5-2010

The Influence of Landscape and Weather on Foraging by Olfactory Meso-predators in Utah

Rebekah E. Dritz
Utah State University

Follow this and additional works at: https://digitalcommons.usu.edu/etd
Part of the Animal Sciences Commons

Recommended Citation
Dritz, Rebekah E., "The Influence of Landscape and Weather on Foraging by Olfactory Meso-predators in Utah" (2010). All Graduate Theses and Dissertations. 725.
https://digitalcommons.usu.edu/etd/725

This Thesis is brought to you for free and open access by the Graduate Studies at DigitalCommons@USU. It has been accepted for inclusion in All Graduate Theses and Dissertations by an authorized administrator of DigitalCommons@USU. For more information, please contact dylan.burns@usu.edu.
INFLUENCE OF LANDSCAPE AND WEATHER ON FORAGING BY OLFACATORY

MESO-PREDATORS IN UTAH

by

Rebekah E. Dritz

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Wildlife Biology

Approved:

______________________________________________________
Dr. Michael R. Conover
Major Professor

______________________________________________________
Dr. Christopher A Call
Committee Member

______________________________________________________
Dr. John A. Shivik
Committee Member

______________________________________________________
Dr. Byron R. Burnham
Dean of Graduate Studies

______________________________________________________

UTAH STATE UNIVERSITY
Logan, Utah

2010
ABSTRACT

The Influence of Landscape and Weather on Foraging
by Olfactory Meso-predators in Utah

by

Rebekah E. Dritz, Master of Science
Utah State University, 2010

Major Professor: Dr. Michael R. Conover
Department: Wildland Resources

Predation by olfactory meso-predators has a large impact on avian nest success, particularly for ground-nesting waterfowl. Olfactory predators rely on odors to locate their prey. Weather conditions (e.g. wind speed, humidity, and temperature), vegetation, and landscape features affect the dissipation rate of odors and could affect the foraging efficiency of olfactory predators. I conducted 2 studies to determine if weather and landscape impact predator foraging ability and behavior: a predator survey study and an artificial nest study. The objective of the predator survey was to investigate how landscape and weather conditions interact to influence the distribution of olfactory meso-predators [e.g. red foxes (Vulpes vulpes), skunks (Mephitis mephitis), and raccoons (Procyon lotor)] in their nightly foraging on the dike. Specifically, I examined how wind speed, wind orientation, temperature, and humidity affect the distribution, number, and species of olfactory meso-predators foraging on the Arthur V. Watkins Dike at Willard Bay State Park and Reservoir. The objective of the artificial nest study was to determine
if weather, vegetation, or nest location relative to a large-scale surface feature have an
effect on survival of artificial ground-nests in an area dominated by olfactory meso-
predators. Artificial nests were placed on the dike throughout the summer of 2009.
Spotlighting surveys for predators were conducted from August 2008 to August 2009. I
found that section of the dike, time since study initiation, terrain type on the dike, wind
speed, and vegetation height during daylight hours affected nest survival. The results
indicated that predators formed olfactory search images in that nest survival decreased
over the summer, while predator populations remained constant. I observed foxes,
skunks, and raccoons while spotlighting for predators. After accounting for time, wind
speed and direction were significant predictors of predators’ nightly foraging activity
with most predators observed when wind speeds were 2 to 4 m/s and winds were blowing
from the northwest. Overall the model accounted for 75% of the nightly variation in
predator numbers. Additionally, wind speed and direction impacted where predators were
foraging. There were interspecific differences among predators in their responses to wind
speed with raccoons being observed more than skunks and foxes when the wind was calm
and blowing from the south. The results of the spotlighting data indicate that wind speed
and direction have a strong effect on foraging activity. Overall, I concluded that wind
speed affects predator foraging ability and behavior.
ACKNOWLEDGMENTS

I would like to thank my advisor, Dr. Michael Conover, for his patience and encouragement. Funding for my research was provided by the Utah Agricultural Experiment Station. The Quinney Foundation provided me with a fellowship for which I am very grateful. I also thank my committee members: Dr. Christopher Call and Dr. John Shivik and technicians (especially Drew White, who kept me organized in the field).

I am eternally grateful to my family – Mom, Frank, Grandma, and Gil – for their unconditional support, encouragement, and love. Many thanks to my Colorado friends, advisors, and surrogate families. And finally, to Kevin: thank you for being there, I love you.

Rebekah Dritz
# CONTENTS

<table>
<thead>
<tr>
<th>ABSTRACT</th>
<th>ii</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>iv</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>viii</td>
</tr>
<tr>
<td>CHAPTER</td>
<td></td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Literature Cited</td>
<td>2</td>
</tr>
<tr>
<td>2. INFLUENCE OF LANDSCAPE AND WEATHER ON FORAGING BY OLFACTORY MESO-PREDATORS</td>
<td>4</td>
</tr>
<tr>
<td>Introduction</td>
<td>5</td>
</tr>
<tr>
<td>Methods</td>
<td>7</td>
</tr>
<tr>
<td>Study Area</td>
<td>7</td>
</tr>
<tr>
<td>Field Methods</td>
<td>8</td>
</tr>
<tr>
<td>Data Analysis</td>
<td>11</td>
</tr>
<tr>
<td>Results</td>
<td>13</td>
</tr>
<tr>
<td>Discussion</td>
<td>21</td>
</tr>
<tr>
<td>Management Implications</td>
<td>25</td>
</tr>
<tr>
<td>Literature Cited</td>
<td>25</td>
</tr>
<tr>
<td>3. INFLUENCE OF LANDSCAPE AND WEATHER ON THE ABILITY OF OLFACTORY MESO-PREDATORS TO LOCATE ARTIFICIAL NESTS</td>
<td>28</td>
</tr>
<tr>
<td>Introduction</td>
<td>29</td>
</tr>
<tr>
<td>Methods</td>
<td>31</td>
</tr>
<tr>
<td>Study Area</td>
<td>31</td>
</tr>
<tr>
<td>Field Methods</td>
<td>32</td>
</tr>
<tr>
<td>Data Analysis</td>
<td>37</td>
</tr>
<tr>
<td>Results</td>
<td>39</td>
</tr>
</tbody>
</table>
Discussion .......................................................... 44
Management Implications ................................. 50
Literature Cited ............................................... 50

4. CONCLUSION .................................................. 54

Literature Cited ............................................... 55
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-1</td>
<td>Number of predator species observed (with row percent) in 4 different types of terrain during year-long spotlighting at Willard Bay State Park and Reservoir Utah, USA.</td>
<td>14</td>
</tr>
<tr>
<td>2-2</td>
<td>Parameter estimates with standard error and t statistics with associated P-values for multiple linear regression model of the number of observed predators per night during yearlong spotlighting as a function of wind speed, wind orientation, and time (spotlighting nights) at Willard Bay State Park and Reservoir, Utah, USA.</td>
<td>16</td>
</tr>
<tr>
<td>2-3</td>
<td>Results from a multinomial logistic regression model that predicts the species of predator (red fox, striped skunk, or raccoon) that would be observed given the wind speed and orientation.</td>
<td>18</td>
</tr>
<tr>
<td>2-4</td>
<td>Parameter estimates with standard error and chi-square statistics with associated P-values for binomial logistic regression model of the predator species observed as a function of wind speed and wind orientation.</td>
<td>18</td>
</tr>
<tr>
<td>2-5</td>
<td>Parameter estimates with standard error and t-statistics with associated P-values for linear regression model of the distance perpendicular to the center of a dike where predators were observed as a function of wind speed.</td>
<td>20</td>
</tr>
<tr>
<td>3-1</td>
<td>Model results table of competing models in program MARK estimating survival (S) of artificial nests in 2009 at Willard Bay State Park and Reservoir, Utah, USA.</td>
<td>41</td>
</tr>
<tr>
<td>3-2</td>
<td>Estimated hourly survival (S), standard error (SE), lower confidence interval (LCI), and upper confidence interval (UCL) for artificial nests on 3 sections of dike at Willard Bay State Park and Reservoir, Utah, USA in 2009.</td>
<td>41</td>
</tr>
<tr>
<td>3-3</td>
<td>Estimated survival for artificial nests on 4 terrain types about the dike in 2009 at Willard Bay Reservoir, Utah, USA.</td>
<td>43</td>
</tr>
<tr>
<td>3-4</td>
<td>Wind speed measurements taken at 44 pairs of depredated and non-depredated artificial nests in 2009 at Willard Bay State Park and Reservoir in Utah.</td>
<td>46</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

Figure | Page |
--- | --- |
2-1 | Overview of Willard Bay State Park and Reservoir, Utah, USA showing sections of the dike where I conducted predator spotlighting surveys | 9 |
2-2 | Percent of predator species observed in 4 different terrain types during year-long spotlighting at Willard Bay State Park and Reservoir Utah, USA | 14 |
2-3 | Number of olfactory predators observed during nighttime spotlighting over time (where one unit time represents one night spotlighting), average wind speed per night (m/s), and average wind orientation per night with 0° and 360° being north | 17 |
2-4 | Results of binomial logistic regression model of the predator species observed as a function of wind speed and wind orientation | 19 |
2-5 | Perpendicular distance from the center of the dike for predators observed during nighttime spotlighting under different wind speed conditions | 20 |
2-6 | Predicted probabilities of observing a predator calculated from a multinomial logistic regression where the section of dike (1, 2, or 3) a predator was observed on was modeled as a function of wind orientation and wind speed | 21 |
3-1 | Overview of Willard Bay Reservoir and State Park in Utah showing sections of the dike where I conducted an artificial nest study | 33 |
3-2 | Infrared photo of raccoon (*Procyon lotor*) depredating an artificial nest consisting of a chicken egg, timing device, and cotton ball soaked with artificial duck scent | 35 |
3-3 | Estimated hourly survival over time, lower confidence interval (LCI), and upper confidence interval (UCI) for artificial nest at Willard Bay State Park and Reservoir, Utah, USA in 2009 | 42 |
3-4 | Estimated survival probability during daylight hours as a function of
vegetation height (m) for artificial nests at Willard Bay State Park and Reservoir, Utah, USA in 2009……………………………………. 42

