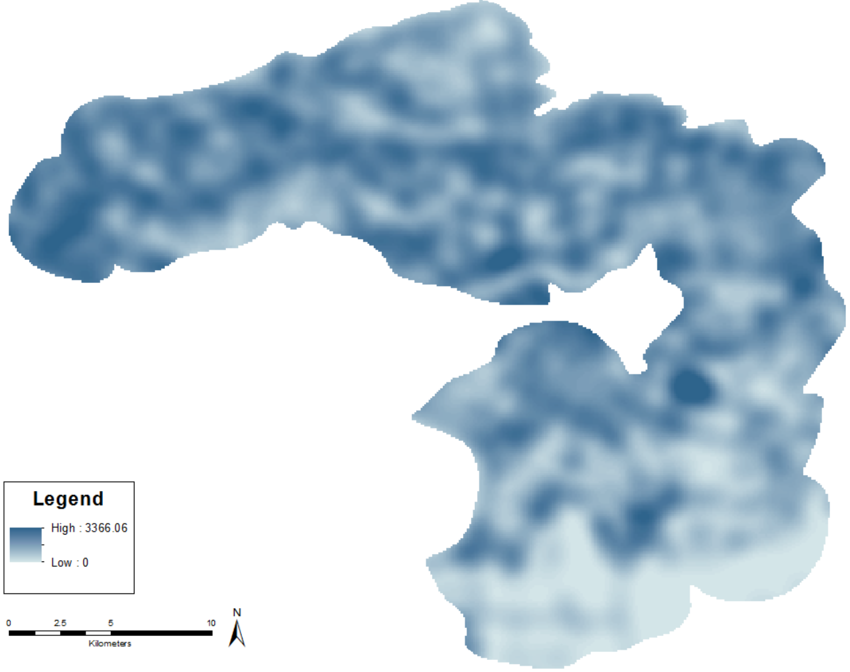

Tree Height
Legend
High : 252
Low : 0
0
2.5
5
10
Kilometers
N

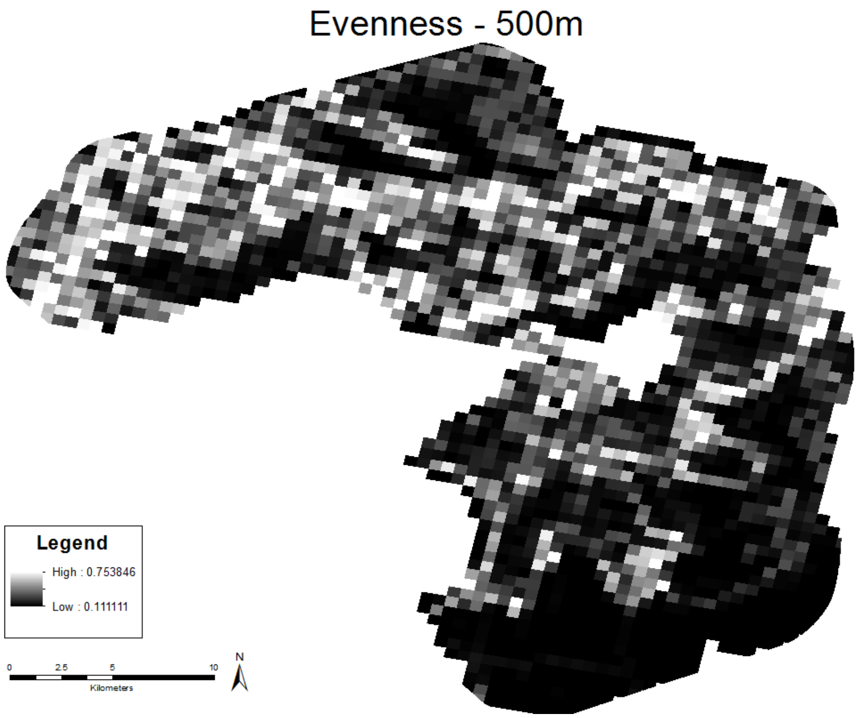

Elevation
Legend
Elevation
Value
High : 6.86796
Low : -0.131855
0
2.5
5
10
Kilometers
N

