INFERENCES ABOUT THE CONSERVATION UTILITY OF USING UNMANNED AERIAL VEHICLES TO CONDUCT RAPID ASSESSMENTS FOR BASKING FRESHWATER TURTLES

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Submitted to the Faculty of the University of
Tennessee at Chattanooga in Partial
Fulfillment of the Requirements of the Degree
of Master of Science: Environmental Science

The University of Tennessee at Chattanooga
Chattanooga, Tennessee

August 2018

ABSTRACT

Unmanned aerial vehicles (UAVs), an emerging technology, show promise in ecological research. In this comparative study, I compare UAVs to a traditional sampling method, observations using spotting scopes. UAVs have yet to be used successfully for sampling freshwater turtles; however, they have been used with mixed success for monitoring mammals and birds. Herein, I propose that the conservation utility of UAVs be formally assessed in the field prior to them being used to make adaptive conservation and management decisions. I quantitatively and qualitatively evaluate the use of UAVs using a mixed methods approach in contrast to a proven field method as a means to elucidate our basic understanding of presence-absence. Being able to successfully use UAVs for ecological surveying would provide an easy, efficient, and less invasive way to study basking turtles.

DEDICATION

To my friends and family: Thank you for standing by me and supporting me through this entire process.

ACKNOWLEDGEMENTS

I am grateful for every person who has helped me with this project over the past two years. I would like to thank Dr. Wilson for his support, patience, and unwavering belief in me. Thank you to my committee members, Dr. Brad Reynolds and Mr. Andy Carroll; this would not have been possible without your support.

I would like to thank the entire Team Salamander crew, all of whom have become like a second family to me. A special thank you to Nyssa Hunt, Tegan Hendricks, Carissa Connor, and Holly Seiler. Your help with my field work and analysis has been invaluable. My family deserves a special thank you. My parents, Mark and Debbie Daniels, have been nothing but supportive and encouraging of me; and my brother, Matthew, has always been my main inspiration to be a scientist.

Lastly, I would like to thank the University of Tennessee at Chattanooga for funding my education while I worked on my thesis and UTC IGTLab for providing the UAV. All research was conducted in accordance with Tennessee Wildlife Resources Agency permit #3082 and the University of Tennessee at Chattanooga's Institutional Care and Use Committee.

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LIST OF ABBREVIATIONS

FAA, Federal Aviation Administration

LT5-M1, Long-Term Study Site 5 at Mullens Cove 1

LT5-M2, Long-Term Study Site 5 at Mullens Cove 2

LT5-M3, Long-Term Study Site 5 at Mullens Cove 3

RPV, Remotely Piloted Vehicle

TN, Tennessee

UAV, Unmanned Aerial Vehicle

CHAPTER I

INTRODUCTION

Development and Use of UAVs

The oldest form of aerial observation is most likely by balloon. In 1858, there were already aerial photos of Paris captured by Tournachon aboard a hot-air balloon (Colomina and Molina 2014). As time went on and camera technology advanced, more modes of aerial imagery were possible such as kites and rockets (Colomina and Molina 2014). In 1903, J. Neubroner proposed mounting cameras to the breasts of pigeons, the same year Orville Wright took flight. Soon after, the Bavarian Pigeon Corps began experiments with attaching cameras to their animals. A little over a decade later, the Army Signal Corps flew its first unmanned aircraft, the Kettering Bug flying bomb (Sullivan 2006). From this point on, most of the developments in unmanned aircraft technology have occurred through military efforts and eventually for recreational use. Initially created for military use, the first official unmanned aerial vehicles (UAVs) were in the form of missiles. Charles Kettering designed a gyroscope-controlled bomb for the Army Signal Corps, while Elmer and Lawrence Sperry designed them for the Navy. These missiles were meant to attack specific targets from a distance of up to 160km (~100 miles) away during World War I and World War II (Newcome 2004).

After losing interest in missiles and torpedoes, the military revisited radio-controlled aircraft in the 1930s to use as target drones. In 1938, the Navy began using UAVs for anti-aircraft gunnery practice and in 1944, the Army released Project Aphrodite, a B-17 with the armor removed and replaced with nine tons of explosives intended for destroying German missile facilities (Newcome 2004). World War II resulted in two different concepts of pilotless aircraft: 1) autonomous missiles that could be fired at an enemy at high speeds from far away, and 2) assault drones which had to stay in sight and were intended for surveillance (Sullivan 2006). Significant advances were made after World War II and into the 1980s. Specifically, drones were developed with features such as infrared-homing, anti-radar, and television and radar-guidance (Sullivan 2006). In the 1950s and 60s, unmanned aircraft were referred to as drones due to them being expendable, unlike piloted aircraft (Sullivan 2006). In 1951, the Firebee drone, a jet-powered and air-launched drone, were used as surveillance in hostile areas.

Until the introduction of the Firebee, drones were typically used as weapons and sent to an area to explode. In contrast, the Firebee was manually controlled by someone on the ground in order to collect the intelligence from targeted areas (Sullivan 2006). Because of this different use, the Firebees were referred to as remotely piloted vehicles (RPVs) instead of drones, so that the pilots controlling them could still be pilots, not drone operators (Newcome 2004). Unmanned aerial vehicles (UAVs) are technically synonymous with RPVs. UAVs are defined as reusable aircraft without a pilot onboard, switching the terminology from RPVs to UAVs in the 1960s denotes a move from direct piloting to semi-autonomous control (Sullivan 2006). Since then, the United States FAA has begun using the term unmanned aircraft system (UAS) (FAA 2018). In addition, the FAA labeled a small UAS as a sUAS (FAA 2018). The development of high-altitude long-endurance (HALE) UAVs began in the 1960s with the Global Hawk UAV in order to safely spy with high resolution (Newcome 2004). A recent advancement is the latest “smart” UAV, the Boeing X-45 unmanned combat air vehicle, one that can search territory, send information to the base, and receive command alterations (Sullivan 2006).

While most advances in UAV technology are by the military, UAVs have recently been used for a multitude of applications. In addition to being military products, UAVs are often used commercially with applications such as measuring aggregate stockpile volumes and topographic mapping and inspection (Whitehead et al. 2014, Jozkow, Toth, and Grejner-Brzezinska 2016). Another non-military use is feature detection. Examples of this are precision agriculture and detecting individual trees in a canpoy (Whitehead et al. 2014, Nevalainen et al. 2017). Within the fields of ecology and environmental science, UAVs are used for animal and wildlife monitoring as well as assessing landscape and habitat dynamics (Whitehead et al. 2014, Watts, Ambrosia, and Hinkley 2012).

Other Forms of Remote Sensing

While the main focus of this review is UAVs, there are other forms of remote sensing that preceded the UAV and are still widely used today. In the hierarchy of altitudes, satellites are at the top. Landsat was the first spacecraft deployed for terrestrial monitoring and is still the main platform today. The basis for Landsat came from the idea of using near-infrared wavelengths to photograph vegetation reflectance (Cohen and Goward 2004). During the 1950s, the United States trumped the Soviet Union by orbiting television cameras for gathering weather information (Cohen and Goward 2004). Proposed by William T. Pecora, the first Landsat satellite was launched into orbit in 1972 (Williams, Goward, and Arvldson 2006). Since then, one Landsat has been launched approximately every three years, through Landsat 5, when Landsat 6 was launched in 1993, it failed and Landsat 7 was not launched until 1999 (Cohen and Goward 2004).

While Landsat was the first program for spaceborne terrain imagery, there are now multiple programs using different sensors such as Terra, which has five satellites with a variety of sensors, and Aqua, which has six satellites (NASA 2017). In addition, popular platforms for ecology are IKONOS, OrbView3, and QuickBird (Loarie, Joppa, and Pimm 2007). A benefit of using satellite data is that they can map large areas at the same time (Matese et al. 2015). This allows for viewing of a large area and, depending on the size of the study site, only having to purchase a few frames. Some drawbacks are that satellites can deliver coarse resolution, be obstructed by cloud cover, and have a long revisit time (Matese et al. 2015). Resolution is improving with some satellites giving <5m resolution, but that is still coarse for studying wildlife and other ecological factors (Matese et al. 2015).

Below satellites are planes and helicopters. Six years after taking flight, Orville Wright brought a video camera aboard his plane and shot a motion picture (Colomina and Molina 2014, Times-Dispatch 1903). Since then, both the military and civilian organizations have shot aerial photos from manned aircraft. The basis for manned versus unmanned aircraft are essentially the same. Both have similar shapes and mechanics with differences just being in the location of the pilot and the size of the aircraft. Compared to satellites, plane routes are planned more flexibly than satellites (Matese et al. 2015). While most satellites are in a set orbit and move independently, it takes more active manpower and organization to run a plane campaign (Matese et al. 2015). Planes and helicopters are both manned and can hold the same sensors, but helicopters are much more maneuverable and can cruise in any direction as well as perform vertical takeoffs, hover over the targeted area, and fly closer to the ground (Sugiura, Noguchi, and Ishii 2005).

Next in the hierarchy after planes and helicopters are balloons. The use of a hot air balloon for aerial photography did not go away after its use in the late 1800s. Balloons continued to be used for decades after, but development slowed after the Hindenburg disaster in 1937 (Tozer and Grace 2001). Balloons and blimps are low-flying, slow, long-endurance aircraft that are useful for long term monitoring of an area (Klemas 2015) The advantages of balloons and blimps are that they are steady, vibration free, and blimps do not require fuel, just helium. A main advantage to balloons is that, unlike aircraft, they can hover over a site for long periods of time (Klemas 2015). There are a variety of different types of balloons such as the simple tethered balloon developed by Shaw et al. (2012) and the Helikite (helium balloon plus kite) design developed at the University of Delaware (Klemas 2015).

Finally, one of the lowest altitude platform for remote sensing is the UAV. Most UAVs used for ecological research are considered small, mini, micro, or nano UAVs (Anderson and Gaston 2013). While there are many types of UAVs, the main two categories are fixed wing or a rotor-based system. Fixed wing UAVs look similar to manned planes and are sometimes built as modified model airplanes. Launching typically depends on bungee propulsion and landing is a controlled glide onto the ground (Anderson and Gaston 2013). These types of UAVs need minimal experience to fly and have a relatively simple interface. In contrast, rotor-based UAVs are similar to helicopters and typically have four to eight propellers. Like helicopters, they can take off at any angle, maneuver easily, perform vertical takeoffs and landings, and fly close to the ground (Sugiura, Noguchi, and Ishii 2005). When comparing the two platforms, fixed-wing systems are larger and can travel faster and have a greater payload (Hardin and Jensen 2011). Rotor-based UAVs also experience less vibration than fixed-wing UAVs which increases photogrammetric applications (Wallace et al. 2011).

Ecological Uses for UAVs

UAVs for Wildlife Studies

UAVs have been used on a multitude of species, mostly terrestrial mammals, birds, and aquatic species (Vermeulen et al. 2013, Vas et al. 2015, Hodgson, Kelly, and Peel 2013). In order for UAVs to be effective for wildlife monitoring, surveying, or studying behavior, sensors must have a spatial resolution fine enough to differentiate between individuals or groups. Species that are typically studied with manned aircraft, like large mammals and aquatic animals, have the easiest transition to being studied with unmanned aircraft in terms of the detection levels and possible factors that would influence detection (Linchant et al. 2015). So far, most studies have been conducted on known populations or utilize known methods in order to check the accuracy of the UAV. Among those that have been surveyed this way are elephants (*Loxodonta africana*) (Vermeulen et al. 2013), white-tailed deer (*Odocoileus virginianus*) and roe deer (*Capreolus capreolus*) (Israel 2011, Kissell and Nimmo 2011), arctic seals (*Arctocephalus gazella*) (Goebel et al. 2015), koalas (*Phascolarctos cinereus*) (Gonzalez et al. 2016), black bears (*Ursus americanus*) (Ditmer et al. 2015), ungulates (*Cervus elaphus*, *Dama dama*, and *Sus scrofa*) (Barasona et al. 2014), chimpanzees (*Pan troglodytes*) (van Andel et al. 2015), and rhinos (*Ceratotherium simum*) (Mulero-Pázmány et al. 2014).