3-5 Estimated survival probability as a function of wind speed for artificial nests at Willard Bay State Park and Reservoir, Utah, USA in 2009…….. 43

3-6 Estimated survival probability as a function of temperature, relative humidity, and wind orientation for artificial nests at Willard Bay State Park and Reservoir, Utah, USA in 2009…………………………………… 45

3-7 Estimated survival probability as a function of hours of the day during a 24-hour period (with 0 and 24 hr both representing midnight) for artificial nests at Willard Bay State Park and Reservoir, Utah, USA in 2009…………………………………………………………………. 46
CHAPTER 1
INTRODUCTION

Much of the research on animal olfaction and its use in finding prey resources concerns insects (Janssen et al. 1997, Vickers 2000) or animals in marine environments (Finelli et al. 1999). Mammalian olfactory meso-predators, such as skunks (*Mephitis mephitis*), red foxes (*Vulpes vulpes*), and raccoons (*Procyon lotor*), are ubiquitous across a wide range of landscapes (Fitzgerald et al. 1994). Predation by these mammals impacts avian nest success, particularly in ground-nesting waterfowl (Bailey 1971, Brua 1999, Schmidt 1999). Livezey (1981) reported 80% predation loss of upland waterfowl nests at Horicon National Wildlife Refuge in Wisconsin, with virtually all losses attributable to these predators. Despite their regular occurrence and significance to avian populations, little is known about how these animals use olfaction to detect and locate prey and how environmental factors affect their ability to do so (Conover 2007).

Predators that rely on scents to locate prey do so by detecting the prey’s odor plume (i.e., scents suspended in the air) or depositional odor (i.e., scents laid on the ground or vegetation). As such, environmental factors that affect odor plumes and depositional trails should affect predator foraging behavior. Some of the factors that affect odors are: temperature, humidity, precipitation, wind, and turbulence. High temperatures and direct sunlight destroy odorants and decrease the scent available for a predator to detect, while humidity counteracts these effects and keeps odors viable (Gutzwiller 1990). Heavy rain or snow washes away or obscures depositional odor trails (Whelan et al. 1994). High wind velocities, turbulence, and shifting wind direction can dilute an odor plume beyond a predator’s ability to detect it (Shivik 2002, Conover 2007,
Borgo 2008). Low wind velocities, laminar flow, and constant wind direction will result in a relatively concentrated odor plume that extends further over the landscape, increasing the likelihood that a predator will come in contact with the odor at detectable levels (Conover 2007, Borgo 2008). Isolated surface features, such as shelterbelts and dikes, block air on the windward side and cause it to accelerate over the top of the feature creating areas of turbulence on the leeward side (Conover 2007). Borgo (2008) hypothesized that shelterbelts in the Prairie Pothole Region of the United States decrease mammalian predation on ground nesting waterfowl by creating turbulence and updrafts on their leeward side. The objective of my research was to determine if weather and landscape influence the number of predators foraging, the species of predators foraging, where predators forage, and/or their ability to locate artificial nests.

LITERATURE CITED


CHAPTER 2
INFLUENCE OF LANDSCAPE AND WEATHER ON OLFACTERY MESO-PREDATOR FORAGING

Abstract. Olfactory predators rely on scents to locate prey. As such, environmental factors that affect an odor plume (i.e. scents suspended in the air) or depositional odor (i.e. scents laid on the ground or vegetation) should affect predator foraging behavior. Past studies have examined the effects of prey distribution and vegetative structure and composition on foraging, but few studies have examined the effects of weather. The objective of this study was to investigate how landscape and weather interact to influence the distribution of olfactory meso-predators (such as red foxes (Vulpes vulpes), skunks (Mephitis mephitis), and raccoons (Procyon lotor) in their nightly foraging on the dike surrounding Willard Bay Reservoir in Willard, Utah. Specifically, I examined how wind speed, wind orientation, temperature, and humidity affect the distribution, number, and species of olfactory meso-predators foraging on Willard Bay Reservoir Dike. Spotlighting surveys for predators were conducted from August 2008 to August 2009. I observed foxes, skunks, and raccoons. After accounting for time, wind speed and direction were significant predictors of predator’s nightly foraging activity with most predators observed when wind speeds were 2 to 4 m/s and winds were blowing from the northwest. Overall the model accounted for 75% of the nightly variation in predator numbers. Additionally, wind speed and direction impacted where predators were foraging. There were interspecific differences among predators in their responses to wind speed with raccoons being observed more than skunks and foxes when the wind was calm
and blowing from the south. Overall, my results indicate that wind speed and direction have a strong effect on foraging activity.

**INTRODUCTION**

Foraging behavior of olfactory predators is a function of the predators themselves, the prey, and the environmental circumstances that exist at the time of foraging (Schmidt 1999). Olfactory predators such as raccoons (*Procyon lotor*), red foxes (*Vulpes vulpes*), and striped skunks (*Mephitis mephitis*) may employ all senses to detect and locate prey depending on the situation, but primarily rely on their acute sense of smell (Conover 2007). Raccoons are known to grope and probe with their forefeet to locate food underwater, but generally detect prey using olfactory cues (Bowman and Harris 1980, McClearn 1992). Red foxes traverse large areas and will hone in on the scent of prey. They are capable of taking larger prey than either raccoons or striped skunks, and will often kill a nesting hen as well as consume the eggs (Fitzgerald 1994). Skunks either roam the landscape searching for immobile and randomly distributed prey, such as bird nests, or sit and wait to ambush predictable, mobile prey on their paths of travel (Crabtree et al. 1989, Nams 1991). In either case, olfactory cues are likely important to prey detection.

The environment can play an important role in shaping predator foraging behavior. Past studies have examined the effects of prey distribution and vegetative structure and composition (Bowman and Harris 1980, Schmidt 1999), but few studies have examined the effects of weather (e.g., rain, wind, or snow). I am aware of 2 studies that have investigated olfactory predator foraging as a function of weather conditions.
Jolly and Jolly (1992) found that wind orientation affected the amount of time it took for captive dingo ($Canis$ $lupus$ $dingo$) to locate meat baits once released in an enclosed area. Shivik (2002) investigated the effect of weather variables on search-dog ability to locate human subjects. Shivik found that as circular standard deviation of wind orientation increased dog search time also increased. Because olfactory predators rely on scents to locate prey, environmental factors that affect an odor plume (i.e., scents suspended in the air) or depositional odor (i.e., scents laid on the ground or vegetation) should affect predator foraging behavior. Some of the factors that affect odors are: temperature, humidity, precipitation, wind, and turbulence. High temperatures and direct sunlight destroy odorants and decrease the scent available for a predator to detect, while humidity counteracts these effects and keep odors viable (Gutzwiller 1990). Heavy rain or snow washes away or obscures depositional odor trails (Whelan et al. 1994). High wind velocities, turbulence, and shifting wind direction can dilute an odor plume beyond a predator’s ability to detect it (Shivik 2002, Conover 2007, Borgo 2008). Low wind velocities, laminar flow, and constant wind direction result in a relatively concentrated odor plume that extends a further distance over the landscape, increasing the likelihood that a predator will come in contact with the odor at detectable levels (Conover 2007, Borgo 2008). Isolated surface features, such as shelterbelts and dikes, block air on its windward side and cause air to accelerate over the top of the feature creating areas of turbulence on the leeward side (Conover 2007). Borgo (2008) hypothesized that shelterbelts in the Prairie Pothole Region of the United States decrease mammalian
predation on ground nesting waterfowl by creating turbulence and updrafts on their leeward side.

The objective of this study was to investigate how landscape and weather conditions interact to influence the distribution of olfactory meso-predators in their nightly foraging on Willard Bay Reservoir Dike in Willard, Utah. Specifically, I examined how wind speed, wind orientation, temperature, and humidity affect the distribution, number, and species of olfactory meso-predators foraging on the dike. I observed red foxes, skunks, and raccoons at night with a spotlight and noted their location with reference to the dike as well as the weather conditions. These animals are secretive, nocturnal, and make use of shelters or dens when not active. Therefore, I assumed predators were foraging when observed, unless it was obvious they were not (e.g., a litter of young foxes in front of a den or a raccoon in a tree cavity).

METHODS

Study Area

This study took place at Willard Bay State Park and Reservoir (hereafter Willard Bay) in Willard, Utah. The state park was bordered by Interstate 15 on its eastern edge and the Great Salt Lake on its western edge. Willard Bay was approximately 5 km south of the Bear River Migratory Bird Refuge at an elevation of 1,287 m. The Arthur V. Watkins Dike at Willard Bay ran approximately 11 km and separated the freshwater of the reservoir from the Great Salt Lake (Fig. 2-1). The reservoir side of the dike itself extended 20 m and was lined with riprap. The riprap consisted of boulders 0.5 to 3.0 m in diameter. The dry side of the dike, opposite Willard Bay, also extended approximately 20
m, was earthen, and covered with vegetation. The dike was approximately 15-m high, 11-m wide at the top, and 40- to 50-m wide at the base. The road on top of the dike was approximately 10-m wide and ran the length of the dike. The swath of land between the dike and the Salt Lake varied from 70- to 135-m in width depending on the level of the lake. A row of tamarisk (Tamarix spp.) was present at approximately 70 m from the dry side of the dike and ran intermittently along most of the dike.