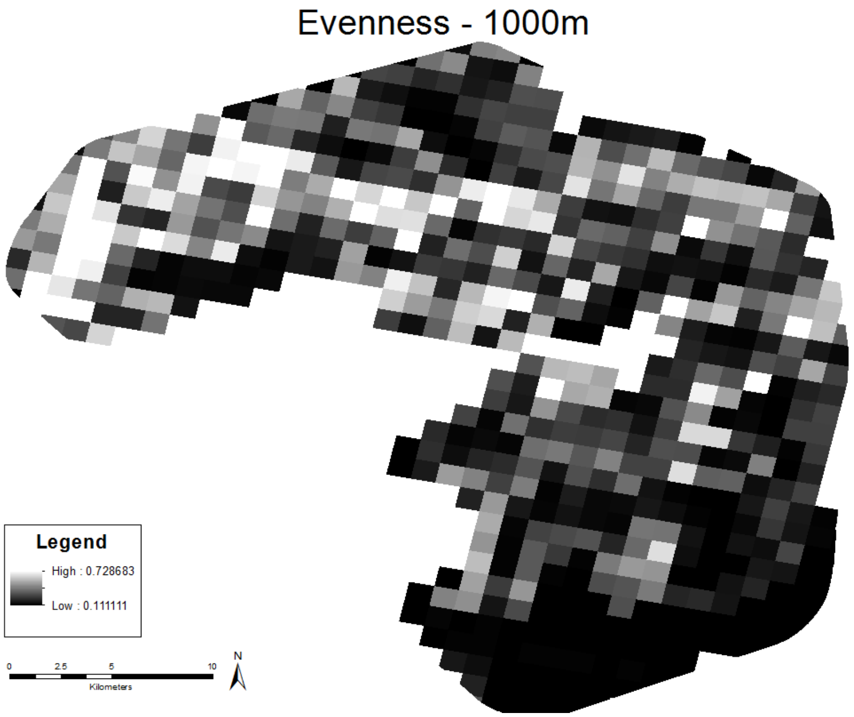
Edge - 500m

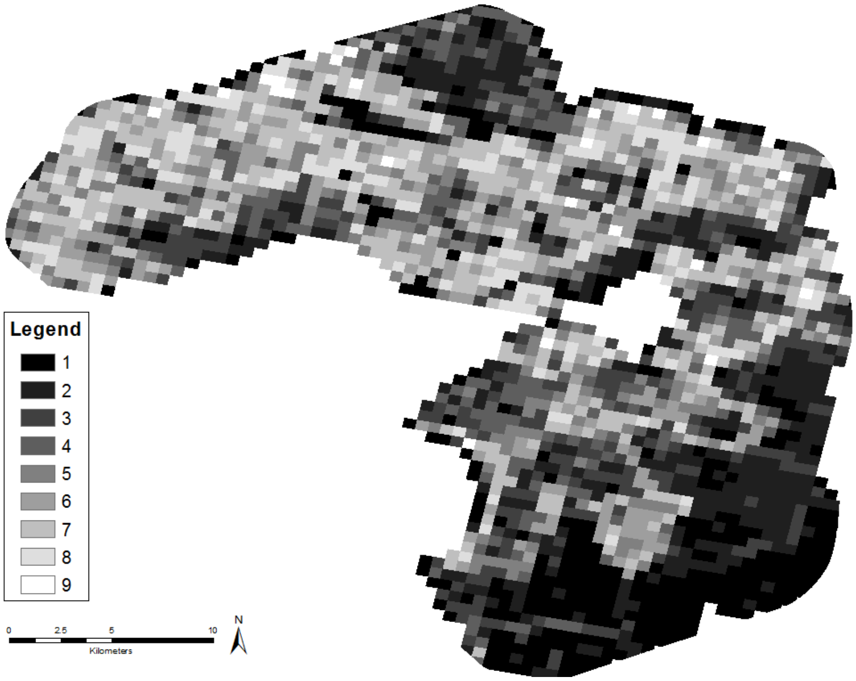


Edge - 1000m

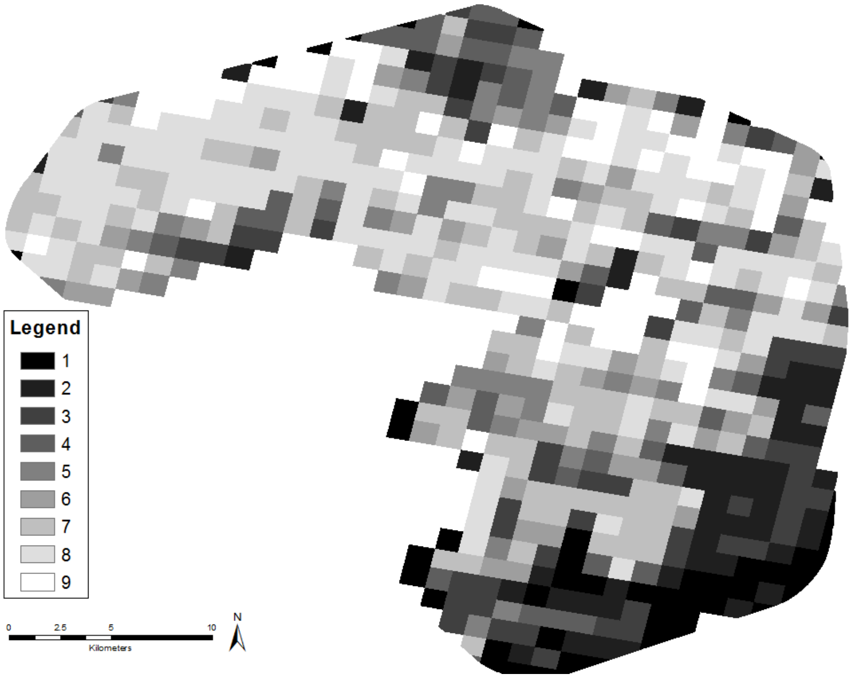



Evenness - 500m
Legend
High : 0.753846
Low : 0.111111
0
2.5
5
10
Kilometers
N


Evenness - 1000m
Legend