When studying terrestrial mammals, there are multiple types of research that can be conducted using UAVs. Mulero-Pazmany et al. (2013) used UAVs as an anti-poaching device. They were able to identify rhinos, people, and at lower flight height and specific hours of the day, they could even see fences. Mounted on the drone was a standard GoPro to take some of the images, but also a thermal video camera to help identify individuals. Like Mulero-Pazmany et al.

(2013), Israel (2011) used a thermal camera, but instead of trying to save species from poaching, he was rescuing roe deer fawns from lawnmowers. This study was different because instead of taking images to analyze at a later date, Israel was able to observe the video feed in real time, identify hotspots where fawns were present, and make an identification on the spot. He was then able to immediately send in a hunter to rescue the fawn. In addition to saving wildlife from human impact, UAVs have been used to conduct surveys. For example, van Andel et al. (2015) used UAVs to conduct aerial detection of chimpanzee nests. Using a logistic regression, they evaluated what factors influenced detectability of chimps in nests when using UAVs as a survey method. While they could only detect nests in areas with an open canopy, the method proved useful in difficult to access areas and species that are known to nest in canopy gaps.

Similar studies on animal response to UAVs have been conducted, but the majority focus on birds. Birds are a frequently aerial-surveyed group due to species with colonial behavior that aggregate for long periods of time, which makes them easier to count (Linchant et al. 2015). UAVs have been used on a variety of bird such as wading birds (decoys) (Abd-Elrahman, Pearlstine, and Percival 2005), species of geese (*Branta canadensis* and *Chen caerulescens*) (Chabot and Bird 2012), flamingos (*Phoenicopterus roseus*), mallards (*Anas platyrhynchos*), and common greenshanks (*Tringa nebularia*) (Vas et al. 2015), multiple species of gulls (*Larus canus* and *Chroicocephalus ridibundus*) (Grenzdörffer 2013, Sardà-Palomera et al. 2012), hooded crows (*Corcus cornix*) (Weissensteiner, Poelstra, and Wolf 2015), penguins (*Pygoscelis papua* and *Pygoscelis antarctica*) (Goebel et al. 2015, Ratcliffe et al. 2015) and multiple seabird taxa (*Fregata ariel, Thalasseus bergii,* and *Eudyptes schlegeli*) (Hodgson et al. 2016). Like terrestrial mammals, UAV studies can be applied to multiple research questions regarding birds and the utility of UAVs in general. When Weissensteiner et al. (2015) studied UAVs as a tool for learning about birds, they tested the method on crows. They assessed the nesting status of 24 hooded crow nests around a city in Sweden and they determined how monitoring crow nests continuously with a UAV is strikingly more efficient than climbing up to the nests due to a lower disturbance and a much faster and easier survey. When studying seabirds, Hodgson et al. (2016) compared unmanned aerial counts to more traditional ground-based approaches. They found that UAV-derived estimates of colony size resulted in a smaller cumulative variance than the ground-based approaches, also they found that UAV-derived counts are either significantly smaller or larger than the ground counts. Although they did not show UAVs to be very effective for this specific study, they determined that the more times the UAV sampling is duplicated, the more accurate the counts, up to +/- 5%. The lack of accuracy in surveying birds has also been investigated by developing pattern recognition algorithms (Abd-Elrahman, Pearlstine, and Percival 2005). Pattern recognition has been used in other aspects of ecology and is a popular topic in current research (Romero et al. 2018, Zaman, McKkee, and Jensen 2017).

In addition to terrestrial mammals and birds, aquatic species are commonly studied with UAVs. A few of the species that have been used to test UAVs are Kemp's ridley sea turtles (*Lepidochelys kempii*) (Bevan et al. 2015), dugongs (*Dugong dugon*) (Hodgson, Kelly, and Peel 2013), sharks (*Selachimorpha*) (Bryson and Williams 2015), chum salmon (*Oncorhynchus keta*) (Kudo et al. 2012), manatees and alligators (*Trichechus manatus latirostris* and *Alligator mississippiensis*) (Jones, Pearlstine, and Percival 2006), as well as freshwater turtles (*Emys orbicularis* and *Mauremys rivulata*) (Biserkov and Ludanov 2017). Bevin et al. (2015) were able to identify both adult and hatchling Kemp's ridley sea turtles within 50 meters of the shore. In a separate study, Jones et al. (2006) were able to easily identify manatee adults and calves as well as moderately sized alligators. In a more prominent study, Hodgson et al. (2013) found that dugongs could be detected and that UAVs actually remedied the issue of waves or rough waters affecting sighting rates like they do for boat or land surveys. Work has also been done to estimate the usefulness of UAVs with marine species. Studies have estimated the distribution of hidden objects to later be applied to manatees (Martin et al. 2012a) as well as a study using whale-like targets to estimate the UAVs ability to survey different whale species (Koski et al. 2009). Biserkov and Lukanov's 2017 study, the only one currently available on freshwater turtles, laid a basic groundwork for surveying pond areas with a UAV. They flew a few ~15-minute passes over their study sites and in total were able to identify 9 turtles. They did not analyze the data or draw statistical conclusions, but they did open the door for more research to be conducted on the topic.

While UAVs have been tested for usefulness for studying multiple species, studies are also used as a means to validate the UAVs utility and are used in studies to answer questions about the effect of the UAVs themselves. One of the most prominent issues when surveying wildlife is disturbance. Many researchers have studied UAV disturbance to wildlife to get the most accurate images or video possible with the least disturbance to the animal. Vas et al. (2015) approached three different species of birds, two wild and one captive, with UAVs and the results were consistent across species. While varying the speed and angle of the UAV, in 80% of the cases they could fly within four meters of the birds without visibly modifying behavior. While aerial surveys with UAVs have been shown to be a low disturbance method for some species, much is still unknown about the unseen effects of UAVs on wildlife (Vas et al. 2015). Ditmer et al. (2015) concluded that black bears (*Ursus americanus*), while not exhibiting a visible response, experience elevated heart rates in the presence of UAVs. Bears responded with increased heart rates in all of the flights they conducted. While most bears did not typically respond behaviorally, in one case, the physiological response was so great that it triggered a behavioral response causing a female bear to move into a neighboring female's home range, where it had never before been observed. Mulero-Pazmany et al. (2017) conducted an expansive review of literature and found that multiple factors come into play when an animal is in the presence of a UAV. First, the flight pattern matters. Target-oriented flights produce more reactions than other patterns and result in higher disturbance due to the fight or flight response seen in some species to a perceived predator (or shadow) coming toward them. Second, power source matters. Flight times vary according to the type of battery, what functions are being used (such as taking photos and videos or using GPS), and how strong the wind is. Fuel engines are louder than electric engines, which also contribute to disturbance. Finally, the animal's life-history stage and level of aggression influence their response. Breeding animals are less likely to flee, but can also react aggressively and territorial toward the UAV. In addition to factors of the UAV itself, Mulero-Pazmany et al. (2017) also found that species type matters. Birds are the most sensitive to UAVs, while aquatic animals, specifically marine mammals, are the least affected. While there is not much data on physiological disturbance yet, conducting an aerial study with the aforementioned factors in mind could at least minimize behavioral disturbance.

UAVs for Landscape Studies

The initial purpose of remote sensing was to have an aerial view of the Earth's terrain from a distance without disturbance. In addition to satellites and manned aircraft, UAVs can be extremely useful in the study of different terrains. Forestry is one field that has had great success using UAVs. Studies have been conducted on canopy gap patterns (Getzin, Nuske, and Wiegand 2014, Getzin, Wiegand, and Schöning 2012), the measuring of tree and canopy height (Lisein, Pierrot-Deseilligny, et al. 2013, Zarco-Tejada et al. 2014), tropical forest recovery (Zahawi et al. 2015), and forest categorization (Dunford et al. 2009). In 2012, Getzin et al. showed how they could use aerial images from a UAV to identify canopy gaps and assess floristic biodiversity of the forest understory. By using very high resolution images (7 cm/pixel) and spatially implicit information on gap shapes, they could show dependency between disturbance patterns and plant diversity. Zarco-Tejada et al. (2014) investigated on a finer scale by using UAV color infrared imagery for canopy height quantification. Generation of three-dimensional scenes to quantify single-tree heights was accomplished with a fully automatic method. Lisein et al. (2013a) also studied canopy height but instead of creating three-dimensional models, they used LiDAR-DTM in combination with UAV imagery. As previously mentioned, UAVs have also been used in forest categorization. Dunford et al. (2009) used UAVs to identify standing dead wood and to determine the best approach for classifying riparian vegetation. When mapping species, they tested both single image and mosaic approaches. Within the single image approach, the object-oriented method was more accurate than pixel based and the opposite was true when using a mosaic scale. In terms of dead wood identification, the object-based approach had a higher accuracy when using a pixel-based scale.

The study of rangeland ecology has used UAVs for many studies including those on how to make UAVs applicable to missions from agencies like the Bureau of Land Management (BLM), to assess vegetation cover in sagebrush ecosystems (Breckenridge et al. 2011), to design a UAV that can image rangelands at low altitudes (Hardin and Jackson 2005), assessing the current and future applications of UAVs for rangelands (Rango et al. 2006), using UAVs for rangeland monitoring (Laliberte et al. 2010), and assessing the bare ground measurements of rangelands (Breckenridge and Dakins 2011, Hodgson, Kelly, and Peel 2013). UAVs have also been used for wetland delineation (Zweig et al. 2015) and various other types of vegetation monitoring (Sugiura, Noguchi, and Ishii 2005, Flynn and Chapra 2014).

UAVs’ Place in the “Ecological Toolbox”

Ecologists have a variety of tools available to aid in answering research questions. Depending on the project, the tools could be electronic, like GPS units, radiotransmitters, and satellites, or manual tools like binoculars, compasses, and measuring tapes. As a means to collect data, UAVs have been used in a multitude of ecological studies, but are still a relatively new tool. In order to expand upon their capabilities and increase their usefulness, more comparative research needs to be done to determine accuracy and efficiency. There is a gap between data collected from the ground and manned aircraft or satellites, and UAVs have the potential to fill that gap (Chabot and Bird 2015). Aerial imagery provides researchers the advantage of viewing animals in open habitats at a higher resolution than could be achieved with satellites (Jones, Pearlstine, and Percival 2006).

As UAVs have been mostly used for species detection or surveys thus far, they are a good option to include when using multiple survey methods. The biggest advances in ecological methods are likely to result from studies that pool and synthesize information from multiple survey types (Elphick 2008). Many researchers that have compared multiple methods do not find that UAVs lack in accuracy at all or at an amount that would prove them to be ineffective when combined with other methods. UAVs are an important addition to the hierarchy of remote sensing. They add a micro prospective that is currently lacking from the macro dominated field of aerial imagery.

Regulations/Legality

In the United States, the Federal Aviation Administration (FAA) oversees all aircraft operations, manned and unmanned. The main concern about UAVs is safety, so the FAA has regulations and guidance on airspace restrictions, pilot requirements, equipment, and performance requirements (Watts, Ambrosia, and Hinkley 2012). While each state has different policies about UAVs, the FAA Small Unmanned Aircraft Rule (Part 107) applies nationwide (FAA 2016). There are many parts to the rule: operational limitations, remote pilot in command certification and responsibilities, aircraft requirements, and model aircraft. Operational limitations, the largest section, has 24 different restrictions such as unmanned aircraft must weigh less than 25kg (55 lbs.), visual line-of-sight only, daylight-only operation, maximum of 121.92 meters (400 feet) above ground level, no careless or reckless operations, no flight over non-participants or moving vehicles without waivers, and minimum weather visibility of three miles from the control station.