The vegetation on the top and slope of the dike was dominated by cheat grass (Bromus tectorum), crested wheatgrass (Agropyron cristatum), and various bluegrass species (Poa spp.). The most common forbs on the dike were Dyer’s woad (Isatis tinctoria), flaxweed (Descurainia sophia), red-stem filaree (Erodium circutatum), and bind weed (Convolvulus arvensis). At the base of the slope, there was a short section of riprap approximately 5 m in width followed by a patch of grasses and forbs intermixed with stands of common reed (Phragmites australis) of the same width that extended along the entire dike. Off dike on the dry side, there was a dirt road approximately 30 to 40 m in width that fishermen use to access the dike. The most common forbs and grasses off dike were cheat grass, inland saltgrass (Distichlis spicata), rabbitfoot grass (Polypogon monspeliensis), poison hemlock (Conium maculatum), Dyer’s woad, pickleweed (Salicornia virginica), creeping spurge (Chamaesyce serpens), and knotweed (Polygonum spp.).

Field Methods

Two people observed predators on either side of the dike using a spotlight from a truck driven at 18 km/hr on top of the dike. The observer in the back of the truck
simultaneously scanned both sides of the dike. The starting location on the dike, either north or south, was determined with a coin flip. Observations began at one-half hour to

Figure 2-1. Overview of Willard Bay State Park and Reservoir, Utah, USA showing sections of the dike where I conducted predator spotlighting surveys. Cutout shows cross section of dike with terrain types: A) off dike dry side, B) slope of dike dry side, C) top of dike, and D) reservoir side.
one hour after sunset and continued until the entire dike had been surveyed (usually two to three hours).

Weekly observations began 20 August 2008 and continued through 18 August 2009, except for a period extending from mid-February to the end of March when winter weather made the dike impassable. Beginning in May 2009, observations were made twice weekly.

I recorded the humidity, temperature, percent cloud cover, and presence/absence of snow on the ground at the beginning and end of each transect. When a predator was spotted, the observer signaled to the driver to stop the truck perpendicular to where the predator was first seen. I recorded the predator’s species, section of the dike, perpendicular distance between the road and the predator’s location (in meters), and type of terrain where the predator was located. I divided the dike into 3 sections based on its orientation. Sections 1, 2, and 3 were oriented northeast/southwest, north/south, and east/west respectively. Terrain was classified into one of 4 categories: reservoir side, top of the dike, slope of the dike dry side, or off dike dry side. I measured wind speed (m/s) using a Kestrel 2000® wind meter (Nielsen-Kellerman, Boothwyn, Pennslyvania) and wind orientation was recorded using a compass. Wind was recorded at a height of 2-m above the ground and measured at the top of the dike every 15 sec for 1 min. I also noted the high and low wind speed during the 1 minute.

At 5-10 random locations along the dike, I measured wind speed and orientation to capture the variation in wind speed and orientation throughout the spotlighting run.
These values were combined with the values taken at predator locations for comparison across nights.

**Data Analysis**

I compared use of terrain type by predators using pairwise Chi-square tests. Stepdown Bonferroni adjusted $P$-values for family-wise comparisons were used to provide a more conservative measure of significance and minimize the probability of making a type I error (Verhoeven et al. 2005). Pairs with $P$-values less than 0.03 were considered to be significantly different. For all other analyses, differences were considered significant at alpha level 0.05.

I determined mean wind speed of each night spotlighting by averaging all wind measurements taken from the top of the dike. Mean wind orientation of each night was calculated using the CIRCSTATS package in Program R (Version 2.9.2, The R Foundation for Statistical Computing, Vienna, Austria) by averaging all measurements taken that night. The number of predators observed per night was modeled in a multiple linear regression using PROC REG in SAS (Version 9.2, SAS Institute, Cary, NC), where the response was average wind speed, average wind orientation, standard deviation of wind orientation, humidity, temperature, and time. One unit of time was one night spotlighting.

Wind orientation is a circular variable. To include it in the linear regression, it was first converted to radians and then cosine and sine of the variable were included in the model (Zar 1984). To accurately describe the wind orientation in the model, it was necessary to include both sine and cosine of wind orientation. Therefore, I decided to
retain both variables if one was significant for all models that contained wind orientation. Quadratic terms of both wind and time were introduced to account for systematic variation in the residuals. Wind and time variables were also centered so that the scale among the variables would be similar for easier interpretation of diagnostics.

To determine if weather conditions had a dissimilar effect on the probability of observing raccoons, striped skunks, and/or red foxes, I used a multinomial logistic regression in PROC LOGISTIC in SAS where species of predator observed was a function of wind speed and orientation. The values used for wind speed and wind orientation were those recorded at the time the animal was spotted. Wind orientation was converted to radians and included in the model as 2 terms: sine and cosine of wind orientation. I averaged the high, low, and the four 15-sec interval wind speed measurements to obtain one measure of wind speed for each predator observed.

I constructed a simple linear regression model using PROC REG in SAS where perpendicular distance was a function of wind speed to test whether predators were foraging closer or farther away from the dike in response to wind speed. I only used observations where the animal was observed on the dry side of the dike and wind was flowing over the dike from the reservoir side and approximately perpendicular to it (i.e., at an angle of 45 – 135° to the dike). I took this approach because it stands to reason that an animal would only need to respond to wind speed by changing its perpendicular location if it were on the leeward side and trying to avoid turbulence. Only dry side observations were used because the bay side was only about 10 to 15m in width, thus predators do not have enough area to move out of turbulent areas.
A multinomial logistic regression was used to model the section a predator was observed as a function of wind speed and wind orientation (PROC LOGISTIC, SAS). The objective of this analysis was to determine if predators changed their foraging location in response to weather conditions. My operating hypothesis was that turbulence caused by air flowing relatively perpendicularly over the dike would make foraging conditions poor in one section of dike and, thus, predators would choose to forage on another section. I also included the interaction between wind speed and orientation. I did this to account for the fact that at very low wind speeds the direction the wind is blowing relative to the dike is not likely to have an impact on predator foraging behavior. This is because turbulence would not be formed at low wind speeds and foraging would therefore be the same on all sections in regards to weather conditions. A multinomial logistic regression requires that one level of the response be designated the reference level to which the other levels of the response are compared. Therefore, I arbitrarily chose section 1 to be the reference level.

RESULTS

In total, I observed 180 predators during 40 nights of spotlighting from August 20, 2008 to August 18, 2009. Raccoons were the most frequently observed predator with 87 observations, while 50 red foxes and 43 striped skunks were observed (Table 2-1). Raccoon use of terrain differed significantly from both skunks ($\chi^2_3 = 32.9, P \leq 0.001$) and foxes ($\chi^2_3 = 22.8, P \leq 0.001$), but foxes and skunks were similar in their terrain use ($\chi^2_3 = 3.8, P = 0.28$). Over 62% of raccoons observed were on the bay side or on top of the dike (Fig. 2-2). I observed skunks most frequently off the dike on the dry side (63%), but I
also observed them frequently on top of the dike (23%). Eighty percent of the foxes observed were off dike.

Table 2-1. Number of predator species observed (with row percent) in 4 different types of terrain during year-long spotlighting at Willard Bay State Park and Reservoir Utah, USA.

<table>
<thead>
<tr>
<th>Species</th>
<th>Slope of dike reservoir side</th>
<th>Top of dike</th>
<th>Slope of dike dry side</th>
<th>Off dike dry side</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red fox</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>Striped skunk</td>
<td>2</td>
<td>10</td>
<td>4</td>
<td>27</td>
<td>43</td>
</tr>
<tr>
<td>Raccoon</td>
<td>40</td>
<td>14</td>
<td>4</td>
<td>29</td>
<td>87</td>
</tr>
<tr>
<td>All predators</td>
<td>44</td>
<td>29</td>
<td>11</td>
<td>96</td>
<td>180</td>
</tr>
</tbody>
</table>

Figure 2-2. Distribution of time (% occurrence) that each species spent in each terrain type during year-long spotlighting at Willard Bay State Park and Reservoir Utah, USA.
Wind speed squared, wind orientation, and time squared were all significant in predicting the number of predator observations per night (Table 2-2). Overall the model was highly significant \( F_{6,32} = 20.89, P < 0.001 \) with an adjusted \( R^2 = 0.76 \). Generally the number of predator observations declined over time, although the time squared term allowed for a small increase in the number of predators seen per night in late July and August of 2009 (Fig. 2-3). The most predators were observed when wind speeds were between 2 and 4 m/s and blowing from the northwest (Fig. 2-3).

A multinomial logistic regression model was used to predict the species of predator (e.g. fox, skunk, or raccoon) that would be observed given the wind speed and orientation. In the first analysis, the probability of observing a skunk was similar to the probability of observing a fox for both wind speed and orientation (Table 2-3). Therefore, foxes and skunks were combined into one group and compared to raccoons to make interpretation clearer in the final logistic model. Both wind speed and orientation were significant predictors of the probability of observing a raccoon over a fox or skunk (Table 2-4). The max rescaled \( R^2 \) was 0.11 and the percent correctly classified at a cutoff probability of 0.5 was 56%. In general, the probability of seeing a raccoon declined with increasing wind speed and was maximized when the wind was blowing from the south (Fig. 2-4).