High : 0.728683
Low : 0.111111
0
2.5
5
10
Kilometers
N

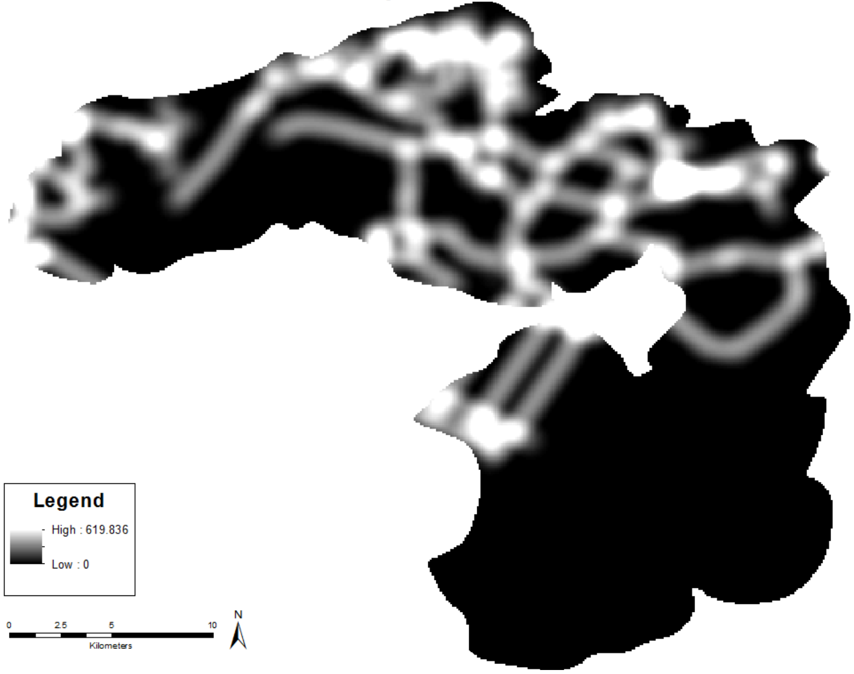


Richness - 500m

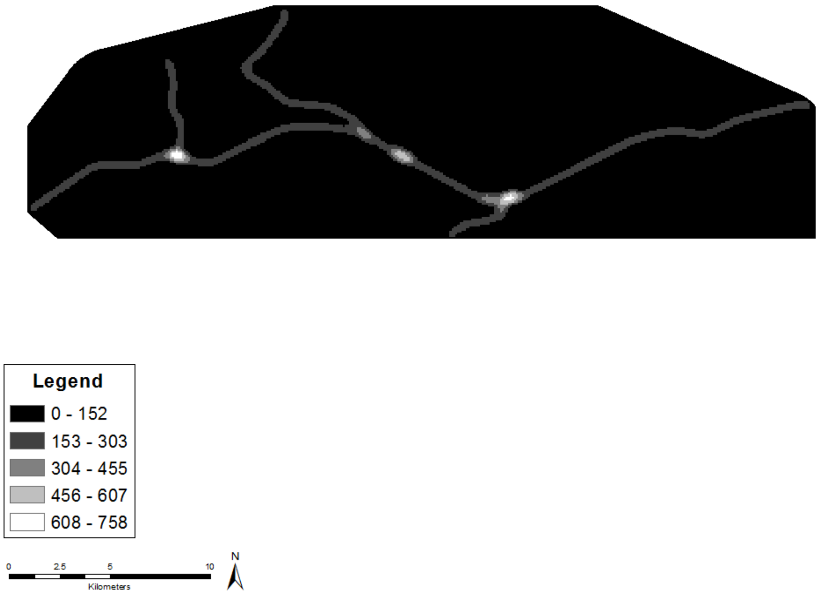


Richness - 1000m


Secondary Roads - 500m


Secondary Roads - 1000m

Primary Roads - 500m



Primary Roads - 1000m