ABSTRACT

LUTZ, GRAHAM D. On the Effectiveness of UAS for Anti-Poaching Enforcement in the Arid Savanna. (Under the direction of Dr. Lawrence Silverberg).

This paper describes a field study that examined the viability of the use of unmanned aerial vehicles (UAV) in anti-poaching enforcement in parks and game reserves. In the field study, a UAV attempts to spot mock poachers while the mock poachers try to spot the UAV. The field study was conducted at N/a'an ku sê, an operational game reserve in the central region of Namibia. In total, 118 trials were completed, providing 236 UAV-poacher interdiction scenarios. Of these, 198 were during the day, 152 with a quadcopter and 46 with a fixed-wing. Live spotting success during the day varied due to the hiding behavior of the mock poachers, with the highest and lowest success rates of spotting being 86% for poachers in the open and 25% for poachers hiding under canopy cover. The UAVs were demonstrated to be a viable tool for deterring poachers because of their ability to spot poachers even with significant auditory presence.

On the Effectiveness of UAS for Anti-Poaching Enforcement in the Arid Savanna

by
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BIOGRAPHY

Graham Daniel Lutz was born November 12th, 1993 in Durham North Carolina. He grew up in Hillsborough North Carolina, graduating from Cedar Ridge High School in 2012. After high school, Graham attended North Carolina State University in Raleigh North Carolina, graduating with Bachelors of Science in Mechanical Engineering in 2017. Upon graduation, Graham enrolled in the masters program at North Carolina State University in pursuit of his Masters of Science in Mechanical Engineering.

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I want to acknowledge the field unit consisting of undergraduate students Christina Burnham, Casey Davidson Ciaran Gallagher, Jordan Hatch, Julia Nelson, Abigale Patten, Ana Solberg, Joshua Spann, Cadman Styers, Jaye Sudweeks, Meredith Tooley, Connor Wheatley, and Evan Winterhalter for their efforts in collecting and reducing the field data.

Finally, I want to recognize Rudie and Marlice vanVuren, founders of N/a’an ku sê, for their support of this research and thank Stuart Munro and the rest of the N/a’an ku sê for their assistance throughout the project.

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CHAPTER 1: INTRODUCTION

The high rate of animal extinction of such high-value African species, such as rhinoceros and elephant, is credited to poaching (Western 1985; Douglas 1987). They are illegally hunted for their horns and tusks, and sold for the production of traditional medicines and for items of cultural status. From 1990 to the present, the African elephant population decreased by 90% and between 1960 and 1990 the black rhino population decreased by 95% (Kamminga, 2018). To combat the decline of high-value African species, effective anti-poaching policies span strong support by the local community, strong anti-poaching efforts by law enforcement, and strong prosecution by the legal system. In law enforcement, a critical part of best practices pertains to how the landscape is surveyed for poachers. Tools include camera traps, walking and ground vehicle patrols, and aircraft patrol. The advent of the unmanned aerial vehicle (UAV) offers law enforcement with a new, potentially powerful tool.

To date, published research on the viability of the UAV in anti-poaching enforcement is scant. Exceptions include anti-poaching UAV research on 13 farms across South Africa with 20 total trials (Mulero-Pazmany, 2014). Their research focused on image quality of three types of cameras mounted on a fixed-wing UAV for day and nighttime trials. They found some viability in using UAVs as an anti-poaching tool to spot both rhinos and humans. Also, a security group implemented an anti-poaching UAV program using a fixed-wing UAV as a nighttime anti-poaching tool (Air Shepherd, 2018). They reported statistics regarding their successes, noting that in one area in which 19 rhinoceros were once killed, there were no killings after deploying their UAVs. Information on their methodology, however, was not released. Ultimately, the role of the UAV in enforcement, despite early signs of great promise, is not yet understood. First, how effective is the UAV in assisting a security team with its cat and mouse game of sensing each other’s presence? If effective, how does is assist with deterrence and with covert operations? How should the UAV be integrated into anti-poaching enforcement at parks and game reserves? What overall level of training and effort is required to be effective? What is its potential impact on animal conservation throughout Africa?

The method section describes a field study in which a UAV attempts to spot mock poachers while the mock poachers try to spot the UAV. The different factors that impact the ability to spot one another are discussed in the results section and the implications of the study to deterrence and covert operations are described in the summary and conclusions section.

CHAPTER 2: METHOD

The objective of the study was to examine the anti-poaching UAV and poacher's ability to sense, by sight and sound, each other's presence. Figure 2.1 below depicts the test area located at N/a'an ku sê, an operational game reserve in the central region of Namibia.