To test whether predators responded to wind speed by increasing their distance from the dike, the dataset was reduced to 32 observations where the wind was flowing over the dike perpendicularly from the reservoir side. Predator distance from the dike varied widely at low wind speeds but then declined generally as wind speed increased;
Table 2-2. Parameter estimates with standard error and $t$ statistics with associated $P$ values for multiple linear regression model of the number of observed predators per night during yearlong spotlighting as a function of wind speed, wind orientation, and time (spotlighting nights) at Willard Bay State Park and Reservoir, Utah, USA.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter estimate</th>
<th>SE</th>
<th>$t$</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average wind speed</td>
<td>2.96</td>
<td>0.92</td>
<td>3.23</td>
<td>0.002</td>
</tr>
<tr>
<td>Average wind speed $^2$</td>
<td>-0.41</td>
<td>0.14</td>
<td>-2.91</td>
<td>0.003</td>
</tr>
<tr>
<td>Sine wind orientation</td>
<td>0.89</td>
<td>0.35</td>
<td>2.52</td>
<td>0.02</td>
</tr>
<tr>
<td>Cosine wind orientation</td>
<td>-0.10</td>
<td>0.38</td>
<td>-0.27</td>
<td>0.79</td>
</tr>
<tr>
<td>Time</td>
<td>-0.58</td>
<td>0.09</td>
<td>-6.35</td>
<td>≤0.001</td>
</tr>
<tr>
<td>Time $^2$</td>
<td>0.01</td>
<td>0.01</td>
<td>5.29</td>
<td>≤0.001</td>
</tr>
</tbody>
</table>

However, these results were not significant ($F_{2,30} = 2.2, P = 0.14$) and an adjusted $R^2$ of 0.03 (Table 2-5, Fig. 2-5).

The interaction term between wind speed and wind orientation was a significant predictor of the section where a predator was observed ($\chi^2 = 8.8, P = 0.01$). The max-rescaled $R^2$ for this model was 0.22 and the percent correctly classified was 72%. Section 3 was significantly different from section 1 ($\chi^2 = 4.96, P = 0.03$), while section 2 was marginally non-significant when compared to section 1, the reference level ($\chi^2 = 3.70, P = 0.054$). To test whether section 2 was different from section 3, I built a separate multinomial logistic model where section 2 was the reference level. Section 2 and 3 were significantly different ($\chi^2 = 6.72, P = 0.009$). For northern wind orientation (0°), predators were more likely to be seen on section 1 when wind speeds were low and on section 2 when wind speeds were high (Figure 2-6). When the wind was blowing from the east (90°), predators were more likely to be seen on section 1 across all wind speeds. At high wind speeds from the south (180°) and west (270°), predators were much more likely to be seen on section 1. However at low wind speeds the model broke down for
both orientations, as it predicts nonsensical probabilities >1 for section 2 and <0 for section 1. For all wind orientations, the probability of seeing a predator on section 3 was very close to 0. One exception was high wind speeds with wind orientation 0°, although there was never > 0.1 probability of observing a predator on section 3.

Figure 2-3. Number of olfactory predators observed (●) during nocturnal spotlighting over time (where one unit time represents one night spotlighting), average wind speed per night (m/s), and average wind orientation per night with 0° and 360° being north. Predicted values (▬) were obtained from a multiple linear regression of the number of predators observed per night on wind speed, wind orientation, and time. Data were collected at Willard Bay State Park and Reservoir, Utah, USA.
Table 2-3. Results from a multinomial logistic regression model that predicts whether a red fox, striped skunk, or raccoon (RAC) that would be observed given the wind speed and orientation. Skunks were arbitrarily assigned to the reference level. Data were collected during yearlong spotlighting surveys for predators at Willard Bay State Park and Reservoir, Utah, USA.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Species</th>
<th>$df$</th>
<th>Parameter estimates</th>
<th>SE</th>
<th>$\chi^2$</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>FOX</td>
<td>1</td>
<td>0.78</td>
<td>0.46</td>
<td>2.93</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>RAC</td>
<td>1</td>
<td>1.78</td>
<td>0.42</td>
<td>17.87</td>
<td>$\leq0.001$</td>
</tr>
<tr>
<td>Sine of wind orientation</td>
<td>FOX</td>
<td>1</td>
<td>-0.64</td>
<td>0.43</td>
<td>2.18</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>RAC</td>
<td>1</td>
<td>-0.46</td>
<td>0.41</td>
<td>1.29</td>
<td>0.26</td>
</tr>
<tr>
<td>Cosine of wind orientation</td>
<td>FOX</td>
<td>1</td>
<td>-0.43</td>
<td>0.38</td>
<td>1.26</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>RAC</td>
<td>1</td>
<td>-0.99</td>
<td>0.35</td>
<td>7.94</td>
<td>0.01</td>
</tr>
<tr>
<td>Average wind speed</td>
<td>FOX</td>
<td>1</td>
<td>-0.07</td>
<td>0.09</td>
<td>0.47</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>RAC</td>
<td>1</td>
<td>-0.19</td>
<td>0.09</td>
<td>4.24</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Table 2-4. Parameter estimates with standard error and chi-square statistics with associated $P$-values for binomial logistic regression model of the predator species observed as a function of wind speed and wind orientation. Data were collected during yearlong spotlighting surveys at Willard Bay State Park and Reservoir, Utah, USA. Three species of predators were observed: raccoon, fox, and skunk. Skunks and foxes were found not to differ ($P < 0.05$) in previous multinomial logistic analysis where response was raccoon, fox, or skunk. Therefore, the response for this analysis was reduced to two categories: raccoon and not raccoon (fox and skunk). Not raccoon was the reference category.

<table>
<thead>
<tr>
<th>Variable</th>
<th>$df$</th>
<th>Parameter estimates</th>
<th>SE</th>
<th>$\chi^2$</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1</td>
<td>0.63</td>
<td>0.30</td>
<td>4.32</td>
<td>0.04</td>
</tr>
<tr>
<td>Average wind speed</td>
<td>1</td>
<td>-0.16</td>
<td>0.08</td>
<td>4.29</td>
<td>0.04</td>
</tr>
<tr>
<td>Sine of wind orientation</td>
<td>1</td>
<td>-0.08</td>
<td>0.30</td>
<td>0.07</td>
<td>0.80</td>
</tr>
<tr>
<td>Cosine of wind orientation</td>
<td>1</td>
<td>-0.73</td>
<td>0.26</td>
<td>8.18</td>
<td>0.004</td>
</tr>
</tbody>
</table>
Figure 2-4. Results of binomial logistic regression model of the predator species observed as a function of wind speed and wind orientation. Data were collected during yearlong spotlighting surveys at Willard Bay State Park and Reservoir, Utah, USA. Three species of predators were observed: raccoon, fox, and skunk. Skunks and foxes were found not to differ ($P < 0.05$) in previous multinomial logistic analysis where response was raccoon, fox, or skunk. Therefore, the response for this analysis was reduced to 2 categories: raccoon and not raccoon (fox and skunk). The predicted probabilities shown are the probability of observing a raccoon (compared to fox or skunk) for wind speed and orientation ($0^\circ$ and $360^\circ$ are north).
Table 2-5. Parameter estimates with associated \( P \)-values for linear regression model of the distance perpendicular to the center of a dike where predators were observed as a function of wind speed. Data were collected during yearlong spotlighting surveys at Willard Bay State Park and Reservoir, Utah, USA.

<table>
<thead>
<tr>
<th>Variable</th>
<th>( df )</th>
<th>Parameter estimates</th>
<th>SE</th>
<th>( t )</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1</td>
<td>35.65</td>
<td>6.16</td>
<td>5.78</td>
<td>( \leq 0.001 )</td>
</tr>
<tr>
<td>Wind speed (m/s)</td>
<td>1</td>
<td>-2.42</td>
<td>1.63</td>
<td>1.63</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Figure 2-5. Perpendicular distance from the center of the dike for predators observed (●) during nighttime spotlighting under different wind speeds. Predicted values (––) were obtained from a linear regression of the number of predators observed per night on wind speed. Data were collected at Willard Bay State Park and Reservoir, Utah, USA.
Figure 2-6. Predicted probabilities of observing a predator calculated from a multinomial logistic regression where the section of dike (1, 2, or 3) a predator was observed was modeled as a function of wind orientation and wind speed. Predicted probabilities are shown across all wind speeds for four values of wind orientation: north (0°), east (90°), south (180°), and west (270°). Data were collected during yearlong spotlighting surveys at Willard Bay State Park and Reservoir, Utah, USA.

**DISCUSSION**

Raccoons were the most commonly observed predator on the dike. Several attributes of raccoon behavior and Willard Bay likely combined to draw raccoons to the area. Raccoons often forage along the edge of water bodies because they are adept at using their front paws to grasp items in shallow water such as mollusks, crayfish, and other invertebrates and will even catch fish (McClearn 1992). Raccoons are also well
known scavengers of human refuse (Huxoll et al. 1998). Fisherman and people walking on top of the dike leave a lot of refuse including human food items as well as fish gut piles (personal observation). It is likely that human sources of food make up a significant portion of the diet of local raccoons during the spring, summer, and fall. Raccoon use of water habitats and their likely use of human food sources was supported by the fact that 62% were observed either on the reservoir side of the dike or on top of the dike.