In Tennessee, there are regulations in Tennessee Code § 39-13-902, lawful capture of images. Of the 21 situations where it is lawful to capture an image with a UAV, the first section is what applies to most ecological research, it states that images may be taken "For purposes of professional or scholarly research and development by a person acting on behalf of an institution of higher education." This includes a person who is "(a) a professor, employee, or student of the institution; or (b) is under contract with or otherwise acting under the direction on or behalf of the institution." Similar regulations are also stated in Tennessee Code § 1720-01-02-.03 which also goes into detail about No-Trespass notices. A No-Trespass Notice is a written directive requiring a non-affiliated person to leave; this also applies to University property. A law enforcement officer employed by a university may issue a No-Trespass Notice to a non-affiliated person: who is not authorized to use University property, who has engaged in a use of University property that is prohibited, and who poses an unreasonable threat. In addition to rules on who can take images and where they can be taken, there are sections on the unlawful capture of images, anything not designated as lawful in Tennessee Code § 39-13-902, possession or distribution and use of unlawfully captured images, use of unlawfully captured images as evidence, violations, and injunctions. The aforementioned rules and regulations, along with others, apply only to the state of Tennessee. Other states have their own code about how UAVs may be used, which may be similar or different to those in Tennessee. Of Chattanooga's surrounding states (Georgia and Alabama), Tennessee laws are the easiest to find and the most accessible. Tennessee also has the most explicit language allowing researchers at Universities to use UAVs. Researchers should check with their local state Code to determine the legality of their use of UAVs.

CHAPTER II

ASSESSING THE EFFICACY OF USING DRONES TO STUDY THE BASKING ECOLOGY OF RIVER TURTLES

Introduction

Turtle Conservation Status

According to the International Union for Conservation of Nature and Natural Resources (IUCN), there are 87 different species of turtle around the world that are listed as endangered or critically endangered (iucnredlist.org). The IUCN also has a Turtle and Tortoise Freshwater Turtle Specialist group that puts together a list of the world's 25+ most endangered tortoises and freshwater turtles. On that list, five of the top 50 endangered turtle species are from the United States (Turtle Conservancy Coalition 2018). The Southeastern United States is an important region for turtle conservation. One reason for this is that it is within close proximity of one of the world's designated biodiversity hotspots and specifically for turtles, it is within the Southeast USA Turtle Priority Area. In the Southeast alone, there are 42 different species and 62 total taxa of turtles which is ~80% of all turtle species and 75% of all turtle taxa in the U.S. (Mittermeier et al. 2015). The decline of turtle species worldwide in concert with the amount of turtle diversity specifically in the Southeastern U.S. makes East Tennessee an important area for furthering research efforts for turtle biology and conservation.

Basking Ecology

Aquatic freshwater turtles are often seen basking in the sun on various objects, or at the surface of the water, in ponds or rivers. Being that they are ectotherms, these turtles primarily bask in order to elevate their body temperature (Ben-Ezra, Bulte, and Blouin-Demers 2008, Wilbur 1975). Some of the benefits of an elevated body temperature are improved locomotor performance and an increase in metabolic rate, resulting in more efficient digestion (Hammond, Spotila, and Standors 1988, Kepenis and McManus 1974). Turtles typically bask during the warmer months of the year with high rates of basking events in late spring and through the summer, with a decrease in events when the winter begins (Grayson and Dorcas 2004). This common basking behavior allows researchers to easily survey freshwater turtles because it results in them staying out in the open and out of the water for extended periods of time.

Common Methods

There are numerous methods that scientists can use to survey for turtles (Vogt 1980). Some commonly used methods are nets, hand capture, spotting scopes, and basking traps (Vogt 1980). A few problems with traditional field methods is their effectiveness in terms of achieving accurate population estimates, sex ratios, the overall diversity of species, and high detection probability. Of those methods, spotting scopes and basking traps are the most commonly used to measure species diversity and richness.

Spotting scopes are small, portable telescopes that provide a hands-off approach to surveying species from afar (Pearson and Kazilek 2007). A benefit of this method is that turtles can be observed without being alerted of, or startled by, the observer’s presence. This method of surveying, while effective, is very time consuming and has environmental constraints such as inclement weather, flooding, and natural barriers in the landscape. As with most survey methods, spotting scopes also have a learning curve. Individuals need to be identified and possibly sexed immediately while looking through the scope (Weber and Layzer 2011). There is no opportunity to look back at images or actually handle the animal unless a camera is attached or photos are taken through the lens.

Basking traps, in contrast, are devices that use known basking behavior to attract turtles to an artificial basking structure and into a trap. Most traps include a basking platform outfitted with some type of buoyant material (such as styrofoam) and a basket underneath to catch the turtles as they try to enter or leave the platform (Gamble 2006). Basking traps are useful for determining species diversity because if a species of basking turtle is in the area, it will likely be accounted for using the traps. The downfall is that factors such as the size of the individual and the possibility of turtles being negatively or positively conditioned to the trap can lead to skewed sex ratios or abundance estimates (Dodd 2016, Thomas, Vogrin, and Altig 1999).

Unmanned Aerial Vehicles

A new survey method among scientists is using unmanned aerial vehicles, commonly referred to as UAVs. The earliest aerial images were captured using balloons and kits in the 1800s (Rango et al. 2006). From there, UAVs were developed alongside piloted aircrafts in the early 1900s (Rango et al. 2006). Initially developed for military use, the first UAVs were large, fixed winged devices used as guided weapons in World War II and while these types of vehicles are still used, they were precursors to the small, lightweight devices seen today (Hardin and Jensen 2011, Lisein, Linchant, et al. 2013). While this technology is useful for a myriad of things, there are still limitations that need to be addressed.

UAVs have platform, sensor, operating, and environmental constraints (Anderson and Gaston 2013). While commercial grade UAVs are robust enough to avoid this problem, most lower level, amateur UAVs have a restricted payload capacity, which in turn restricts use to only simple sensors. The lightness of the vehicles also affects the ability to pilot and operate and environmentally, there is danger in high winds and canopy cover situations (Anderson and Gaston 2013).

In environmental research, UAVs can be used for many fields. Work has been done using them for assessing overall vegetation cover (Breckenridge et al. 2011), surveying for specific habitat (Chabot, Carignan, and Bird 2014), and even remote sensing of submerged aquatic vegetation (Flynn and Chapra 2014). When it comes to animals, UAVs have been mostly used for studying bears (Ditmer et al. 2015), ungulates (Barasona et al. 2014, Kissell and Nimmo 2011) and birds (Groom et al. 2011). Recently, the use of UAVs has expanded and has been used in a multitude of studies ranging from measuring killer whales (Durban et al. 2015) to locating chimpanzee nests (van Andel et al. 2015). In terms of smaller species, while UAVs may not be able to detect small insect species as well, they have been used in concert with field surveys to evaluate microhabitats for butterfly larvae (Habel et al. 2016). It has been shown in these and many other studies that UAVs are more precise and exhibit less variance in results than ground techniques (Hodgson et al. 2016). In terms of reptiles, having only used this technology for marine turtles and crocodilians (Bevan et al. 2015, Martin et al. 2012b) and never for freshwater turtles, further research needs to be done to determine utility. If the data can be used to accurately identify basking turtles, UAVs could be more effective than spotting scopes. In addition, knowing the costs and benefits of both methods of sampling will determine if the UAVs are a viable and realistic option for turtle research.

Objectives

The main objectives of this project are to determine if UAVs are effective for wildlife conservation and if they are suited for surveying freshwater turtles. More specifically are the questions of how UAVs compare to spotting scopes in terms of making base level identifications and determining presence-absence and species diversity as well as if they are effective in pond and riverine habitats in the area.

Hypotheses

Are unmanned aerial vehicles suited for surveying freshwater turtles?

1. Do UAVs have greater than or comparable success when compared to spotting scopes?
    a. Can UAVs be used as a conservation tool to determine presence-absence and species diversity?
        1. Are UAVs useful in a pond environment?
        2. Are UAVs useful in a riverine environment?

Methods

Study Organisms

There are a total of nine aquatic turtle species in the Chattanooga, TN area (Manis 2008). Of these nine species, *Apalone spinifera* (spiny softshell turtle) and *Kinosternon subrubrum* (Eastern mud turtle) are not typically found in ponds and *Chelydra serpentina* (common snapping turtle) and *Sternotherus odoratus* (common musk turtle) are not typical basking turtles (Ernst and Lovich 2009). The remaining basking turtles that are likely to be seen on UAV footage are turtles in the Emydidae family such as *Chrysemys picta* (painted turtle), *Trachemys scripta* (common slider), *Pseudemys concinna* (river cooter), and both *Graptemys ouachatensis*

(Ouachita map turtle) and *G. geographica* (common map turtle). Emydid turtles can be distinguished by their large plastron, wide bridge between their carapace and plastron, and their adapted limbs with toe webbing for swimming (Ernst and Lovich 2009).

Study Areas

Before moving forward with the project, a beta phase was conducted to determine if the UAV could recognize turtles and be reliable enough to use in the full study. The study area for the beta phase was an area of land at Greenway Farms in Hixson, TN (35.124966, -85.217999) (North Chickamauga Creek Conservancy 2015). The property is a 72.84-hectare city park managed by the City of Chattanooga along the North Chickamauga Creek (Figure 1). There are multiple trails and paths as well as a dog park and facilities for various outdoor activities. Upon entering the park, there is a large grassy field with no canopy cover and plenty of space to test the UAV. The field is about four hectares and includes a few small patches of trees, a small building, and an area of gardening plots. The majority of the field is open and used for recreation.

The study area for the pond phase was at the Reflection Riding Arboretum and Nature Center in Chattanooga, TN (35.007932, -85.366150) (Reflection Riding Arboretum and Nature Center 2018). The property is a 128-hectare nature center that runs along Lookout Creek and includes a visitor center, outdoor activity facilities, animal enrichment areas, greenhouses, stables, and many trails around the park (Figure 2). The natural area includes two ~0.4 hectare ponds that are roughly 70 meters apart and the lower pond is ~80 meters from Lookout Creek. Lookout Creek begins on the south side of the Tennessee River, just west of downtown Chattanooga. The creek runs for ~4 kilometers before it passes the Nature Center.

The study area for the river phase was along the Tennessee River Gorge (Figure 3) (Tennessee River Gorge Trust 2018). All three sites were located off of Mullens Cove Road/River Canyon Road. The most Westward site, labeled LT5-M1 (35.050119, -85.476992), was on a small cove-like area with multiple snags as possible basking structures. The middle site, LT5-M1 (35.061946, -85.417230), was about 10 kilometers (6.21 miles) East of LT5-M1. It was an open beach-like areas directly on the river with snags that could be seen along the banks. The farthest East site, LT5-M3 (35.071181, -85.392177), was about 2.5 kilometers (1.6 miles) from LT5-M2 and was the same type of environment.

Data Collection

Beta Phase

To test the hypothesis that UAVs are comparable to spotting scopes, a beta test was initially conducted to ensure the visibility of basking turtles using a UAV. Using what museum specimens were available and similar to the species present in the pond and river sites (*C. serpentina, T. scripta, C. picta, A. spinifera, P. concinna,,* and *G. geographica*) from the University of Tennessee at Chattanooga, individuals were placed on different colored sheets of paper (e.g., blue, green, and black) to emulate the background environment that may be observed in UAV footage. UAV photos were taken using a DJI Mavic Pro to assess whether the turtles were likely to be distinct enough from their basking environment to be detected on the images. Once detectability was ensured, the project moved on to the pond and river phases.