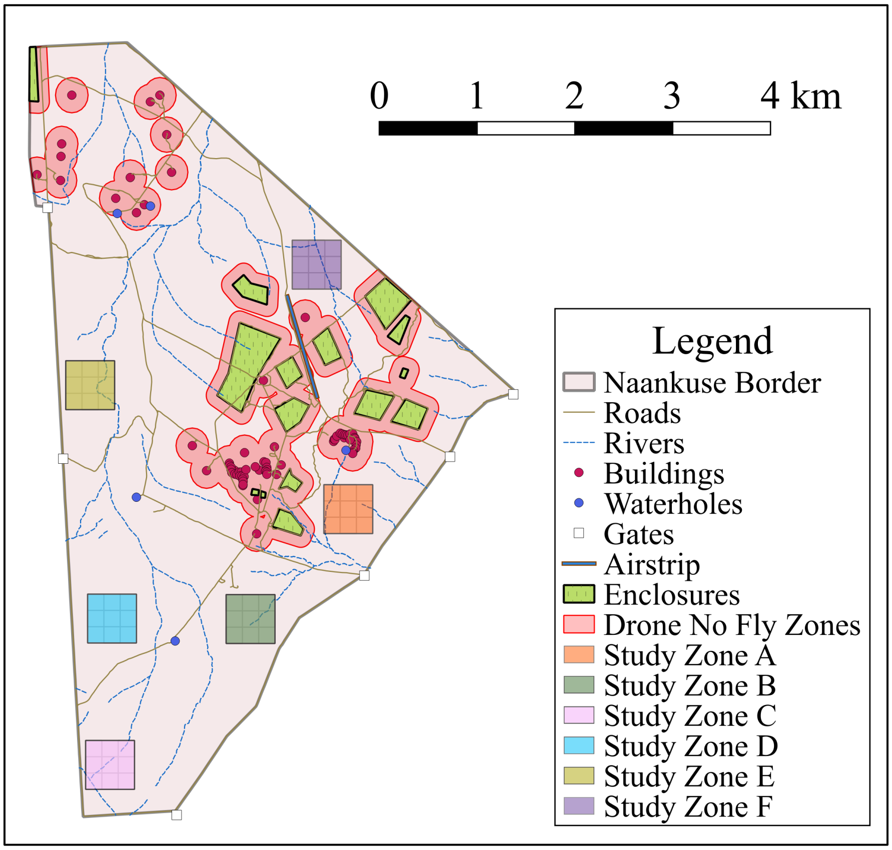

Figure 2.1: N/a'an ku sê Map and Study Zones

As shown, the test area was divided into six study zones. Each had differences in terrain and vegetation cover. Each measured 500m by 500m which was sufficiently large to challenge the UAVs and the mock poachers and which was sufficiently small to enable the sighting to be accomplished in an appropriately small amount of time. As shown, each of the zones was further subdivided into a grid of nine sectors, each sector serving as a hiding area for the mock poachers. Three hiding behaviors were defined as follows:

1. In the open: *uncovered by and separated from any vegetation by at least 5 meters*

2. Amongst the bush*: within five meters or less of vegetation but with a clear view of the sky above*

3. Under the canopy: *completely underneath the cover of the bush*

The tests were performed over a 10-week period in 2018. Each test was accomplished by a six-person field unit consisting of two mock poachers, a pilot, a co-pilot, a note-taker and an observer. The roles were randomized after each trial to reduce biases resulting from variations in skill levels. The pilot was responsible for setting up the radio control equipment, launching and landing the UAV, and video observation. The co-pilot was responsible for the initial UAV setup and video observation. The note-taker was responsible for scribing all data that was recorded, before, during and after the test. The observer maintained situational awareness and visual contact with the UAV and operated the radio for safety purposes. In each test, the mock poachers were assigned to a random sector and to a random hiding behavior.

Before the beginning of each test, role assignments, wind speed and direction, cloud cover, flight altitude, flight speed and the UAV camera angle, and GPS location of the takeoff were recorded. Next, at the beginning of each test, the field unit set up its equipment at a takeoff location just outside of the zone while the mock poachers went to their assigned random hiding sectors and assumed their hiding behaviors. Then, upon takeoff, the note taker started a stopwatch and the observer told the poachers via radio to start their stopwatch. The two synced stopwatches were later used to correlate UAV and mock poacher observations. After takeoff, the UAV autonomously flew a pre-programmed search pattern, with the pilot and co-pilot continuously monitoring a live video feed. Any time the pilot and co-pilot thought they spotted a mock poacher, the time was recorded. During the test, the mock poachers recorded the GPS coordinates of their hiding spot and their assigned hiding behavior and the times they first heard the UAV, see the UAV, and when the UAV was directly overhead. The note-taker entered this data into the dataset at the conclusion of the test.

A post processing review of photos and recorded video allowed the sightings to be either confirmed or marked as false and it enabled the identification of any sightings that the pilot and the co-pilot missed. This later allowed the effectiveness of the UAV and the visual observer to be analyzed.

Three UAV systems were chosen: two quadcopter systems and a fixed-wing UAV system. They were meant to be representative of the different systems that for anti-poaching efforts. Table 2.1 describes the technical features of the UAV systems.