Foxes and skunks were less numerous than raccoons and did not differ in their use of terrain types. Both species were seen most often on the dry side where the terrain is more suited to their hunting methods than the riprap on the reservoir side. Skunks commonly employ a wide-searching foraging strategy (Crabtree 1989). Foxes also use a wide-searching strategy covering 8 to 13 km per night (Jędrzejewski and Jędrzejewski 1992). They typically avoid water (Sargeant et al. 1984) and prefer open habitats for foraging (Jędrzejewski and Jędrzejewski 1992).

With the data collected, I was unable to estimate how detection probability varied across species and terrain. My feeling is that the detection probability was the highest for foxes across all terrains, all predators off dike dry side, and all predators on top of the dike. Foxes were larger than skunks and raccoons and were easily visible in all terrain types. Their behavior also increased their visibility as they would often freeze and look at the spotlight before running. Raccoons tended to freeze and look at the spotlight as well, and their medium size made them easy spot on all terrain types except the bay side. On the reservoir side, the large rocks and crevices made it possible for raccoons to hide, and it is likely that there were more raccoons present there than I observed.
Time, wind speed, and wind orientation combined described 75% of the variation in the number of predators seen per night. From August 2008 to June 2009, the number of predators decreased with a small increase in July and August 2009. There was an outbreak of sarcoptic mange in the Salt Lake Valley during the course of the study (Ron Merrill, USDA/APHIS/Wildlife Services, personal communication). This could have resulted in the decrease in predators observed over the course of the study (Lindström et al. 1994). The small increase of predators in July and August is most likely attributed to juvenile predators born that same year beginning to forage for themselves. The highest numbers of predators per night were observed when the wind speeds were between 2 and 4 m/s. Few predators were observed at low and high wind speeds. Conover (2007) predicted that optimal foraging conditions for olfactory predators should occur at wind speeds between 1 and 3 m/s with conditions poor at lower and higher wind speeds. Odor plumes at low wind speeds remain localized and at high wind speeds are broken-up. Although the results of this study indicate a different range of optimal wind speed, the general trend, of an optimal range with decreased optimality above and below, is the same. For wind orientation, most predators were observed when winds were coming from the northwest. With this wind orientation air flowed perpendicular to sections 1 and 2 of the dike with the dry side of the dike on the windward side. This would give predators a large area to forage, the dry side of sections 1 and 2, without being effected by turbulence caused by the dike.

Wind speed and orientation were significant predictors of the probability of seeing a raccoon versus a skunk or fox. Overall, the number of predators observed in high
wind conditions declined, especially the probability of observing a raccoon. My model indicates that raccoons are the most sensitive to high wind speeds. Winds from the south increased the probability of observing a raccoon. This contradicted the model describing the combined number of predators observed each night, in that it indicated that most predators were observed when winds were coming from the northwest. These contradictions are likely the result of different responses to wind speed and orientation in foxes and skunks when compared to raccoons. However, poor fit of the predator species model must be taken into account. Only 10% of the variation in the response (raccoon, not raccoon) was explained by wind speed and orientation. Only 56% of the observations were correctly classified, which is not much better than chance with a binary response.

For olfactory predators at Willard Bay Reservoir, wind speed and wind orientation interact to influence the section where predators were observed. I hypothesized that the mechanism driving predator location in response to wind speed and orientation would be the orientation of the dike itself and the resulting turbulence pattern. Therefore, it is likely that at low wind speeds, orientation of either the dike or wind matters less than at high wind speeds. Section 1 is the most probable location to observe a predator at low wind speeds when the wind is blowing from the north and east. However, the model breaks down at low wind speeds for south and west winds, predicting probabilities $> 1$ and $< 0$ for sections 2 and 3. This is unsurprising given that the sample size is very small for these wind orientations. I concluded from these data that there likely is an interaction between wind speed and wind orientation (given the significance of the
term) effecting the section of dike where predators forage, but it is impossible to
determine the intricacies of the effect with this data set.

**MANAGEMENT IMPLICATIONS**

After accounting for time, wind speed and orientation were significant predictors
of the number of predators observed in a night of spotlighting. Overall this model
accounted for 75% of the variation in predator numbers. This indicates that wind speed
and wind orientation have a strong effect on predator foraging activity. Not only did the
levels of predator activity change with wind speed and orientation, but the location of
predator activity changed as well (manifested in the significance of wind speed and
orientation interaction in predicting what section a predator would be observed on).
These results indicate that olfactory meso-predators take into account wind speed and
orientation when determining if and where to forage.

**LITERATURE CITED**

Borgo, J. S. 2008. Effects of olfactory and visual predators on nest success and nest-site
selection of waterfowl in North Dakota. Dissertation, Utah State University,
Logan, USA.

Bowman, G. B., and L. D. Harris. 1980. Effect of spatial heterogeneity on ground-nest

Boca Raton, Florida, USA.


Schmidt, K. A. 1999. Foraging theory as a conceptual framework for studying nest
predation. Oikos 85:151–160.


CHAPTER 3
INFLUENCE OF LANDSCAPE AND WEATHER ON THE ABILITY OF
OLFACTORY MESO-PREDATORS TO LOCATE ARTIFICIAL NESTS

Abstract. Predation by olfactory meso-predators has a large impact on avian nest success, particularly in ground-nesting waterfowl. Olfactory predators rely on odors to locate their prey. Weather conditions (e.g., wind speed, humidity, and temperature, etc.), vegetation, and landscape features affect the dissipation rate of odors and, thus, could affect the foraging efficiency of olfactory predators. The objective of this study was to determine if weather, vegetation, or nest location relative to a large scale-surface feature, the Arthur V. Watkins Dike at Willard Bay Reservoir, Utah, affect the survival of artificial ground-nests in an area dominated by olfactory meso-predators. Five-hundred-nine nests were placed on 21 separate occasions spanning from 21 May 2009 to 18 August 2009. Nest survival models in program MARK were used to determine what covariates influenced artificial nest survival. I tested 10 variables associated with the artificial nests to determine which had an impact on nest survival. I found that section of the dike, time since study initiation, terrain type on the dike, and wind speed affected survival during both day and night. Vegetation height only affected survival during daylight hours. The results of this study also support past research on the formation of olfactory search images in that nest survival decreased over the summer, while predator populations remained constant.
INTRODUCTION

Olfactory meso-predators such as raccoons (*Procyon lotor*), red foxes (*Vulpes vulpes*), and striped skunks (*Mephitis mephitis*) primarily use their acute sense of smell to detect and locate prey (Conover 2007). Predation by olfactory predators has a large impact on avian nest success, particularly in ground-nesting waterfowl (Bailey 1971, Brua 1999, Schmidt 1999, Frey and Conover 2006). Livezey (1981) reported 80% predation loss of upland waterfowl nests at Horicon National Wildlife Refuge in Wisconsin, with virtually all losses attributable to striped skunks (*Mephitis mephitis*), raccoons (*Procyon lotor*), and red foxes (*Vulpes vulpes*).

After repeated exposure to a prey type, predators will form search images and become more efficient at detecting and locating prey (Nams 1991, Nams 1997, Gazit 2005). This gives predators an advantage over nesting birds in that they can respond behaviorally to where birds are nesting through the formation of search images, but birds cannot move their nests in response to increased predation pressure (Conover 2007). Instead, many birds rely on concealment to avoid nest predation. Studies investigating the environmental factors associated with nest success and nest selection have produced varied results. Most of these studies have focused on visual aspects of nest concealment (Clark and Nudds 1991, Mankin and Warner 1992, Brua 1999, Jimenez and Conover 2001). Brua (1999) measured visual cover of nests and concluded that although the leading cause of nest failure in ruddy ducks (*Oxyura jamaicensis*) is predation and that nest success remains unpredictable due to the wide suite of predators preying on duck nests. In spite of the prevalence of olfactory predators and their impact on nest success,
few studies have investigated the factors that would cause nests to be concealed from olfactory predators.

The olfactory concealment theory predicts that animals that have small or highly diluted odor plumes should be the most successful at avoiding predation by olfactory predators (Conover 2007). In a situation where prey is stationary and predators are traversing a landscape at random, a predator is less likely to come in contact with an odor plume that covers a smaller area rather than a larger area. If an odor plume is large but highly dilute a predator may come in contact with it and still fail to detect the prey’s presence. Therefore, environmental conditions that increase dissipation of an odor plume should be disadvantageous to foraging predators resulting in increased nest success. Wind speeds over approximately 3 m/s will cause air mixing and turbulence that will dilute an odor plume. Wind flowing at high speed over an isolated surface feature such as a dike creates areas of updrafts and turbulence on the leeward side of the feature as well (Conover 2007). Air that is very still may also be disadvantageous to olfactory predators because odor plumes will remain small decreasing the chance a predator will come into contact with it. Additionally, cool, humid conditions will allow scents to linger longer in the air, on the ground, and on vegetation. During hot and dry conditions, scents are vaporized and dispersed into the atmosphere much more readily (Gutzwiller 1990, Conover 2007). Therefore, I hypothesized that the most advantageous conditions for the predator should be cool, humid days with moderate air movement. Moderate air movement should lengthen the odor plume without breaking it up. Alternately, nest
survival should be the highest on warm, dry days with either no air movement or high wind speed.