Pond Phase

Two small ponds were used that were approximately 61m apart at the Reflection Riding Arboretum and Nature Center with a total of ~600 meters of banks. Both sampling methods were deployed at each pond. In addition, four 78.74x55.88x55.88cm Sure-Ketch Turtle Traps (Memphis Net and Twine, stock number: SURKTH) basking traps were placed along the banks of the upper pond and five traps on the banks of the lower pond. The purpose of the basking traps was to assess what species were present in the ponds and use that information when determining the usefulness of the other methods. The ponds were sampled with a spotting scope and a UAV for a total of 24 times over the sampling period. Due to technical difficulties such as the memory card not saving files and photos being extremely blurry, only seven of the drone passes were complete for the study and therefore only the corresponding spotting scope data was tested against it. Basking traps were checked every weekday of the sampling period to ensure the wellbeing of any organism caught and traps were closed during the weekends. Each time the traps were checked, the measurements and sex of each turtle were documented before release. To assess spotting scopes, a Leica Televid 62 Straight View Spotting Scope with a Leica Televid 62/77 20-60x Zoom Spotting Scope Eyepiece was used to count basking and swimming individuals. Due to irregular shaped ponds and vegetation around the banks, the spotting scope surveys were conducted from multiple vantage points and the vantage point where the most turtles observed was used in data analysis. Spotting scope surveys were taken at each site that had a basking trap for a total of four sites in the upper pond and five in the lower pond.. Each sampling day consisted of counting and recording the number of individuals and identifying species. Finally, using a DJI Mavic Pro, a route was programmed on the Pix4D app and the UAV was deployed on that route for each pass over the ponds. During each pass, the UAV took images over the entirety of both ponds. After collecting the data, the images were manually analyzed to tally individuals. The lack of basking structures in the pond resulted in the majority of the turtles completely submerged except for their heads. While they could be seen and counted on the UAV images, positive identifications were not possible. Identifications were only able to be inferred by the data collected with the spotting scope and basking traps.

River Phase

In this phase, sampling was performed using the same spotting scope and UAV as the pond phase, except in the Tennessee River. Due to preexisting diversity data for the Tennessee River Gorge, basking traps were not necessary to identify potential species present in the river phase. Three sites were chosen along the banks of the Tennessee River Gorge off of Mullens Cove/River Canyon Road. Spotting scope surveys, two hours each, and UAV surveys, roughly five minutes each, were performed at each location but unlike in the pond phase, the UAV was set to take video footage instead of transect images due to the increased canopy cover. Each video was reviewed and individuals were manually counted. Making positive species identifications using the UAV was not consistently possible, partly due to the fact that as the UAV approached, turtles tended to flee from their basking structures. Since the UAV could only come within a certain distance (typically, between four and 10 meters) of the individuals before they fled, the video quality was not high enough to distinguish the diagnostic characters for specific species. To conduct statistical tests, count data from the first 10 minutes of all of the spotting scope surveys was compared to the total number of individuals counted with the UAV.

Data Organization and Statistical Analysis

All data was compiled into Microsoft Excel for each phase of the project. For the comparison of the UAV with the spotting scope, a test for normality was conducted on both the pond and river data sets using a Kolmogorov-Smirnov test with a Lilliefors Significance Correction (Mendes and Pala 2003). For both phases, a chi-square analysis was used to compare the data from the two methods. The chi-square analysis was chosen due to the data being classified as non-normal. The expected values for the ponds were assumed to be the same due to the semi-closed environment. Expected values for the river sites were calculated using the observed data and were relative to each site and each method. Chi-square was used because the data are nonparametric and the sample sizes were unequal among groups. The issue of normality is not assumed in a chi-square analysis, the assumptions of the test are as follows: (1) the data are frequencies, (2) the categories are mutually exclusive, (3) the subject contributes to only one cell in the chi-square, (4) the study groups are independent, (5) there are two variables measured as categories, and (6) at value of least 80% of the cells exceed a frequency of five, all of which were met by the data (McHugh 2013). Analyses were run using IBM SPSS 24 statistical program, a standard chi-square procedure was used in both phases to compare overall data for each method. In addition to the chi-square analysis, a Morisita's index was calculated using Ecological Methodology Volume 2 software, version 7.2 (Krebs 1999), to determine a metric of similarity by counts across methods, as well as sites, for each data set. Morisita's index was chosen due to its use as a similarity index specifically for counts of individuals (Dodd 2016).

Results

Beta Phase

Of the six species used, all were identifiable from three and five meters. Identifications were easiest when the specimens were placed on lighter color papers (green and blue) due to higher contrast. Comparatively, when specimens were placed on darker colors (black), there was lower contrast, which led to more challenging identifications. Images taken from 10 and 30 meter elevations were not reliably identifiable (Figures 7-9).

Pond Phase

A total of 141 turtles were observed over the seven sampling events using both methods (Figure 10). The spotting scope surveys detected the presence of 63 individuals and the UAV surveys detected 78. Each sampling day was different in terms of weather, cloud cover, and wind intensity, the individual results are shown in Table 1. When tested for normality, the test statistics for the pond surveys were 0.841 for spotting scopes and 0.006 for UAVs. All of the data except for the UAV pond data had a p-value less than the predetermined alpha value of 0.05 but the UAV pond data had a p-value greater than 0.05 which would classify it as normal. Due to the Q-Q plot generated in SPSS, the data was determined to likely be non-normal, so with all of the data being non-normal, a chi-square test was appropriate. With all assumptions of the test being met, the chi-square statistic for the ponds were 1.596 with a p-value of 0.207. The Morisita-Horn Coefficient was calculated for both ponds and methods resulting in the two ponds being 94% similar and the two methods being 90% similar (Tables 6 and 7).

River Phase

A total of 559 turtles were seen over 27 spotting scope surveys and 26 UAV surveys (Figures 11-13). Comparatively, 498 turtles were counted using the spotting scope and 61 were counted using the UAV (Table 2). After calculating normality for the river surveys, the spotting scope and UAV values both had a p-value of less than 0.0001, resulting in a failure to reject the null hypothesis and classification as normally distributed. While the p-value suggests that the data is normal, the Q-Q plots clearly display the data as not normal and it was subsequently treated as such. With all assumptions of the test being met, the chi-square statistic for the river was 1.309 with a p-value of 0.253, therefore there was no significant difference between the data for the spotting scope and the UAV. The Morisita-Horn Coefficient was calculated for both sites and methods resulting in the sites being between 66% and 100% similar and the methods were 72% similar (Tables 4 and 5)

Comparison across Various Specifications for Common UAVs and Scopes

The visual results from both methods had varying degrees of quality which effected the reliability of the method for identification of individual turtles. Because of this, further research into other popular models of UAVs and spotting scopes was conducted. In this analysis, certain specifications were selected for each method. For UAVs, the fields included pixels per column (4K being 4000 pixels) and frames per second, megapixels, fly time, payload, and price. For spotting scopes, the fields included the objective lens size, magnification, field of view, and price.

Discussion

The results suggest that the use of UAVs in both a pond and river setting was not significantly different than the use of spotting scopes; this results in the null hypothesis being rejected in both landscape scenarios. This is supported further by the results of the Morisita-Horn index, suggesting that the sites and methods in both scenarios were 72% similar and higher.

With the main objective of this project being to determine if UAVs are effective for wildlife conservation and if they are suited for surveying freshwater turtles, the project was successful. Through this research, it was determined that in multiple aquatic environments, UAVs are equally effective as spotting scopes for surveying freshwater turtles and that in general, the method is effective for wildlife conservation. The more specific questions of making identifications was shown to be difficult with the quality of UAV available. This can be improved in future studies by using UAVs with better quality cameras, a range of costs and resolutions are available. Due to the lack of reliable identifications it was difficult to consistently determine species diversity. The spotting scope was able to be used for species identification but compared to the UAV used, the spotting scope was more expensive and higher quality. The proposed hypothesis that UAVs have greater than or equal success as spotting scopes was not rejected for either phases of the project. UAVs were shown to be useful in both pond and riverine environments at determining occupancy data of freshwater turtles.

Due to the novelty of this project and the differences in environments and effort for each method, a qualitative assessment can be as significant as a quantitative assessment. During the beta phase, museum specimens were muted in color and pattern as well as varying in size. This was useful to determine a baseline effectiveness of the UAV; turtles in the ponds were mostly in the water so the contrast was similar to the museum specimens on blue and black paper.

Alternatively, turtles in the river had better contrast from their basking structures and had slightly more detail. In the pond phase, there were very few basking structures. Though the ponds were treated as one site due to them being statistically similar, one of the ponds had no basking structures whatsoever. The site was selected based on it being a small, relatively closed, and safe environment to test the method as well as the observer's skill using it. Canopy-cover was not an issue which allowed for a preprogrammed overhead transect for each sampling event. This resulted in images of turtles that were swimming or basking at the surface and few that were basking on structures. The pond's lack of basking structures eliminated the issue of individuals fleeing from basking structures, as they were all at least partially submerged in the water. While in the water, turtles showed no sign of being startled or concerned with the presence of the UAV. The spotting scope surveys gave similar results because only turtles whose heads were out of the water while they were swimming were counted; barely any were caught basking.

In the river setting, the environment was very open. The canopy-cover near the snags that were surveyed prevented a preprogrammed flight and a true overhead view of the area. Instead, the video recordings were attempted to get as good of a view of the snags and basking individuals as possible. In this scenario, the possibility that the same turtles seen with the spotting scope are seen with the UAV are much lower than in the ponds. Both methods only surveyed individuals that were on basking structures and they were able to flee when startled by the UAV approaching.

Since both methods were used for different amounts of time, an effort bias was introduced. There was much less of a bias for the pond scenario, this was addressed by suggesting that the flights that were roughly five minutes each, paired with about five minutes to count turtles in the images post flight. This is a similar amount of effort as sitting with the spotting scope and recording individuals for 10 minutes. For the river, the effort bias was much larger. In the initial stages of the project, it was decided that it would be useful to compare the methods in their most standard use. A common method for spotting scope surveys was used and consists of sitting and documenting turtles for two hours, but this varies greatly from the flights with the UAV that were only about five minutes for capturing data (Lindeman 2014, 2000, Lindeman 1999a, Lindeman 1999b, Coleman and Gutberlet 2008, Dodd 2016). To account for this difference, number of turtles seen per minute was calculated for each method and applied to a 10-minute interval. This length of time was chosen because it is a reasonable amount of time for both methods to complete a rapid assessment of an area (Dodd 2016). Extrapolating the data in this way resulted in the UAV counting significantly more turtles than spotting scopes and a rejection of the null hypothesis. Unfortunately, this proved to not be the best way to reduce bias in the data and it was determined that it would be more accurate to use the count data from the first 10 minutes of the spotting scope surveys; that way the raw data was able to be directly compared without alteration. This is the method that lead to the null hypothesis not being rejected.

The feasibility of using UAVs to study basking turtles may depend solely on what equipment is available. In this project, the DJI Mavic Pro was able to determine occupancy but not reliably deliver species identifications or gender. The DJI Mavic Pro used in this study had a 12-megapixel camera, so a UAV with a higher resolution camera may be more well suited to determine identifications and sex of individuals. Unfortunately, the higher resolution cameras are costlier, and lower cost UAVs without an attached camera still have a payload limitation and can only operate with a certain amount of weight added, hindering the types of cameras able to be attached. If the budget for a project is similar to this one, a UAV like the Mavic can still be useful in turtle research. For a basking turtle survey where the observer is interested solely in occupancy, it is possible to collect that data with midrange UAV, like the one used here (Table 8). If the observer is more interested in species richness or diversity, those results may not be feasible unless UAV with a resolution at least higher than 12 megapixels is available. Alternatively, it could be used to scan the banks of the river for optimal study sites for a spotting scope or basking trap survey. In the same way, it could be used to check the security and presence of traps that are currently in use.