Table 2.1: UAV Technical Descriptions

	DJI Phantom 3 Professional	**Modified DJI Phantom 3 Professional**	**X-UAV Talon**
Aircraft type	Quadcopter	Quadcopter	Fixed-wing
Camera	RGB	9Hz FLIR Thermal	4K RGB
Resolution	4K / 12MP	336 x 256	4K / 12MP
Flight speeds	0 - 15 m/s	0 - 15 m/s	15 - 25 m/s
Endurance	20 min	20 min	30 min
Noise Level at 50m	56 dBa	56 dBa	50 dBa
Width (wingspan)	0.29 m	0.29 m	2.02 m
Length	0.29 m	0.29 m	1.10 m
Flight planning software	Drone Deploy, Pix4D, Litchi	Drone Deploy, Litchi	Mission Planner
Live video feed	HD video on smartphone	SD video on 7” LCD	SD video on 7” LCD

The parallel track search method was employed during the tests (WSDOT, 2008). The parallel tracks were flown in a north-south orientation to prevent fling into or away from the sun thereby increasing visibility. The ability to adjust parameters was also necessary throughout the flights to obtain the best results. The adjusted parameters were camera angle, flight speed, altitude, and recording mode (stills and video). For the fixed-wing system, a modified version of the parallel track search method was flown to account for its limited turning radius. The difference in flight paths is shown in Fig. 2 below.

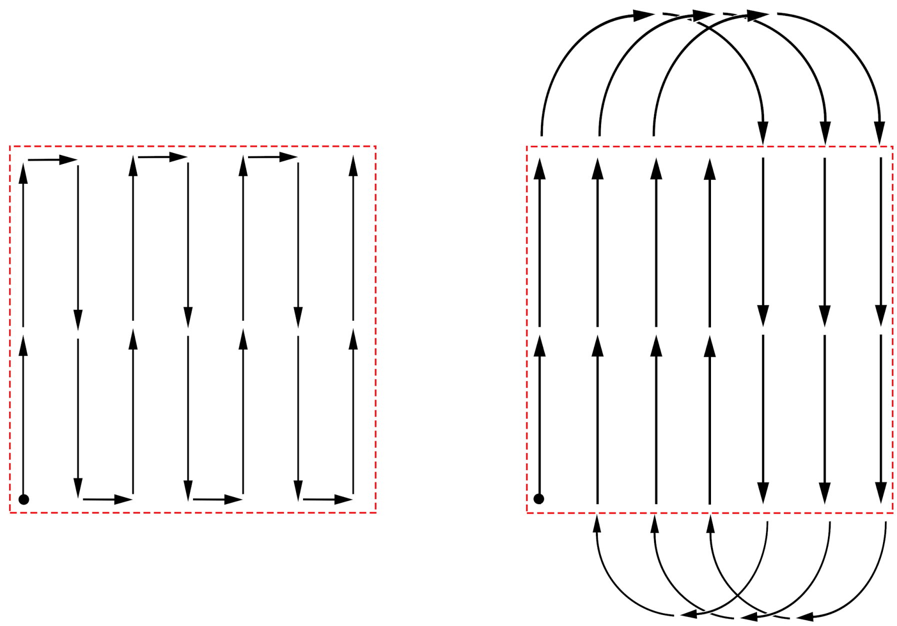

Figure 2.2: Parallel track search method for the quadrotors (left) and its modification for the fixed-wing UAV (right)

The quadcopter systems required two batteries to complete the search pattern, returning to the take off location to change batteries half way through the trial. The fixed-wing system was capable of completing two search patterns per battery, and, to minimize wear and tear on the UAV, was allowed to circle, rather than land between tests. In the night tests using the quadcopter system with a FLIR camera, the lights were blacked out except for the navigation lights, which were allowed to remain turned on during takeoff and landing. Several color pallets were available for the thermal imagery however, after testing, the “white hot” pallet was chosen because it provided the most definition; the humans stood out best with it.

An even number of tests were conducted in each of the 6 zones so that the environmental factors, such as vegetation cover and terrain, would be evenly represented. Daytime flights were conducted between the hours of 9:00 and 17:00. The thermal camera required ground temperatures that are cool relative to the body temperature so the flights with the thermal camera were conducted 30 minutes or more after dusk.

CHAPTER 3: RESULTS

In total, 118 trials were completed with 236 mock poachers in the field in numerous varying scenarios. From the trails, information was gleaned on the capabilities of the UAV and to spot poachers in the field in three different hiding behaviors, and on the contest between UAV and mock poacher to be the first to spot the other.

Figures 3.1, 3.2, and 3.3 below show illustrative images of mock poachers in the field. In each of the figures there are 2 poachers. In Figs. 3.1 and 3.2, one is in the open and the other is amongst the bush. In Fig. 3.3, one is amongst the bush and the other is under a canopy. For all tests camera angles were measured from nadir, with any angles deviating from nadir in the forward facing direction of the UAS. Figures 3.1 and 3.2 compare the nadir and 45° off nadir camera angles respectively, showing that the 45° camera angle is preferred over the nadir camera angle due to the increased visibility of the human figure.