The objective of this study was to test the hypothesis that weather or vegetation affect an olfactory predator’s foraging ability. I used the survival of artificial ground-nests in an area dominated by olfactory meso-predators to test this hypothesis. I assumed that a decreased survival of nests in response to a weather or vegetation factor was the result of augmented predator foraging ability in response to that same factor, or vice versa.

**METHODS**

**Study Area**

This study took place at Willard Bay State Park and Reservoir (hereafter Willard Bay) in Willard, Utah. The state park was bordered by Interstate 15 on its eastern edge and the Great Salt Lake on its western edge. Willard Bay was approximately 5 km south of the Bear River Migratory Bird Refuge at an elevation of 1,287 m. The Arthur V. Watkins dike at Willard Bay ran approximately 11 km and separates the freshwater of the reservoir from the Great Salt Lake (Fig. 2-1). The reservoir side of the dike itself extended 20 m and was lined with riprap. The riprap consisted of boulders 0.5 to 3.0 m in diameter. The dry side of the dike, opposite Willard Bay, also extended approximately 20 m, was earthen, and covered with vegetation. The dike was approximately 15-m high, 11-m wide at the top, and 40- to 50- m wide at the base. The road on top of the dike was approximately 10-m wide and ran the length of the dike. The swath of land between the dike and the Salt Lake varied from 70 to 135 m in width depending on the level of the
lake. A row of tamarisk (*Tamarix* spp.) was present at approximately 70 m from the dry side of the dike and ran intermittently along most of the dike.

The vegetation on the top and slope of the dike was dominated by cheat grass (*Bromus tectorum*), crested wheatgrass (*Agropyron cristatum*), and various bluegrass species (*Poa* spp.). The most common forbs on the dike were Dyer’s woad (*Isatis tinctoria*), flixweed (*Descurainia sophia*), red-stem filaree (*Erodium circutatum*), and bind weed (*Convolvulus arvensis*). At the base of the slope, there was a short section of riprap approximately 5 m in width followed by a patch of grasses and forbs intermixed with stands of common reed (*Phragmites australis*) of the same width that extended along the entire dike. Off dike on the dry side, there was a primitive dirt road approximately 30 to 40 m in width that fishermen use to access the dike. The most common forbs and grasses off dike were cheat grass, inland saltgrass (*Distichlis spicata*), rabbitfoot grass (*Polypogon monspeliensis*), poison hemlock (*Conium maculatum*), Dyer’s woad, pickleweed (*Salicornia virginica*), creeping spurge (*Chamaesyce serpens*), and knotweed (*Polygonum* spp.).

**Field Methods**

I placed artificial nests along the dike on 21 separate occasions spanning from 21 May 2009 to 18 August 2009. Nests were placed approximately twice per week during that time span. The nests consisted of a prey item and a timing device. The prey item was either a dead starling that was obtained from USDA/APHIS/Wildlife Services or a medium-sized white chicken egg which I dyed brown with generic black tea. I placed a cotton ball soaked with Cabela’s® Bird Dog Duck Scent next to each chicken egg to give
the nest scent similar to that provided by an incubating hen. A 118 ml bottle was used to soak 100 cotton balls. I alternated the nest prey item (i.e. egg or dead starling) over the 21

Figure 3-1. Overview of Willard Bay State Park and Reservoir, Utah, USA showing sections of the dike where I conducted predator spotlighting surveys. Cutout shows cross section of dike with terrain types: A) off dike dry side, B) slope of dike dry side, C) top of dike, and D) reservoir side.
occasions, but on each of the 21 occasions all prey items were the same. Timing devices of the design described in Borgo and Conover (2009) recorded the exact minute a depredation event occurred (Fig. 3-2). The timing devices were made-up of a travel alarm-clock housed in a plastic box and connected with wires to a treadle that held the prey item. When the prey item was removed from the treadle it connected the circuit from the clock to the battery and the clock started keeping time. By recording the time on the clock and the time when the nest was picked-up, it was possible to back-calculate when the nest was depredated. I set up nests before dusk hours and usually left them out for 24 hours. On some occasions, the exposure time was shorter, but it was never less than 14 hours and always extended over night.

Nests were placed on dike sections 1, 2, and 3 because all of these sections had similar vegetation of dike with similar vegetation. I divided the dike into sections based on which way it was oriented (Fig. 3-1). Section 1 was oriented southwest/northeast, while sections 2 and 3 were oriented north/south and east/west, respectively.

I recognized 4 terrain categories about the dike: slope of dike reservoir side (RD), top of dike (TD), slope of dike dry side (DD), and off dike dry side (ODD) (Fig. 3-1). I placed one nest per terrain category (i.e. RD, TD, DD, or ODD) per 1 km of dike length for a total of 24 nests on the dike per occasion. Nests were distributed among the 3 sections at equal densities of 4 nests per km to minimize the effect of density dependent nest depredation. This resulted in 12 nests on section 1 (3 km in length), 8 nests on section 2 (2 km), and 4 nests on section 3 (1 km).
I picked a starting distance for nest placement between 0.0 and 1.0 km on section 1 and 0.0 and 0.3 on sections 2 and 3 using a random numbers table. Nests were then randomly assigned a terrain category as well as a location within that terrain. For example, nests that fell in the top of the dike terrain I randomly assigned either left or right side of the road. The nests placed on either slope of the dike were randomly assigned a number 1 through 4 that corresponded to 0 – 5 m, 5 – 10 m, 10 – 15 m, and 15 – 20 m away from the side of the road on top. Nests off dike dry side I placed in 1 of 5 intervals of approximately 10 m each, excluding the access road.

![Image](image.png)

Figure 3-2. Infrared photo of raccoon (*Procyon lotor*) depredating an artificial nest consisting of a chicken egg, timing device, and cotton ball soaked with artificial duck scent. Inset is a diagram of the timing device described in Borgo and Conover (2009). Photo was taken July 2009 at Willard Bay State Park and Reservoir in Utah.
On each occasion, I randomly assigned 4 Cuddeback No Flash® motion-triggered infrared cameras to individual nests on the dike. These cameras were used to identify the predator species depredating nests. The cameras were attached to rebar stakes pounded into the ground and positioned approximately 1 m away from the nest where there was a clear view of the nest.

I measured a suite of vegetation characteristics at each nest. I visually estimated the percent ground surface area that was covered with grass, forb, shrub, bare ground or rock, and dead and down vegetation within a 0.5-m radius around the nest while standing directly over it. A cover board was used to measure the visual concealment of each nest in the 4 cardinal directions. The cover board dimensions were 10 x 10 cm with 100 squares. I placed the board in the nest so that it stood perpendicular to the ground. I then moved 1.5 m away from the board and counted the squares visible from a height of 1 m off the ground. The tallest vegetation within a 0.5-m radius of the nests was also measured using a 2-m measuring rod.

I randomly selected a non-depredated nest and a nest that had been depredated during the prior night within each section and paired them together for small scale wind measurements. I set up two CSAT3 3-D Sonic Anemometers (Campbell Scientific) directly over the 2 nests at a height of 0.5-m. Each ran for 30 min concurrently, recording the instantaneous wind velocities on an x, y, z axis every second. The x axis was aligned with magnetic north, and the y axis was aligned east-to-west. Values on the z axis correspond to vertical movements of air with a negative value being a downdraft and a positive value an updraft.
I used temperature, precipitation, humidity, wind speed, and wind orientation data downloaded from a Utah Department of Transportation weather station that was located < 3 km north of Willard Bay. The weather variables were recorded every 10 min for the entire study period.

**Data Analysis**

I used nest survival models in program MARK to determine which covariates influenced artificial nest survival. There were 3 types of covariates for each nest: location, vegetation, and weather. The location covariates referred to sections of dike (1, 2, or 3), terrain (RD, TD, DD, or ODD), and perpendicular distance from the middle of the dike. The vegetation covariates referred to ground cover, nest cover, and vegetation height. Shrubs were rare and were combined with forbs to reduce the number of parameters describing ground cover. Also, I averaged the 4 readings of nest cover together to obtain mean nest cover for each nest. The weather covariates included wind speed and direction, humidity, and temperature. These I averaged out to 1 hr intervals to simplify the model. In addition, I created a wind speed squared term (wind speed$^2$) to describe a potentially quadratic relationship between survival and wind speed that could occur if depredations were unlikely at high and very low wind speeds but maximized in the mid-range. The 2 types of prey items, eggs and starlings, were entered into the analysis as separate groups.

In most nest success survival studies, a nest is assumed to have been depredated half way between the time of the investigator’s last visit to the nest before it was depredated and the time of the investigator’s first visit afterwards. In this study, the nest
timers indicated the exact minute a nest was depredated. Although the timers would essentially allow for survival to be estimated every minute, a 1 hour time interval was used to simplify the model. Each hour of nest exposure constituted 1 time interval so that if the first set of nests were left out for 24 hours the next set of nests would begin on encounter occasion 25 and so on sequentially throughout the summer. I did this to determine if survival varied over the summer.

All 10 covariates, as well as a nest-type model (where nest-types were starlings or eggs) and 2 time models (where survival varied by day and hour of the day) were run individually and compared against the null model. In addition, models were built for the vegetation and weather covariates where survival varied by these covariates during daylight and nighttime encounter occasions, respectively. I ran these models because the vegetation covariates dealt with visual concealment and would be more likely to affect visual predators during the day. Similarly, the weather covariates would be more likely to affect olfactory predators at night. Any models that did not perform more than 2 AICc’s better than the null model I discarded. From the remaining models, I built more complex models (i.e. combining >1 covariate in a single model). I considered top models to be those that produced the lowest AICc values and were not more than 2 values different from each other (Burnham and Anderson 2004). I took this model selection approach to eliminate models that were truly poor while simultaneously retaining models that showed a small effect on survival.