Directions for the Future

Considering that there is currently no literature on using UAVs for sampling freshwater basking turtles, more methodology studies need to be conducted to develop standard practices. Most ecological literature is focused on finding the best way to use the UAV for specific tasks so there is not yet a widely accepted sampling protocol. Future research should focus on standardizing methods and retesting previous projects that were successful. It would also be useful to continue investigating and create a developed protocol for using UAVs specifically in turtle research.

While this project was able to compare two different methods, it seems that UAVs are truly a rapid assessment tool when surveying basking turtles. That being said, future studies could take this project and replace full spotting scope surveys with other rapid assessment techniques. This could include spotting scope boat surveys, binocular surveys, and transects using visual counts and hand capture. If the UAV budget for a project can only afford a UAV like the Mavic, it could still be useful in turtle research.

Future research should focus on using better quality UAVs and cameras or comparing ecological research across different UAV types. In addition to that, computer assisted image analysis and pattern recognition software could be used to assist in the photointerpretation of images and video taken from the UAV. This could improve speed and accuracy of counts and well as species recognition. With higher resolution images and a way to automatically analyze the data, UAVs could be streamlined and more accurate for freshwater turtle surveys.

Unmanned aerial vehicles are a promising tool for wildlife research, as shown by multiple studies. This project extended the uses further by using UAVs for basking turtle surveys with the same effectiveness as a widely accepted method. For future research, using different quality UAVs and applying the method to a variety of questions about basking turtles will further identify the utility as well as the pitfalls when using them as an ecological tool. With additional study, UAVs can become a key to advancing ecological research and allow researchers to see the environment in a different way.

REFERENCES

3DR. 2015. *SOLO User Manual V9*. Berkeley, CA: 3D Robotics Inc.

Abd-Elrahman, Amr, Leonard G. Pearlstine, and Franklin H. Percival. 2005. "Development of Pattern Recognition Algorithm for Automatic Bird Detection from Unmanned Aerial Vehicle Imagery." *Surveying and Land Information Science* 65 (1):37-45.

Anderson, Karen, and Kevin J. Gaston. 2013. "Lightweight Unmanned Aerial Vehicles Will Revolutionize Spatial Ecology." *Frontiers in Ecology and the Environment* 11 (3):138-146.

Barasona, José A., Margarita Mulero-Pázmány, Pelayo Avevedo, Juan J. Negro, María J. Torres, Christian Gortázar, and Joaquín Vicente. 2014. "Unmanned Aircraft Systems for Studying Spatial Abundance of Ungulates: Relevance to Spatial Epidemiology." *PLoS ONE* 9 (12):17.

Ben-Ezra, E., G. Bulte, and G. Blouin-Demers. 2008. "Are Locomotor Performances Coadapted to Preferred Basking Temperature in the Northern Map Turtles (*Graptemys geographica*)?" *Journal of Herpetology* 42 (2):322-331.

Bevan, Elizabeth, Thane Wibbels, Blanca M.Z. Najera, Marco A.C. Martinez, Laura A.S. Martinez, Francisco I. Martinez, Javier M. Cuevas, Tiffany Anderson, Amy Bonka, Mauricio H. Hernandez, Luis Jamie Pena, and Patrick M. Burchfield. 2015. "Unmanned Aerial Vehicles (UAVs) for Monitoring Sea Turtles in Near-Shore Waters." *Marine Turtle Newsletter* 145:19-22.

Biserkov, Vulco, and Simeon Ludanov. 2017. "Unmanned Aerial Vehicles (Uavs) for Surveying Freshwater Turtle Populations: Methodology Adjustment." *Acta Zoologica Bulgarica* 10:161-163.

Breckenridge, Robert P., and Maxine Dakins. 2011. "Evaluation of Bare Ground on Rangelands Using Unmanned Aerial Vehicles: A Case Study." *GIScience & Remote Sensing* 48 (1):74-85.

Breckenridge, Robert P., Maxine Dakins, Stephen Bunting, Jerry L. Harbour, and Sera White. 2011. "Comparison of Unmanned Aerial Vehicle Platforms for Assessing Vegetation Cover in Sagebrush Steppe Ecosystems." *Rangeland Ecology & Management* 64 (5):521-532.

Bryson, Mitch, and Stefan Williams. 2015. Review of Unmanned Aerial Systems (UAS) for Marine Surveys. Australian Centre for Field Robotics, University of Sydney.

Bushnell. 2018. "POWERVIEW 20x 50mm." accessed April 11, 2018. http://www.bushnell.com/all-products/binoculars/powerview/20x-50mm.

Canon. 2018. "18 x 50 IS All Weather." accessed April 11, 2018. https://www.usa.canon.com/internet/portal/us/home/products/details/binoculars/is-binoculars/18-x-50-is-all-weather.

Chabot, Dominique, and David M. Bird. 2012. "Evaluation of an Off-the-shelf Unmanned Aircraft System for Surveying Flocks of Geese." *Waterbirds* 35 (1):170-174.

Chabot, Dominique, and David M. Bird. 2015. "Wildlife Research And Management Methods In The 21st Century: Where Do Unmanned Aircraft Fit In?" *J. Unmanned Veh. Sys.* 3 (4):137-155.

Chabot, Dominique, Vincent Carignan, and David M. Bird. 2014. "Measuring Habitat Quality for Least Bitterns in a Created Wetland with Use of a Small Unmanned Aircraft." *Wetlands* 34:527-533.

Cohen, Warren B., and Samuel N. Goward. 2004. "Landsat's Role in Ecological Applications of Remote Sensing." *BioScience* 54 (6):535-545.

Coleman, Jessica L., and Ronald L. Gutberlet. 2008. "Seasonal Variation in Basking in Two Syntopic Species of Map Turtles (Emididae: Graptemys)." *Chelonian Conservation and Biology* 7 (2):276-281.

Colomina, I., and P. Molina. 2014. "Unmanned Aerial Systems for Photogrammetry and Remote Sensing: A Review." *ISPRS Journal of Photogrammetry and Remote Sensing* 92:79-97.

Ditmer, Mark A., John B. Vincent, Leland K. Werden, Paul A. Iaizzo, David L. Garshells, and John R. Fieberg. 2015. "Bears Show a Physiological but Limited Behavioral Response to Unmanned Aerial Vehicles." *Current Biology* 25:2278-2283.

DJI. 2018a. "INSPIRE 2." DJI, accessed April 13. https://store.dji.com/product/inspire-2?from=menu_products.

DJI. 2018b. "MAVIC PRO." DJI, accessed 2018. https://store.dji.com/product/mavic-pro?from=menu_products.

DJI. 2018c. "PHANTOM 4 PRO." DJI, accessed April 13. https://www.dji.com/phantom-4-pro/info#specs.

Dodd, C. Kenneth. 2016. *Reptile Ecology and Conservation: A Handbook of Techniques*: Oxford University Press.

Dunford, R., K. Michel, M. Gagnage, H. Piégay, and M.-L. Trémelo. 2009. "Potential and Constraings of Unmanned Aerial Vehicle Technology for the Characterization of Medeterranean Riparian Forest." *International Journal of Remote Sensing* 30 (19):4915-4935.

Durban, J.W., H. Fearnfach, L.G. Barrett-Lennard, W.L. Perryman, and D.J. Leroi. 2015. "Photogrammetry Of Killer Whales Using A Small Hexacopter Launched At Sea." *Journal of Unmanned Vehicles* 3:131-135.

Elphick, Chris S. 2008. "How You Count Counts: The Importance of Methods Research in Applied Ecology." *Journal of Applied Ecology* 45:1313-1320.

Ernst, Carl H., and Jeffrey E. Lovich. 2009. *Turtles of the United States and Canada*. 2nd ed. Baltimore, Maryland: The Johns Hopkins University Press.

FAA. 2016. "Summary of Small Unmanned Aircraft Rule (Part 107)." https://www.faa.gov/uas/media/Part_107_Summary.pdf.

FAA. 2018. "Unmanned Aircraft Systems." https://www.faa.gov/uas/.

Flynn, Kyle F., and Steven C. Chapra. 2014. "Remote Sensing of Submerged Aquatic Vegetation in a Shallow Non-Turbid River Using an Unmanned Aerial Vehicle." *Remote Sensing* 6 (12):12815-12836.

Gamble, Tony. 2006. "The Relative Efficiency of Basking and Hoop Traps for Painted Turtles (*Chrysemys picta*)." *Herpetological Review* 37 (2):308-312.

Getzin, Stephan, Robert S. Nuske, and Kerstin Wiegand. 2014. "Using Unmanned Aerial Vehicles (UAV) to Quantify Spatial Gap Patterns in Forests." *Remote Sensing* 6:6988-7004.

Getzin, Stephen, Kerstin Wiegand, and Ingo Schöning. 2012. "Assessing Biodiversity in Forests Using Very High-Resolution Images and Unmanned Aerial Vehicles." *Methods in Ecology and Evolution* 3:397-404

Goebel, Michael E., Wayne L. Perryman, Jefferson T. Hinke, Douglas J. Krause, Nancy A. Hann, Steve Gardner, and Donald J. LeRoi. 2015. "A Small Unmanned Aerial System for Estimating Abundance And Size of Antarctic Predators." *Polar Biology* 38:619-630

Gonzalez, Luis F., Glen A. Montes, Eduard Puig, Sandra Johnson, Kerrie Mengersen, and Kevin J. Gaston. 2016. "Unmanned Aerial Vehicles (UAVs) and Artificial Intelligence Revolutionizing Wildlife Monitoring and Conservation." *Sensors* 16 (97). doi: 10.3390/s16010097.

GoPro. 2018. "HERO." GoPro Inc., accessed April 13, 2018. https://shop.gopro.com/cameras/hero/CHDHB-501-master.html.

Grayson, Kristine L., and Michael E. Dorcas. 2004. "Seasonal Temperature Variation in the Painted Turtle (*Chrysemys Picta*)." *Herpetologica* 60 (3):325-336.

Grenzdörffer, G.J. 2013. "UAS-based Automatic Bird Count of a Common Gull Colony." *International Archives of the Photogrammetry, Remote Sensing Information Sciences* 500 (1):169-174.

Groom, Geoff, Ib Krag Petersen, Mark D. Anderson, and Anthony D. Fox. 2011. "Using Object-Based Analysis of Image Data to Count Birds; Mapping of Lesser Flamingos at Kamfers Dam, Northern Cape, South Africa." *International Journal of Remote Sensing* 32 (16):4611-4639.

Habel, Jan Christian, Mike Teucher, Werner Ulrich, Markus Bauer, and Dennis Rodder. 2016. "Drones for Butterfly Conservation: Larval Habitat Assessment With an Unmanned Aerial Vehicle." *Landscape Ecology* 31 (10):2385-2396

Hammond, K. A., J. R. Spotila, and E. A. Standors. 1988. "Basking Behavior of the Turtle *Pseudemys scripta*: Effects of Digestive State, Acclimation Temperature, Sex, Season." *Physiological Zoology* 61 (1):69-77.

Hardin, Perry J., and Mark W. Jackson. 2005. "An Unmanned Aerial Vehicle for Rangleland Photography." *Rangeland Ecology and Management* 58 (4):439-442.

Hardin, Perry J., and Ryan R. Jensen. 2011. "Introduction - Small-Scale Unmanned Aerial Systems for Environmental Remote Sensing." *GIScience & Remote Sensing* 48 (1):1-3.