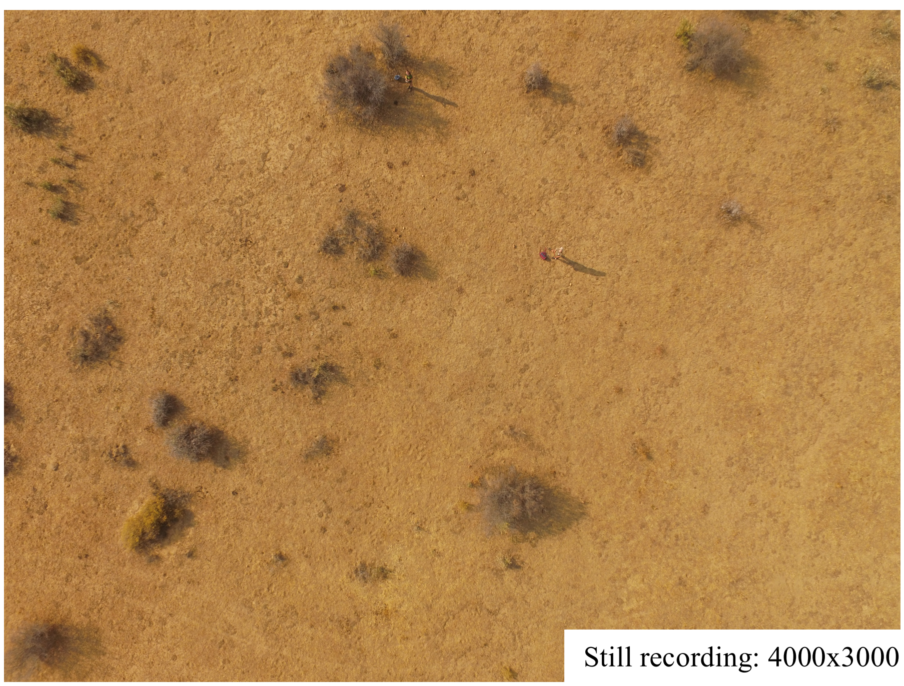

Figure 3.1: Mock poachers, 0 degree nadir camera angle

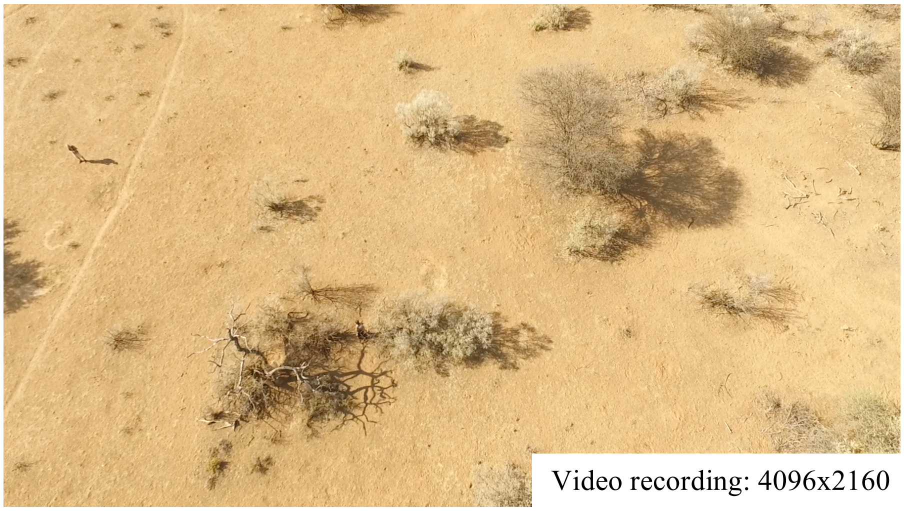

Figure 3.2: Mock poachers, 45 degree off nadir camera angle

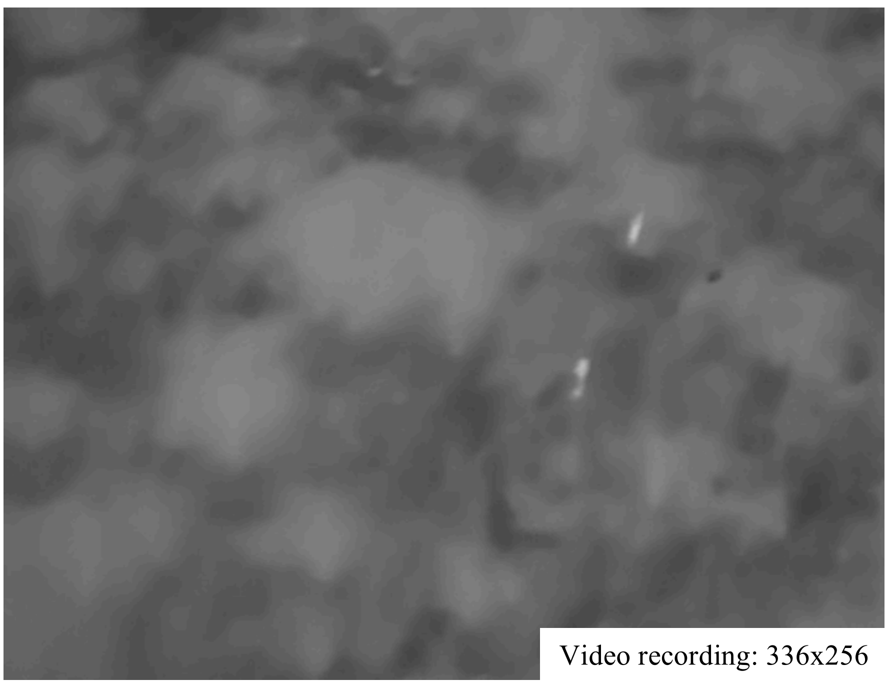

Figure 3.3: Mock poachers, FLIR camera, 45 degree off nadir camera angle

For still pictures, camera angles of both nadir and 30° off nadir were considered. For flights where video was recorded, camera angles of 30° off nadir and 45° off nadir were used. Table 3.1 below tabulates the successes rates for the different camera angles and recording modes. Video recording and the 45° off nadir camera angles yielded the best results and were also preferred by all of the observers.