In addition to the nest survival analysis in program MARK, I also compared depredation frequencies between nests located near the top or bottom of the dry side dike
slope to those located in the middle using a chi-square test. I did this to determine the effect a travel lane might have on nest depredations. Nest located near the top or bottom of the dry side dike slope would be in close proximity to travel lanes (i.e. the road on top of dike and the flat area at the base of the dike). I presumed that predators would prefer to travel in these lanes rather than on the slope of the dike. I used only those nests on the slope of the dike dry side for this analysis because this terrain is the only one with discrete travel lanes as most of the other terrain types were flat with little vegetation.

The paired wind-speed measurements were used to calculate 4 variables that described the micro-site conditions at each nest over the 30-min interval. Mean vertical wind velocity ($W$) was calculated as the average of the instantaneous wind speeds on the $z$ axis. Mean horizontal wind velocity ($U$) averaged the square root of $x^2 + y^2$. Turbulence ($T$) was the standard deviation of $U$. Turbulence intensity ($T/U$) was $T$ divided by $U$. Turbulence was an index of how much an odor plume would disperse over time, while turbulence intensity measured dispersal over distance (Conover et al. 2010). I used a paired $t$-test to compare variables between depredated and non-depredated nests ($\alpha = 0.05$). The variables $W$, $U$, and $T$ were log transformed to meet the assumption of normalcy.

**RESULTS**

Twenty depredation events were recorded by the motion triggered cameras. Of those, 10 were depredated by raccoons, 7 were red foxes, and 2 were striped skunks. I included for the analysis in program MARK only nests where vegetation and weather
data were collected and where there were no clock failures. This resulted in a sample size of 323 nests with 347 time intervals. There were 124 egg and 199 dead starling nests.

Only 4 simple models performed better than the null model. These were survival (S) during day and night as a function of dike section, day (time varying model), dike terrain, and wind speed\(^2\). Survival during daylight hours only varied with vegetation height (Table 3-1). Ground cover, nest cover, wind orientation, humidity, temperature, and hour of day models did not perform better than the null model. From the top models, I built 4 more complex models: S(section, day), S(section, day, terrain), S(section, day, terrain, wind speed\(^2\)), and S(section, day, terrain, wind speed\(^2\), vegetation height during daylight hours). Of these models, the last 2 models were the top models as defined above. Ultimately for parameter estimates, I chose to go with the most inclusive model. Although it was neither the most parsimonious nor the lowest AICc value, I chose this model because I am interested in the general trends of survival and not the specific parameter estimates.

Dike section and day had the strongest effect on survival with the narrowest confidence intervals as was indicated by the model results. Section 1 had the lowest survival followed by section 2, while section 3 was the highest (Table 3-2). Survival declined sharply with increasing number of days into the study (Fig. 3-4). Wind speed also had a pronounced effect.

Survival was maximized when wind speeds were between 4 and 5 m/s. Survival increased during daylight hours only with increasing vegetation height (Fig. 3-5). Nests on the reservoir side had the lowest survival probability followed by nests on top of the
dike. Survival on the slope of the dike dry side and off dike dry side was approximately equal and greater than the other 2 terrain types (Table 3-3).

Table 3-1. Model results table of competing models in program MARK estimating survival (S) of artificial nests in 2009 at Willard Bay State Park and Reservoir, Utah, USA. Artificial nests consisted of a timing device and either a chicken egg or dead starling.

<table>
<thead>
<tr>
<th>Model</th>
<th>AICc</th>
<th>Delta AICc</th>
<th>Number of Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>S(day, section, terrain, wind speed²)</td>
<td>1422.14</td>
<td>0.00</td>
<td>6</td>
</tr>
<tr>
<td>S(day, section, terrain, vegetation height during daylight hours, wind speed²)</td>
<td>1423.86</td>
<td>1.71</td>
<td>7</td>
</tr>
<tr>
<td>S(day, section, terrain)</td>
<td>1425.48</td>
<td>3.33</td>
<td>4</td>
</tr>
<tr>
<td>S(day, section)</td>
<td>1426.72</td>
<td>4.57</td>
<td>3</td>
</tr>
<tr>
<td>S(day, section, terrain, vegetation height during daylight hours)</td>
<td>1427.18</td>
<td>5.04</td>
<td>4</td>
</tr>
<tr>
<td>S(sec)</td>
<td>1443.16</td>
<td>21.01</td>
<td>2</td>
</tr>
<tr>
<td>S(day)</td>
<td>1454.30</td>
<td>32.15</td>
<td>2</td>
</tr>
<tr>
<td>S(terrain)</td>
<td>1463.63</td>
<td>41.48</td>
<td>2</td>
</tr>
<tr>
<td>S(wind speed²)</td>
<td>1467.73</td>
<td>45.58</td>
<td>3</td>
</tr>
<tr>
<td>S(vegetation height during daylight hours)</td>
<td>1469.09</td>
<td>46.94</td>
<td>2</td>
</tr>
<tr>
<td>S(.)</td>
<td>1470.36</td>
<td>48.21</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 3-2. Estimated hourly survival (S), standard error (SE), lower confidence interval (LCI), and upper confidence interval (UCI) for artificial nests on 3 sections of dike at Willard Bay State Park and Reservoir, Utah, USA in 2009. Artificial nests consisted of a timing device and either a chicken egg or dead starling.

<table>
<thead>
<tr>
<th>Section</th>
<th>S</th>
<th>SE</th>
<th>LCI</th>
<th>UCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.97</td>
<td>0.004</td>
<td>0.97</td>
<td>0.98</td>
</tr>
<tr>
<td>2</td>
<td>0.99</td>
<td>0.003</td>
<td>0.98</td>
<td>0.99</td>
</tr>
<tr>
<td>3</td>
<td>0.99</td>
<td>0.002</td>
<td>0.98</td>
<td>0.99</td>
</tr>
</tbody>
</table>
Figure 3-3. Estimated hourly survival over time, lower confidence interval (LCI), and upper confidence interval (UCI) for artificial nest at Willard Bay State Park and Reservoir, Utah, USA in 2009. Artificial nests consisted of a timing device and either a chicken egg or dead starling.

Figure 3-4. Estimated hourly survival probability during daylight hours as a function of vegetation height (m) for artificial nests at Willard Bay Reservoir, Utah, USA in 2009. Lower confidence interval (LCI) and upper confidence interval (UCI) also shown. Artificial nests consisted of a timing device and either a chicken egg or dead starling. Estimates were obtained using program MARK.
Figure 3-5. Estimated hourly survival probability as a function of wind speed for artificial nests at Willard Bay State Park and Reservoir, Utah, USA in 2009. Lower confidence interval (LCI) and upper confidence interval (UCI) also shown. Artificial nests consisted of a timing device and either a chicken egg or dead starling.

Table 3-3. Estimated survival for artificial nests on 4 terrain types about the dike in 2009 at Willard Bay Reservoir in Utah, USA. Artificial nests consisted of a timing device and either a chicken egg or dead starling. Lower confidence interval (LCI) and upper confidence interval (UCI) also shown.

<table>
<thead>
<tr>
<th>Terrain</th>
<th>S</th>
<th>SE</th>
<th>LCI</th>
<th>UCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir side</td>
<td>0.985</td>
<td>0.003</td>
<td>0.975</td>
<td>0.990</td>
</tr>
<tr>
<td>Top of dike</td>
<td>0.986</td>
<td>0.003</td>
<td>0.979</td>
<td>0.990</td>
</tr>
<tr>
<td>Slope of dike dry side</td>
<td>0.987</td>
<td>0.002</td>
<td>0.982</td>
<td>0.991</td>
</tr>
<tr>
<td>Off dike dry side</td>
<td>0.989</td>
<td>0.002</td>
<td>0.983</td>
<td>0.992</td>
</tr>
</tbody>
</table>

In addition to the top model, I also looked at the survival probabilities predicted by the individual models of the remaining weather predictors (humidity, temperature, and wind orientation) and the hour-of-the-day predictor. Temperature and humidity affect survival (Fig. 3-6). Wind orientation showed a small effect with survival maximized at
90° (wind from the east) and minimized at 270° (wind from the west). Survival did not change during a 24-hour day (Fig. 3-7).

Survival did not defer between nests near a travel lane when compared to those in the middle of the dry side dike slope \((n = 113, \chi^2 = 1.3, P = 0.29)\). Wind speed measurements were taken at 44 pairs of depredated and non-depredated nest sites. There was no difference between depredated and non-depredated sites for \(W, U, T, T/U\). In fact all were highly non-significant (Table 3-4).

**DISCUSSION**

I tested 10 variables associated with the artificial nests to determine which had an impact on nest survival. I found that vegetation height affected survival during daylight hours and dike section, time, dike terrain, and wind speed\(^2\) affected nest survival during day and night. Time, wind speed\(^2\), and section had the largest effects.