Hodgson, Amanda, Natalie Kelly, and David Peel. 2013. "Unmanned Aerial Vehicles (UAVs) for Surveying Marine Fauna: A Dugong Case Study." *PLOS One* 8 (11): e79556.

Hodgson, Jarrod C., Shane M. Baylis, Rowan Mott, Ashley Herrod, and Rohan H. Clarke. 2016. "Precision Wildlife Monitoring Using Unmanned Aerial Vehicles." *Scientific Reports 6.* doi: 10.1038/srep22574.

Israel, Martin. 2011. "A UAV-Based Roe Deer Fawn Detection System." *International Archives of the Photogrammetry, Remote Sensing Information Sciences* 38 (1).

Jones, George Pierce, Leonard G. Pearlstine, and H. Franklin Percival. 2006. "An Assessment of Small Unmanned Aerial Vehicles for Wildlife Research." *Wildlife Society Bulletin* 34 (3):750-758.

Jozkow, G., C. Toth, and D. Grejner-Brzezinska. 2016. "UAS Topographic Mapping With Velodyne Lidar Sensor." *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences; Gottingen* 3:201-208.

Kepenis, Vito, and John J. McManus. 1974. "Bioenergetics of Young Painted Turtles, *Chrysemys picta*." *Comparative Biochemistry and Physiology Part A: Physiology* 48 (2):309-317.

Kissell, Robert E., and Susan K. Nimmo. 2011. "A Technique To Estimate White-Tailed Deer *Odocoileu Virginianus* Density Using Vertical-Looking Infrared Imagery." *Wildlife Biology* 17:85-92.

Klemas, Victor V. 2015. "Coastal and Environmental Remote Sensing from Unmanned Aerial Vehicles: An Overview." *Journal of Coastal Research* 31 (5):1260-1267.

Koski, William R., Travis Allen, Darren Ireland, Greg Buck, Paul R. Smith, A. Michael Macrander, Melissa A. Halick, Chris Rushing, David J. Sliwa, and Trent L. McDonald. 2009. "Evaluation of an Unmanned Airborne System for Monitoring Marine Mammals." *Aquatic Mammals* 35 (3):347-357.

Krebs, Charles J. 1999. *Ecological Methodology*. 2nd ed. Menlo Park, CA: Addison-Welsey Educational Publishers, Inc.

Kudo, Hideaki, Yousuke Koshino, Akihiro Eto, Masaki Ichimura, and Masahide Kaeriyama. 2012. "Cost-Effective Accurate Estimates Of Adult Chum Salmon, *Oncorhynchus Keta*, Abundance in a Japanese River Using Radio-Controlled Helicpoter." *Fisheries Research* 119-120:94-98.

Laliberte, Andrea S., Jeffrey E. Herrick, Albert Rango, and Craig Winters. 2010. "Acquisition, Orthorectification, and Object-based Classification of Unmanned Aerial Vehicle (UAV) Imagery for Rangeland Monitoring." *Photogrammetric Engineering & Remote Sensing* 76 (6):661-672.

Leupold. 2018. "SX-1 Ventana 2 15-45x60mm Angled Spotting Scope." accessed April 11, 2018. https://www.leupold.com/spotting-scopes/angled-eyepiece-spotting-scopes/sx-1-ventana-2-15-45x60mm-angled-spotting-scope.

Linchant, Julie, Jonthan Lisein, Jean Semeki, Philippe Lejeune, and Cedric Vermeulen. 2015. "Are Unmanned Aircraft Systems (Uass) The Future Of Wildlife Monitoring? A Review of Accomplishments and Challenges." *Mammal Review* 45:239-252.

Lindeman, P. V. 1999 "Surveys of Basking Map Turtles Graptemys Spp. in Three River Drainages and the Importance of Deadwood Abundance." *Biological Conservation* 88 (1):33-42. doi: 10.1016/s0006-3207(98)00093-7.

Lindeman, Peter V. 2000. "Resource Use of Five Sympatric Turtle Species: Effects of Competition, Phylogeny, and Morphology." *Canadian Journal of Zoology* 78:992-1008.

Lindeman, Peter V. 2014. "Surveys of Basking Turtles in the Rivers of Northeastern Oklahoma, with Emphasis on *Graptemys geographica* (Common Map Turtle)." *Proceedings of the Oklahoma Academy of Science* 94:1-9.

Lisein, Jonathan, Julie Linchant, Philippe Lejeune, Philippe Bouche, and Cedric Vermeulen. 2013. "Aerial Surveys Using an Unmanned Aerial System (UAV): Comparison of Different Methods for Estimating the Surface Area of Sampling Strips." *Tropical Conservation Science* 6 (4):506-520.

Lisein, Jonathan, Marc Pierrot-Deseilligny, Stéphanie Bonnet, and Philippe Lejeune. 2013. "A Photogrammetric Workflow for the Creation of a Forest Canopy Height Model from Small Unmanned Aerial System Imagery." *Forests* 4:922-944.

Loarie, Scott R., Lucas N. Joppa, and Stuart L. Pimm. 2007. "Satellites Miss Environmental Priorities." *TRENDS in Ecology and Evolution* 22 (12):630-632.

Manis, Christopher. 2008. "The Community Ecology Of A Riverine Turtle Asssemblage In The Tennessee River Gorge." *Masters Theses and Doctoral Dissertations.* https://scholar.utc.edu/theses/182

Martin, Julien, Holly H. Edwards, Matthew A. Burgess, Franklin H. Percival, Daniel E. Fagan, Beth E. Gardner, Joel G. Ortega-Ortiz, Peter G. Ifju, Brandon S. Evers, and Thomas J. Rambo. 2012a. "Estimating Distribution of Hidden Objects with Drones: From Tennis Balls to Manatees." *PLOS ONE* 7 (6). https://doi.org/10.1371/journal.pone.0038882

Matese, Alessandro, Piero Toscano, Salvatore Filippo Di Gennaro, Lorenzo Genesio, Francesco Primo Vaccari, Jacopo Primicerio, Claudio Belli, Alessandro Zaldei, Roberto Bianconi, and Beniamino Gioli. 2015. "Intercomparison of UAV, Aircraft and Satellite Remote Sensing Platforms for Precision Vitculture." *Remote Sensing* 7:2971-2990.

McHugh, Mary L. 2013. "The Chi-square test of independence." *Biochemia Medica* 23 (2):143-149.

Mendes, Mehmet, and Akin Pala. 2003. "Type I Error Rate and Power of Thre Normality Tests." *Pakistan Journal of Information and Technology* 2 (2):135-139.

microdrones. 2018. "Microdrone MD4-1000 - MDMapper1000 Package." Martin Instrument, accessed April 13. https://www.microdrones.com/en/mdaircraft/md4-1000/.

Mittermeier, Russell A., Peter Paul van Dijk, Anders G.J. Rhodin, and Stephen D. Nash. 2015. "Turtle Hotspots: An Analysis of the Occurrence of Tortoises and Freshwater Turtles in Biodiversity Hotspots, High-Biodiversity Wilderness Areas, and Turtle Priority Areas." *Chelonian Research Foundation* 14 (1):2-10.

Mulero-Pázmány, Margarita, Roel Stolper, L. D. Van Essen, Juan J. Negro, and Tyrell Sassen. 2014. "Remotely Piloted Aircraft Systems as a Rhinoceros Anti-Poaching Tool in Africa." *PLOS ONE* 9 (1). https://doi.org/10.1371/journal.pone.0083873

NASA. 2017. "Remote Sensors." https://earthdata.nasa.gov/user-resources/remote-sensors#current.

Nevalainen, Olli, Eija Honkavaara, Sakari Tuominen, Niko Viljanen, Teemu Hakala, Xiawei Yu, Juha Hyyppä, Heikki Saari, Ilkka Pölönen, Nilton Imai, and Antonio Tommaselli. 2017. "Individual Tree Detection and Classification With UAV-Based Photogrammetric Point Clouds and Hyperspectral Imaging." *Remote Sensing* 9 (2):185.

Newcome, Laurence R. 2004. *Unmanned Aviation: A Brief History of Unmanned Aerial Vehicles*. Reston, Virginia: American Institute of Aeronautics and Astronautics.

North Chickamauga Creek Conservancy. 2015. "Greenway Farm." accessed April 12, 2018. http://www.northchick.org/adventure/greenway-farm/index.html.

Pearson, David, and C. J. Kazilek. 2007. "Advanced Birders' Guide."1-15.

Rango, Albert, Andrea Laliberte, Caiti Steele, Jeffrey E. Herrick, Brandon Bestelmeyer, Thomas Schmugge, Abigail Roanhorse, and Vince Jenkins. 2006. "Using Unmanned Aerial Vehicles for Rangelands: Current Applications and Future Potentials." *Environmental Practice* 8 (3):159-168.

Ratcliffe, N., D. Guihen, J. Robst, and P. Enderlein. 2015. "A Protocol for the Aerial Survey of Penguin Colonies Using UAVs." *Journal of Unmanned Vehicle Systems* 3 (3):96-101.

Reflection Riding Arboretum and Nature Center. 2018. "Maps and Trails." accessed April 12, 2018. https://reflectionriding.org/105/maps-trails.

Romero, Maria, Yuchen Luo, Baofeng Su, and Sigfredo Fuentes. 2018. "Vinyard Water Status Estimation Using Multispectral Imagery From an UAV Platform and Machine Learning Algorithms for Irrigation Scheduling Management." *Computers and Electonics in Agriculture* 147:109-117.

Sardà-Palomera, Francesc, Gerard Bota, Carlos Viñolo, Oriol Pallarés, Víctor Sazatornil, Lluís Brotons, Spartacus Gomáriz, and Francesc Sardà. 2012. "Fine-Scale Bird Monitoring From Light Unmanned Aircraft Systems." *Ibis* 143:177-183.

Sugiura, Ryo, Noboru Noguchi, and Kazunobu Ishii. 2005. "Remote-sensing Technology for Vegetation Monitoring using an Unmanned Helicopter." *Biosystems Engineering* 90 (4):369-379.

Sullivan, Jeffrey M. 2006. "Evolution or Revolution? The Rise of UAVs." *IEEE Technology and Society Magazine* 25 (3):43-49.

Tennessee River Gorge Trust. 2018. "Protected Lands." accessed April 13. http://www.trgt.org/lands/.

Thomas, R. Brent, Nusa Vogrin, and Ronald Altig. 1999. "Sexual And Seasonal Difference in Behavior of Trachemys scripta (Testudines: Emydidae)." *Journal of Herpetology* 33 (3):511-515.

Times-Dispatch. 1903. "A Machine that Flies." *The Times-Dispatch*, December 19.

Tozer, T. C., and D. Grace. 2001. "High-Altitude Platforms for Wireless Communications." *Electronics & Communication Engineering Journal* 13 (3):127-137.

Turtle Conservancy Coalition. 2018. *Turtles in Trouble The World's 25+ Most Endangered Tortoises and Freshwater Turtles*.

van Andel, A. C., S. A. Wich, C. Boesch, L. P. Koh, M. M. Robbins, J. Kelly, and H. S. Kuehl. 2015. "Locating Chimpanzee Nests and Identifying Fruiting Trees With an Unmanned Aerial Vehicle." *American Journal of Primatology* 77 (10):1122-34. doi: 10.1002/ajp.22446.

Vas, Elisabeth, Amélie Lescroël, Olivier Duriez, Guillaume Boguszewski, and David Grémillet. 2015. "Approaching Birds with Drones: First Experiments and Ethical Guidelines." *Biology Letters*.

Vermeulen, Cédric, Philippe Lejeune, Jonathan Lisein, Prosper Sawadogo, and Philippe Bouché. 2013. "Unmanned Aerial Survey of Elephants." *PLOS ONE* 8 (2).