Table 3.1: Spotting success with different camera angles and recording types

Recording Mode	Camera angle	Mock Poachers Present	Number Spotted Live
Pictures	nadir	32	17 (53.13%)
	30° off nadir	38	23 (60.52%)
Video	30° off nadir	38	14 (36.84%)
	45° off nadir	44	30 (68.18%)

Observers preferred the video recording to pictures because, in picture mode, the live video feed flashed black every time a picture was taken which was distracting and disorienting. For camera angles, 45° off nadir was preferred as it allowed a humans profile to be seen which allowed for better identification than a 0° nadir view. The 45° off nadir angle gave the observers a better chance of seeing under canopy and also resulted in mock poachers being on screen for a longer time than the 30° off nadir or 0° nadir camera angles. In their work, Mulero-Pazmany, et al. tested camera angles of 15° off nadir and 60° off nadir however no distinction was made as to which was superior.

Flight speeds for all of the trials ranged from 4.7 m/s to 9.5 m/s as shown in Table 3.2. These were broken into three ranges with the majority of the trials falling into the lower two of the three ranges. This is because live observers immediately noticed that in the fastest range the UAV was moving too fast for them to effectively scan the live video feed for poachers. Despite the percent of mock poachers spotted being almost identical for the two slower flight speeds, all observers agreed that the slower flight speed made their job feel much easier & less stressful.

Table 3.2: Spotting success with different flight speeds

Flight speed	Mock Poachers Present	Number Spotted Live
4.7-6 m/s	64	36 (56.25%)
6.1-7.5 m/s	78	44 (56.41%)
7.6-9.5 m/s	10	4 (40.00%)

Table 3.3 below shows the success rates for spotting poachers in the field during the daytime using both the fixed-wing and quad platforms. Overall the quadcopter system was more successful than the fixed-wing system with both systems having the highest success spotting poachers in the open and the least success spotting poachers under the canopy. The hiding behavior has a very strong effect on the ability of the UAV system and live observer to spot the mock poacher, with the mock poachers under the canopy being 2 to 3 times as hard to spot as those in the open.

Table 3.3: Spotting success by hiding behavior for fixed-wing and quadcopter

Hiding Behavior	Mock Poachers Present		Number Spotted Live	
	Quadcopter	Fixed-wing	Quadcopter	Fixed-wing
Open	44	13	38 (86.36%)	9 (69.23%)
Bush	44	17	30 (68.18%)	7 (41.18%)
Canopy	64	16	16 (25.00%)	5 (31.25%)

The observers watching the live video noted that spotting with the fixed-wing was more difficult because the camera was not gimbaled causing the camera to shake. Observers also noted the higher flight speeds of the fixed-wing resulted in their job being both more difficult and tiring. The un-gimbaled camera and higher flight speeds are likely what caused the overall lower success rates of the fixed-wing platform. It is also important to note that the fixed-wing had considerably fewer trials than the quadcopter.

A post processing review of the recorded photos and videos was used to assess whether each of the potential sighting noted by the observers was correct. The post processing review was performed with the knowledge of the time when the poachers recorded the UAV passed overhead. This was used to identify any instances where the mock poacher was visible but the observer failed to see them. Figure 3.4 shows the success rates for live spotting mock poachers in each hiding behavior compared to mock poachers spotted in the post processing review. As shown, not all of the poachers were visible, even in the post processing review and the live observers did not catch all of the poachers that were visible to the UAV.

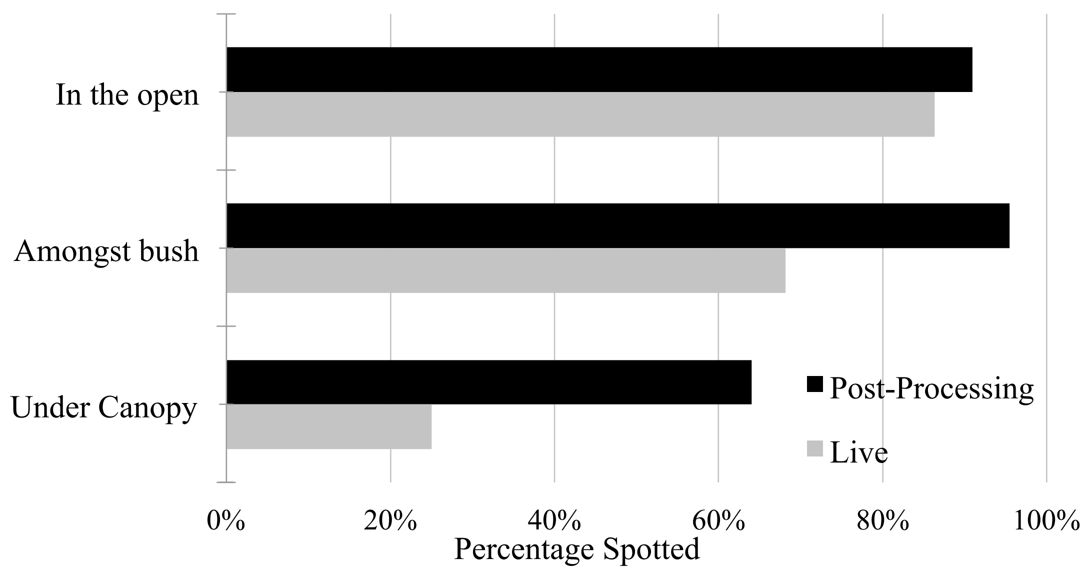

Figure 3.4: Spotting Live vs. Post-Processing; Quad Daytime

The largest discrepancies between the live observer and post processing occurred when the poachers were fully obscured by canopy and could only be spotted in post processing with a careful playback.