The nests were exposed to the same predator population over a relatively short period of time. Although it was not a closed population, there was no reason to suspect a large increase or decrease in the number of predators foraging in the area. Therefore, the precipitous decline in survival over the summer (i.e. day) could indicate that the predators were forming search images and consequently became more efficient at finding nests as time progressed. The ability of predators to form search images of prey is well documented in the literature. Nams (1997) showed that with repeated offerings of the same food type, skunks were able to increase the distance at which they detected the food. Gazit et al. (2005) found that trained dogs used to locate explosives will also form olfactory search images.
Figure 3-6. Estimated survival probability as a function of temperature, relative humidity, and wind orientation (0° = north) for artificial nests at Willard Bay State Park and Reservoir, Utah, USA in 2009. Artificial nests consisted of a timing device and either a chicken egg or dead starling.
Figure 3-7. Estimated survival probability as a function of hours of the day during a 24-hour period (with 0 and 24 hr both representing midnight) for artificial nests at Willard Bay State Park and Reservoir, Utah, USA in 2009. Artificial nests consisted of a timing device and either a chicken egg or dead starling. Estimates were obtained using program MARK.

Table 3-4. Wind speed measurements taken at 44 pairs of depredated and non-depredated artificial nests in 2009 at Willard Bay State Park and Reservoir in Utah, USA. A paired t-test was used to determine if depredated and non-depredated nests differed. Artificial nests consisted of a timing device and either a chicken egg or dead starling.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Non-Depredated</th>
<th>Depredated</th>
<th>t</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>x</td>
<td>SE</td>
<td>x</td>
<td>SE</td>
</tr>
<tr>
<td>Vertical Wind Velocity</td>
<td>0.10</td>
<td>0.03</td>
<td>0.12</td>
<td>0.04</td>
</tr>
<tr>
<td>Horizontal Wind Velocity</td>
<td>0.98</td>
<td>0.13</td>
<td>1.11</td>
<td>0.18</td>
</tr>
<tr>
<td>Turbulence</td>
<td>0.43</td>
<td>0.05</td>
<td>0.44</td>
<td>0.06</td>
</tr>
<tr>
<td>Turbulence Intensity</td>
<td>0.48</td>
<td>0.02</td>
<td>0.45</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Wind speed had a strong effect on survival, although the direction of the curve was counterintuitive. Survival was maximized between 4 and 5 m/s and declined with both increasing and decreasing wind speeds from the maxima. Conover (2007) identified
a range between 1 and 3 m/s as being optimal foraging conditions for olfactory predators. This range of wind speed is fast enough to elongate an odor plume but not fast enough to cause it to break up and dilute. If this is true, then I would expect survival to be minimized between 1 and 3 m/s and increase at both lower and higher wind speeds. I found the opposite shaped curve at a slightly higher wind speed. At low wind speeds survival was also low. Although Conover (2007) hypothesized that at low winds speeds (< 1m/s) odor plumes would remain small and thus make it more difficult for predators to detect, it is possible that even at undetectable wind speeds (for this study: <0.1 m/s) there is still enough air movement to elongate an odor plume. The relationship between survival and wind speed is harder to explain at very high wind speeds. However, I suspect that this response was influenced by the dike. A calm zone formed on the leeward side of the dike during the highest wind speeds, creating an environment with relatively little air movement (R. Dritz, personal observation). One caveat in interpreting this model at high wind speeds is that there were only 6 encounter occasions where wind speeds were greater than 8m/s.

With increased vegetation height, nest survival increased during daylight hours. Tall vegetation may have obscured the nest from visual predators hunting during the day, but did not deter olfactory predators at night. This is evidenced by the fact that the model where survival varied by vegetation for both day and night did not perform well. Vegetation height was found to be positively correlated with nest success at the Bear River Migratory Bird Refuge just a few kilometers north of Willard Bay (Crabtree et al. 1989).
Nest survival was the lowest in the 2 terrain types closest to the water, slope of
dike reservoir side and top of dike. Raccoons were the most frequently observed predator
on the dike and on the reservoir side (Chapter 2). Raccoons also foraged in family
groups. These factors could have contributed to lower nest survival on the reservoir side
for a couple of reasons. First, there were more predators searching for nests in a smaller
area compared to the area of the other 2 terrain types. Second, the raccoons in family
groups would not only have more search effort per group but would also presumably
search for longer periods of time to feed the whole group. Lastly by foraging is a group,
individual raccoons man be able to forage more efficiently in that they can space
themselves out so that an individual’s search area is less likely to overlap with that of
other individuals.

Differences in survival across the dike sections corresponded roughly to the
number of predators I observed (Chapter 2). Survival was slightly lower on section 1
where I observed the most predators. Although I would expect to observe more predators
on section 1 because it was the longest, the density of predators was also greater in that
section. My findings that those dike sections and terrains where nest survival was low
also had high predator densities indicate that the density of foraging predators impact the
probability that a nest will survive. Other studies have found that removal of predators
This suggests that nesting birds may be able to increase their nest success by nesting in
areas with low predator densities. However that can be difficult to achieve because meso-
predators are mobile and can quickly change their foraging sites in response to changes in food availability (Conover 2007).

The weather covariates – temperature and humidity – did not have an effect on either overall survival or nighttime survival. The nests were exposed to temperatures ranging from 11 to 37°C and humidity ranging from 10 to 75%. Temperature modeled for both day and night survival as well as strictly nighttime survival did not have an effect indicates that this range of temperatures, which are fairly typical for summer, do not affect olfactory predator foraging ability. It is possible that temperatures outside of this range would influence depredation. The nests were exposed to a wide range of the possible values for humidity. Therefore, I concluded that humidity does not affect olfactory predator foraging ability.

The wind-orientation model did not perform better than the null model and exhibited minimal differences in survival over different wind orientations. Although the confidence intervals overlapped, survival was lowest when the wind was blowing from the south and highest when the wind was blowing from the west. I hypothesized that wind orientation would affect nest survival because the dike should cause turbulence when high winds are blowing perpendicular to a section of it at a high rate of speed. Turbulence would not form under conditions of low wind speeds or wind flowing parallel to the dike. During most of my trials, the wind speeds were <3 m/s and wind orientation would be a non-factor because the air would not flow fast enough for the dike to cause turbulence. Therefore, it would not matter whether the wind was parallel or perpendicular to the dike.
There was no difference between depredated and non-depredated nests in their vertical wind speed, horizontal wind speed, turbulence, or turbulence intensity. These results could also be attributed to the lack of variation at nest sites within the study area. The time gap between depredation and wind measurements could have been another factor. The measurements at paired depredated and non-depredated nests were taken at the same time to insure that weather conditions were the same. However, wind orientation could be a confounding factor if at the time of measurement it was different from the time of depredation. For example, the wind might have been coming from the east at the time a nest was depredated and from the west at the time of measurement. Hence, a nest on the east side of dike could have been on the windward side when it was depredated and in the turbulent zone on the leeward side when measurements were taken.

MANAGEMENT IMPLICATIONS

The results of this study support past research on the formation of olfactory search images (Nams 1997, Gazit 2005) in that nest survival decreased over the summer. In addition, these results indicate that predators can form olfactory search images of 2 types of prey simultaneously (in this case duck scented chicken eggs and dead starlings), as the 2 prey types were alternated with each occasion. Predators maintained these images for 3-4 months with constant, but infrequent, exposure to the prey items.

Wind speed affected nest survival, although it was not the effect that I hypothesized. The fact that survival actually decreased at high wind speeds indicates that the dike was creating conditions favorable for foraging predators when wind speeds were
greatest. Turbulence can be caused by high wind speed or large isolated surface features. As such, a large open plain in windy areas may be more advantageous to ground nesting birds, than a landscape with large isolated surface features.

**LITERATURE CITED**


CHAPTER 4

CONCLUSION

After accounting for time, wind speed and wind orientation were significant predictors of the number of predators observed in a night of spotlighting. Overall this model accounted for 75% of the variation in predator number. This indicates that wind speed and orientation have a strong effect on predator foraging activity. Not only did the number of foraging predators change with wind speed and orientation, but the location of predator activity changed as well. An interaction between wind speed and orientation was a significant predictor of the dike section where predators were observed foraging. The olfactory predators observed also exhibited differences in foraging habits among the species. Raccoons foraged more frequently in areas near water compared to the other species. Foxes and skunks were similar in their use of terrain as well as their probability of being seen under certain wind speeds and orientations, and both were different from raccoons. These results indicate that olfactory meso-predators take into account wind speed and orientation when determining if and where to forage.

I tested 10 variables associated with the artificial nests to determine which had an impact on nest survival. I found that only vegetation height during daylight hours, dike section, time, dike terrain, and wind speed\(^2\) affected nest survival. Time, wind speed\(^2\), and section had the largest effects. Survival decreased over time, even though the predator population remained fairly constant. Therefore, the precipitous decline in survival over the summer (i.e. day) could indicate that the predators were forming search images and consequently became more efficient at finding nests as time progressed. Wind speed had
a strong effect on survival; however, the shape of the curve was surprising. I found that survival actually decreased at higher wind speeds. This could be due to a calm zone that formed on the leeward side of the dike during the highest wind speeds, creating a pocket of still air and likely good foraging. The sections with the highest number of predators exhibited the lowest survival rates. Many studies have documented the deleterious effect olfactory predators can have by depredating natural (Bailey 1971, Livezey 1981, Sargent et al. 1984, Brua 1999, Jimenez et al. 2007) and artificial ground nests (Hoi and Winkler 1994, Whelan et al. 1994, Clark and Wobeser 1997).

For both the artificial nest study and the predator spotlighting surveys, wind speed was an significant predictor of all indices of predator activity I measured. Wind speed influenced predators’ ability to find nests, how many predators were foraging, where they were foraging, and what species of predators were foraging. I concluded that wind speed affects not only an olfactory predator’s ability to find food items, but also predator foraging behavior.

LITERATURE CITED