Vogt, Richard C. 1980. "New Methods for Trapping Aquatic Turtles." *Copeia* 1980 (2):369-371.

Vortex. 2018. "Diamondback 20-60x60." Diamondback Optics, accessed April 13, 2018. http://www.vortexoptics.com/product/vortex-diamondback-20-60x60-straight-spotting-scope.

Wallace, Luke, Arko Lucieer, Darren Turner, and Christopher Watson. 2011. "Error Assessment and Mitigation for Hyper-Temporal UAV-borne LiDAR Surveys of Forest Inventory." SilviLaser 2011, Hobart, Australlia.

Watts, Adam C., Vincent G. Ambrosia, and Everett A. Hinkley. 2012. "Unmanned Aircraft Systems in Remote Sensing and Scientific Research: Classification and Considerations of Use." *Remote Sensing* 4:1671-1692.

Weber, Andrew S. , and James B. Layzer. 2011. "A Comparison of Turtle Sampling Methods in a Small Lake in Standing Stone State Park, Overton County, Tennessee." *Journal of the Tennessee Academy of Science* 86 (2):45-52.

Weissensteiner, M.H., J.W. Poelstra, and J.B.W. Wolf. 2015. "Low-Budget Ready-to-Fly Unmanned Aerial Vehicles: An Effective Tool for Evaluating the Nesting Status of Canopy-Breeding Bird Species." *Journal of Avian Biology* 46:425-430.

Whitehead, Ken, Chris H. Hugenholz, Stephen Myshak, Owen Brown, Adam LeClair, Aaron Tamminga, Thomas E. Barchyn, Brian Moorman, and Brett Eaton. 2014. "Remote Sensing of the Environment With Small Unmanned Aircraft Systems (UASs), Part 2: Scientific and Commercial Applications." *Journal of Unmanned Vehicle Systems* 2 (3):86-102.

Wilbur, Henry M. . 1975. "The Evolutionary and Mathematical Demography of the Turtle *Chrysemys picta*." *Ecology* 56 (1):64-77.

Williams, Darrel L., Samuel N. Goward, and Terry Arvldson. 2006. "Landsat: Yesterday, Today and Tomorrow." *Photogrammetric Engineering & Remote Sensing* 72 (10):1171-1178.

Zahawi, Rakan A., Jonathan P. Dandois, Karen D. Holl, Dana Nadwodny, J. Leighton Reid, and Erie C. Ellis. 2015. "Using Lightweight Unmanned Aerial Vehicles to Monitor Tropical Forest Recovery." *Biological Conservation* 186:287-295.

Zaman, Bushra, Mac McKkee, and Austin Jensen. 2017. "UAV, Machine Learning, and GIS For Wetland Mitigation in Southwestern Utah, USA." Esri India User Conference.

Zarco-Tejada, P. J., R. Diaz-Varela, V. Angileri, and P. Loudjani. 2014. "Tree Height Quantification Using Very High Resolution Imagery Acquired from an Unmanned Aerial Vehicles (UAV) and Automatic 3D Photo-Reconstruction Methods." *European Journal of Agronomy* 55:89-99.

Zweig, Christa L., Matthew A. Burgess, Franklin H. Percival, and Wiley M. Kitchens. 2015. "Use of Unmanned Aircraft Systems to Delineate Fine-Scale Wetland Vegetation Communities." *Wetlands* 35 (303-309).

APPENDIX A

TABLES

Table 1 Count Data for Both Methods from the Pond Phase at Reflection Riding Arboretum and Nature Center

Method	**Upper Pond**	**Lower Pond**	**Total**
Spotting Scope	25	38	63
UAV	11	67	78

Table 2 Count Data from the River Phase at the Tennessee River Gorge

Method	**Site 1**	**Site 2**	**Site 3**
Spotting Scope	11	39	7
UAV	39	19	3

Table 3 Species Data from the Spotting Scope Surveys in the River Phase

Species	**LT5-M1**	**LT5-M2**	**LT5-M3**
T. scripta	194	166	12
T. scripta elegans	17	18	1
P. concinna	9	14	1
G. geographica	1	27	15
G. ouachitensis	0	7	1
S. odoratus	16	0	0

Table 4 Morisita-Horn Coefficient of Similarity of the Three River Sites on a Scale of 0 (Not Similar) and 1 (Identical)

	LT5-M1	**LT5-M2**	**LT5-M3**
Site 1	1.01	0.74	0.66
Site 2	0.74	1.02	1.04
Site 3	0.66	1.04	1.09

Table 5 Morisita-Horn Coefficient of Similarity of the Two Methods when Used on the River on a Scale of 0 (Not Similar) and 1 (Identical)

	Spotting Scope	**UAV**
Spotting Scope	1.02	0.72
UAV	0.72	1.02

Table 6 Morisita-Horn Coefficient of Similarity of the Two Ponds on a Scale of 0 (Not Similar) and 1 (Identical)

	Upper Pond	**Lower Pond**
Upper Pond	1.01	0.94
Lower Pond	0.94	1.02

Table 7 Morisita-Horn Coefficient of Similarity of the Two Methods when Used on the Ponds on a Scale of 0 (Not Similar) and 1 (Identical)

	Upper Pond	**Lower Pond**
Upper Pond	1.01	0.90
Lower Pond	0.90	1.03

Table 8 A Selection of Common UAVs on the Market and Their Specific Details and Price

Model	K/fps	Megapixels	Maximum Fly Time	Flight Range	Price	Source
3DR SOLO (w/ GoPro HERO)	1080p/60fps	10	25 min	0.8km	$830 ($1,119.99 w/ camera)	(3DR 2015, GoPro 2018)
DJI Mavic Pro	4K/30fps	12	27 min	13km	$999	(DJI 2018c)
DJI Phantom 4 Pro	4K/60fps	20	30 min	7km	$1,499	(DJI 2018b)
DJI Inspire 2 (w/ Zenmuse X4S camera)	5.3K/20fps	20.8	25-27 min	7km	$2,999 ($4,100 w/ camera)	(DJI 2018a)
Microdrone MD4-1000	Camera not included	Camera not included	45 min	0.5km (20km w/ way points)	$28,500	(microdrones 2018)

Table 9 A Selection of Common Spotting Scopes on the Market and Their Specific Details and Price

Model	Objective Lens	Magnification	Field of View	Price	Source
Leica Televid 62/77 (w/ 20-60x zoom eyepiece, not included)	62mm	16-48x	40m @ 1,000m	$2,099.00 (+$299.99 eyepiece)	Product Packaging
Vortex Optics Diamondback Spotting scopes	60mm	20-60x	38.42-17.46m @1,000m	$499.00	(Vortex 2018)
Leupold SX-1 Ventana 2 15-45x60mm	60mm	15-45x	40.16m @ 1,000m	$317.94	(Leupold 2018)
Cannon 18x50 IS Image Stabilized Binoculars	50mm	18x	64.51 @ 1,000m	$999.00	(Canon 2018)
Bushnell 20x50 Powerview Binocular	50mm	20x	64.51m @ 1,000m	$99.99	(Bushnell 2018)

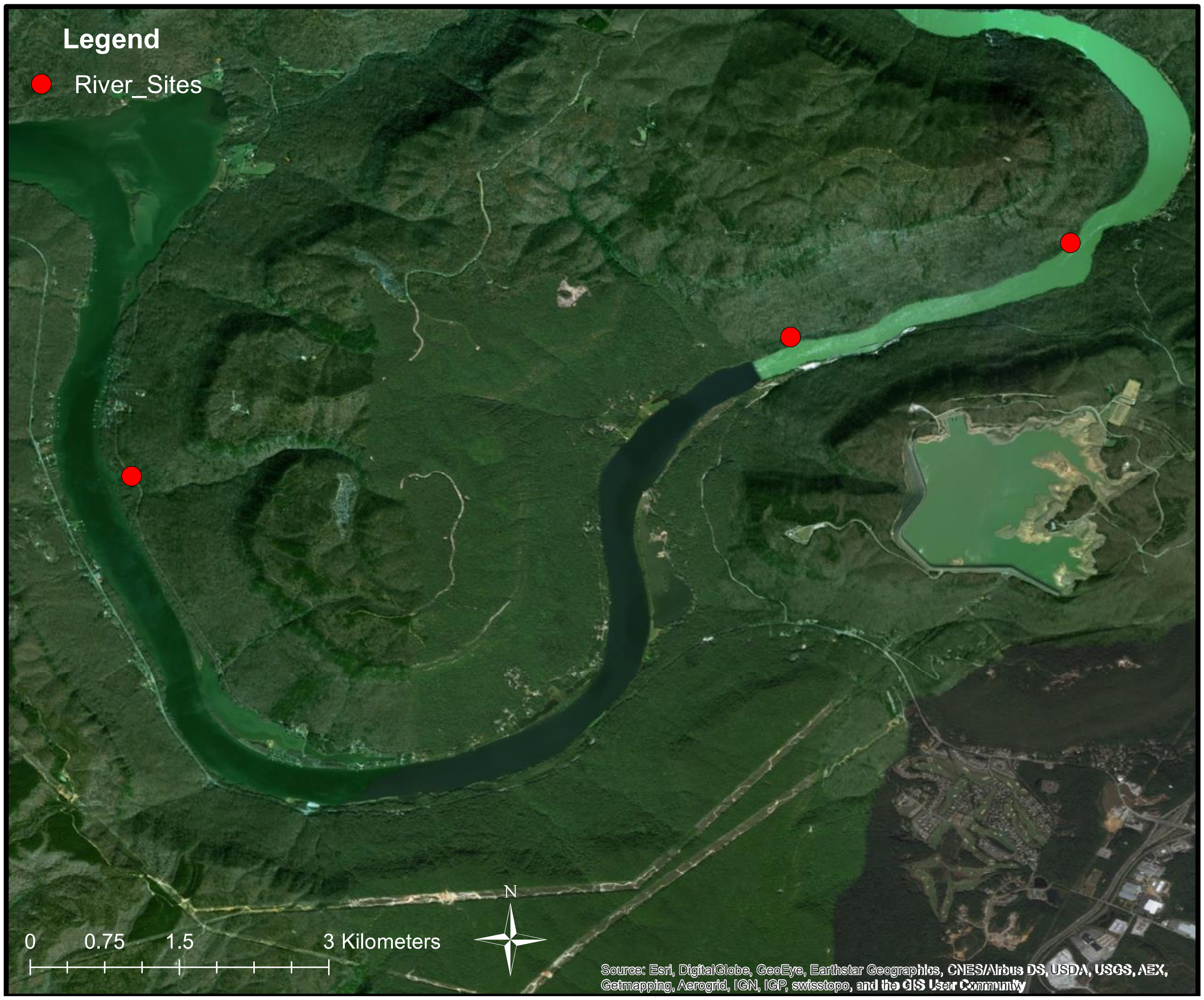
APPENDIX B

FIGURES

Figure 1 A map of the site for the Beta Phase, Greenway Farms (generated using ArcGIS)

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community, Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community

Figure 2 A map of the site for the Pond Phase, Reflection Riding Arboretum, and Nature Center (generated using ArcGIS)



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 3 A map of the sites for the River Phase, the Tennessee River Gorge (generated using ArcGIS)