Figure 3.5 below shows the same live versus post processing comparison as above except it is with the fixed-wing UAV. The fixed-wing shows similar trends as the quadcopter system however with overall lower success rates.

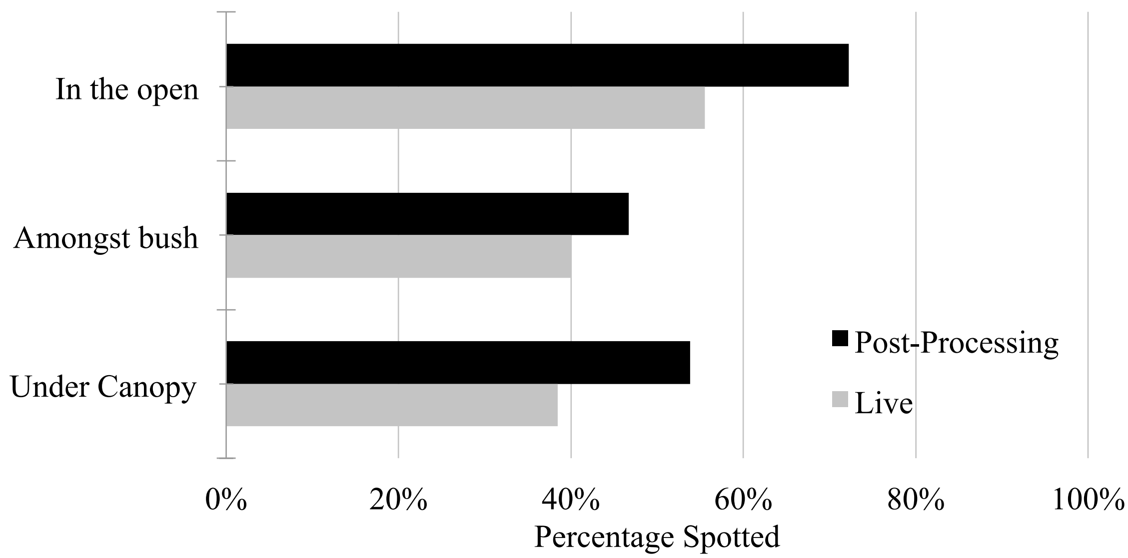

Figure 3.5: Spotting Live vs. Post-Processing; Fixed-wing Daytime

Figure 3.6 shows the success rates for spotting poachers using the FLIR camera at night in comparison to those visible in the post processing review. The quadcopter system at night had higher success rates than during the day, spotting all mock poachers in the open and no less than 67% in any of the 3 hiding behaviors.

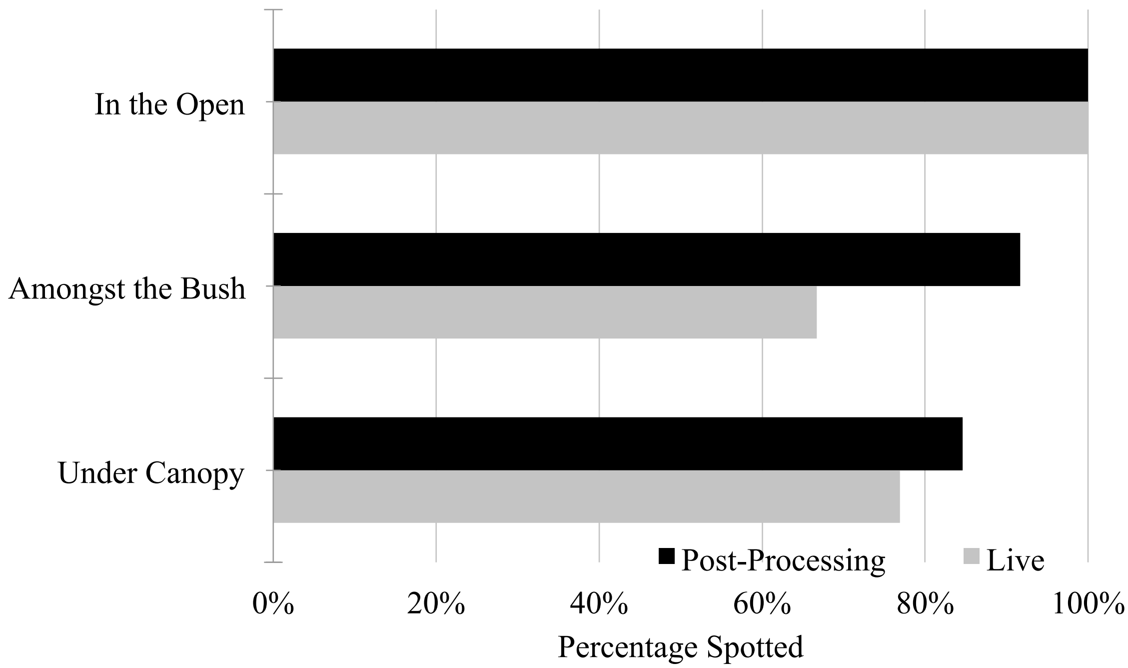

Figure 3.6: Live Spotting vs. Post-Processing; Quad Night

The high success rates during the night came from the high contrast between human body temperatures and the background. Additionally, the thermal camera almost completely penetrated the canopy unlike the RGB cameras during the day, again allowing for clearer spotting.