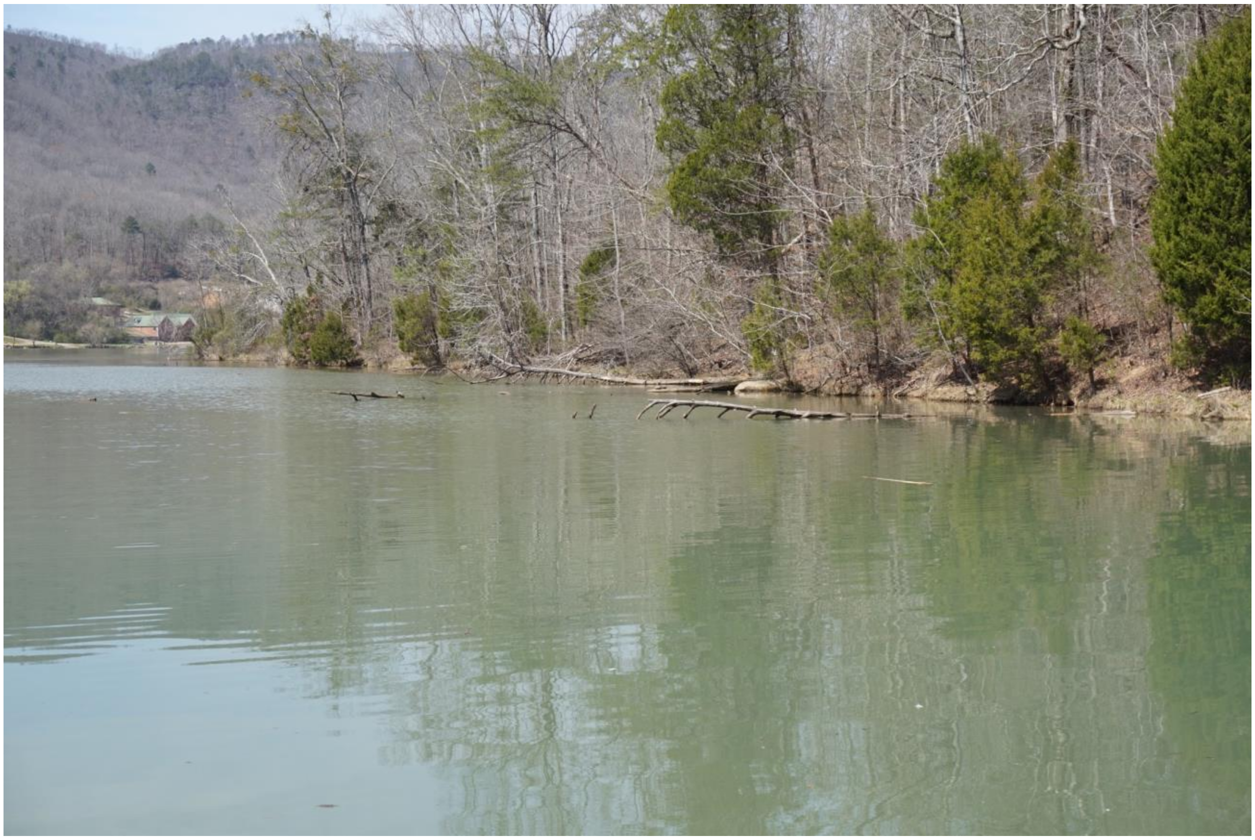


Figure 4 An image of LT5-M1 at the Tennessee River Gorge

Figure 5 An image of LT5-M2 at the Tennessee River Gorge

Figure 6 An image of LT5-M3 at the Tennessee River Gorge

Figure 7 UAV images at 3, 5, 10, and 30 meter elevations of a *C. picta* museum specimen on green paper

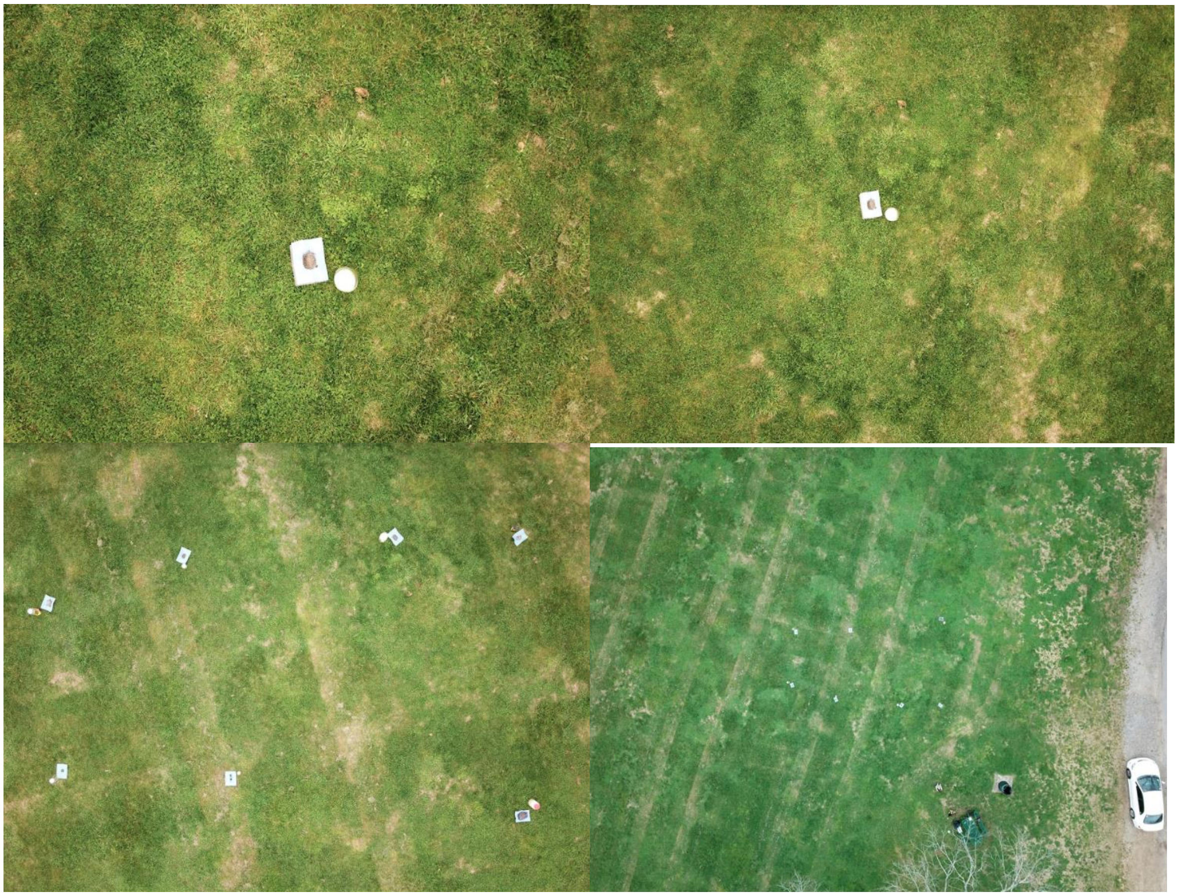


Figure 8 UAV images at 3, 5, 10, and 30 meter elevations of a *T. scripta* museum specimen on blue paper

Figure 9 UAV images at 3, 5, 10, and 30 meter elevations of a *K. subrubrum* museum specimen on black paper

Figure 10 UAV footage from the Pond Phase at Reflection Riding Arboretum and Nature Center

Figure 11 A still frame from the UAV footage at LT5-M1 in the Tennessee River Gorge

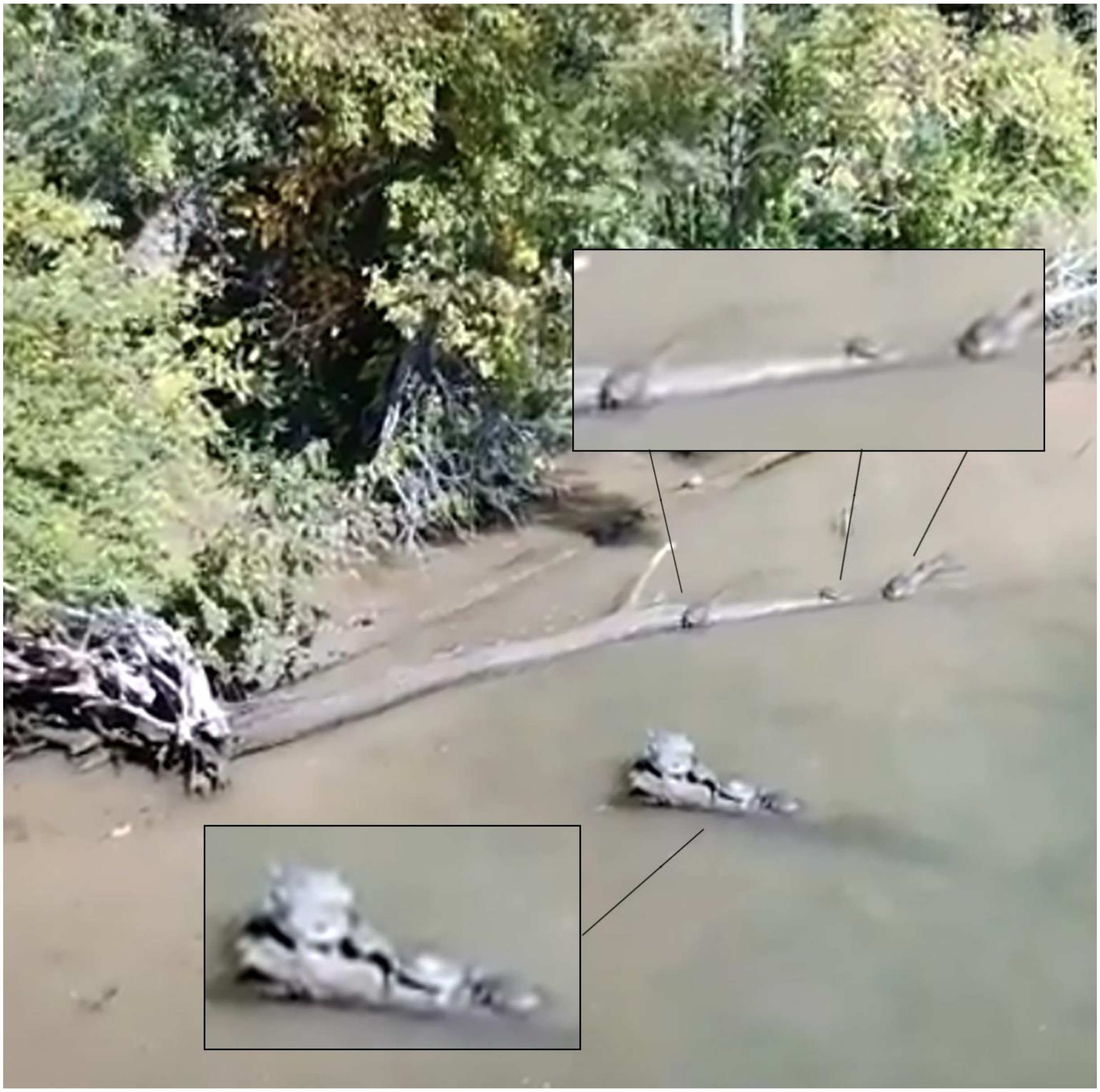


Figure 12 A still frame from the UAV footage at LT5-M2 in the Tennessee River Gorge

Figure 13 A still frame from the UAV footage at LT5-M3 in the Tennessee River Gorge

VITA

Kelly Daniels was born in Charleston, SC, to Mark and Debbie Daniels. She is the second of two children with an older brother, Matthew. She attended Orange Grove Elementary School and continued to the Charleston County School of the Arts in Charleston, SC. After graduating, she attended Clemson University and completed a Bachelor of Science in Environmental and Natural Resources in May 2016. Kelly spent summers volunteering at the South Carolina Department of Natural Resources where she became interested in biological field work, specifically herpetology. She entered the Master of Science program at the University of Tennessee at Chattanooga in August 2012. Kelly graduated with a Master of Science degree in Environmental Science in August 2018.