In order to assess the reaction time that a poacher or the anti-poaching team would have before the other party was alerted, all of the trials were divided into five categories. During the day, the mock poachers always had the advantage while during the nighttime the UAV, and thus anti-poaching unit had the advantage in the majority of the trials. This can be attributed to the blacked out UAV being very difficult to spot. Mock poachers reported they were really only able to spot when it flies overhead and when it momentarily passed in front of stars or the moon (See Table 3.4).

Table 3.4: Reaction advantage

		Quadcopter Day	Fixed-wing Day	Quadcopter Night
	Total number of trials	152	46	38
UAV spots mock poacher.	**Mock poacher does not spot UAV**	0	0	18 (47.4%)
	Mock poacher spots UAV after	0	0	7 (18.4%)
	Mock poacher spots UAV before	84 (55.3%)	21 (45.6%)	5 (13.2%)
UAV does not spot mock poacher.	**Mock poacher spots UAV**	68 (44.7%)	25 (54.4%)	2 (5.3%)
	Mock poacher does not spot UAV	0	0	6 (15.8%)

For trials where the both the poachers and the UAV spotted each other, the average time difference was calculated. For the day, the average reaction time was 732s in favor of the poachers with a standard deviation of 578s. For the night trials, the average reaction time was 29.3s in favor of the poacher with a standard deviation of 137.7s. The very large standard deviations can be attributed to where the poacher was in relation to the start of the flight pattern since the UAV only sees a poacher as it passes overhead, but the poacher has the advantage of being able to see the UAV whether it is approaching, receding, or passing by laterally.

In all cases, day or night, the mock poacher heard the UAV well before spotting it or being spotted. Mock poachers reported that being able to hear the UAV first helped spot it because the sound provided a general direction to look. The distance between the poacher and the UAV at the time when the poacher heard the UAV is not known, as it was not possible to record the UAVs exact position when the poacher heard the UAV. To allow the auditory detection of the UAV to be examined, the ability of the poachers to hear the UAV on takeoff was evaluated for all of the quadcopter flights. The quadcopter took approximately 30 seconds after takeoff to ascend to flight altitude and load waypoints before starting the autonomous flight pattern. Based on this knowledge, any mock poacher who heard the UAV within the first 30 seconds could hear the quadcopter at the takeoff location at the 30m-flight altitude. A slight trend between auditory detection and distance was present, however there was no strong evidence of a distance at which the quadcopter is no longer audible. This lack of clear correlation is possibly due to the effects of varying terrain between the different zones. Figure 3.7 below shows the locations where the UAV was heard on takeoff for Zone A. The area shaded in red represents the viewshed from the UAVs perspective. A ridge running through Zone A blocks line of sight from the takeoff location to the eastern edge of the zone, which is also where the UAV was not heard.

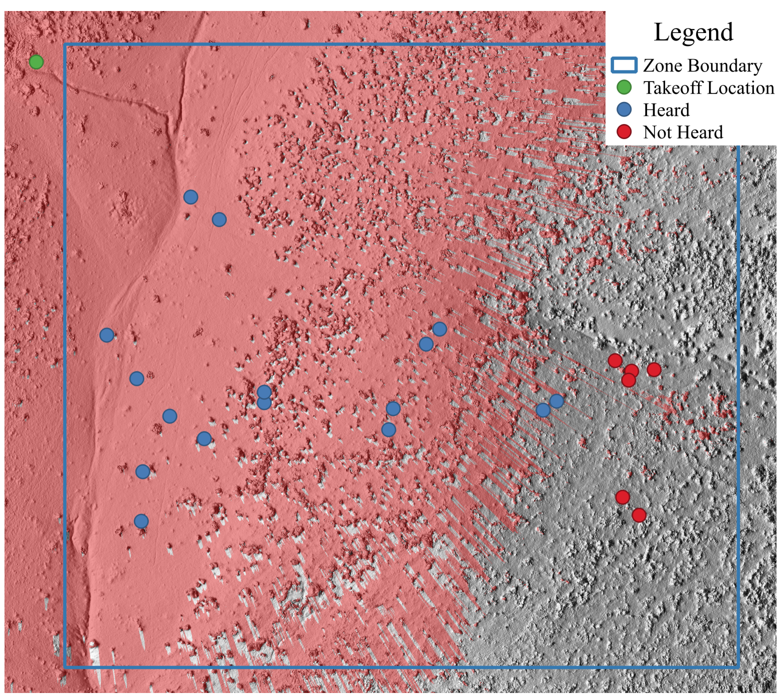

Figure 3.7: Viewshed effect on auditory detection

CHAPTER 4: SUMMARY AND CONCLUSIONS

In total, 118 trials were completed, providing 236 UAV-poacher interdiction scenarios. Of these, 198 were during the day, 152 with the quadcopter and 46 with the fixed-wing. Live spotting success during the day varied heavily depending on the hiding behavior of the mock poachers, with the highest success rate being 86% for poachers in the open and the lowest of just 25% for poachers hiding under canopy cover. Both video and still recording were assessed, however the video recording proved to be much more beneficial since the photo mode caused the live video feed to annoyingly flash black each time a photo was taken. Below 7.5 m/s the flight speed did not have a significant impact on the live spotting success rate, but observers reported that keeping the flight speed closer to 5 m/s made their role much less stressful and they were more confident in their spotting. The camera angle also affected confidence of spotting as well as success rates. A more forward camera angle rather than nadir allowed for the human profile to be better seen as well as remaining on the screen for a longer time. For all of the day trials, the mock poachers were easily able to spot the UAV in the sky before being spotted by it.

The remaining 38 interdiction scenarios were at night with the thermal equipped quadcopter. At night the live spotting success rates were much higher due to the thermal cameras ability to better see through bush cover as well as the increased contrast between body temperature and the surrounding temperature. In the open, 100% of the mock poachers were spotted and the lowest live spotting rate was amongst the bush, with 67% spotted. Although the thermal camera provided an advantage in spotting success, the resolution hindered the confidence of the observers because of the lack of detail. The mock poachers also struggled with spotting the UAV in the sky due to all of the lights being blacked out and on the majority of the trials the UAV was not spotted by the mock poachers.

In contrast to spotting the UAV, the mock poachers had no trouble hearing the UAV from a great distance and often used this to help visually search for the UAS. There was no clear correlation between hearing the UAV distance because the terrain varied greatly between the different study zones and geographic obstructions had a large effect on how far the UAV could be heard from. While the distance at which the UAV could be heard varied greatly, the mock poacher heard the UAV long before the UAV could spot them or they could spot it in every trial. In a real life scenario this early auditory detection would give a poacher an advantage, allowing them to react before the UAV is close enough to catch them. It can be assumed that the poacher would either choose to flee the area or hide under cover until the UAV leaves the area.

During the day, in every trial, the mock poachers were also able to spot the UAV before being detected. Hiding under cover of canopy after hearing and seeing the UAV approaching would reduce the poachers chances of being spotted by the UAV to as low as 25%. This low success rate would limit the UAVs ability to be used as a covert (offensive) tool for catching poachers during the day. Despite this, the UAV can still play an important roll in a more deterrence (defensive) strategy. The far reaching auditory signature combined with the one-in-four chance of being spotted under cover would be threatening enough to serve as a deterrent to poaching on properties employing UAVs for anti-poaching.

At night, the scenario would be similar to the day, however the mock poachers struggled to see the UAV in most of the trials, unlike during the day. The confusion caused by not being able to pinpoint the location of the UAV gives an advantage at night to the security by keeping the poachers uncertain of its exact location. In addition, the thermal camera provides an advantage to the UAV by allowing it to better detect humans, achieving greater than 65% success rate of live spotting across all hiding behaviors. This makes the UAV a much better covert tool for catching poachers at night, however it is still best suited as a deterrent because it can still be heard from far allowing poachers time to flee.

For maximum effectiveness across all platforms and times of daytime, the flight speeds should be maximized to give the poachers the least amount of time to react after hearing or seeing the UAV. The limiting factor for flight speed will be the ability of observers to successfully spot poachers without missing people or getting overly fatigued. A forward facing camera angle, preferably around 45° off nadir was found to aid with live spotting success as it increases the time poachers are on screen and makes their profile more visible. Finally, using video allows for both less interrupted live video feed as well as more information saved for review after flights.

In this study, the quadcopter proved more successful than a fixed-wing, primarily due to its gimbaled camera, higher quality live video transmission, and slower flight speeds. With further improvements the fixed-wing would provide similar success rates to the quad during the day while also covering more ground and staying aloft for longer. At night the fixed-wing would be much more difficult to implement due to the need to takeoff and land on a clearly lit runway.

While the vehicles in this study proved capable of spotting poachers, for them to act as more of a covert tool rather than a deterrent, the noise signature would need to be reduced. Choosing quieter propulsion systems or flying at higher altitudes may achieve the necessary noise reduction. Flying at higher altitudes would also allow each transect to cover a wider strip of land however it would compound the issue of spotting small figures live. To assist in spotting and positively identifying poachers, the use of larger screens and higher quality video for live viewing would help observers be more effective. At night, the slow frame rate and resolution of the thermal camera was a hindrance so a higher resolution thermal camera, with higher frame rate would also be a large improvement. During the day, image quality was not the issue; instead human contrast against the background terrain was the issue. In the future, a computer algorithm that highlights possible shapes could help a human observer to be more successful and become less fatigued during observation. Despite this need for continued technical improvements, UAVs were proven to be a viable tool for deterring poachers because of their ability to spot poachers even with significant auditory presence. In their current form, the UAVs tested in this study were already a viable tool for anti-poaching units.

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