**ABSTRACT**

GLAZER, JOSHUA TYLER. The Effect of Bush Cover and Zone Size on UAV Anti-Poaching in the Savanna. (Under the direction of Dr. Larry Silverberg).

The objective of this thesis is to better understand the effectiveness of UAV surveillance of poaching activities under the protective cover of the savanna. We performed interdiction exercises with mock poachers and anti-poaching unit (APU) UAV operators – keeping the exercises competitive to create a data-rich environment that would more effectively determine the effect of bush cover and zone size on surveillance effectiveness. We conducted 58 exercises over a ten-week period. The success rate of capture depended strongly on bush cover. The success rate in the study zones with the highest bush cover (40% to 55%) was 64.81% with an average capture time of 38.7 minutes. The success rate in the medium bush cover (20% to 35%) zone was 63.02% with an average capture time of 22.32 minutes. The success rate in the zone with low bush cover (0% to 15%) had the highest success rate of 90.48% with an average capture time of 20.97 minutes. The zones were of three sizes: 500 m by 500 m, 750 m by 750 m, and 1 km by 1 km. The success rate of capture of the APU turned out to vary with bush cover more than the sizes of the zones considered. The article also discusses the strategies that the mock poachers and the APU UAV teams employed.

The Effect of Bush Cover and Zone Size on UAV Anti-Poaching in the Savanna

by
Joshua Tyler Glazer

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APPROVED BY:

Dr. Larry Silverberg
Committee Chair

Dr. Ashok Gopalarathnam

Dr. Andre Mazzoleni

## DEDICATION

To my family for all their love and support

# BIOGRAPHY

Joshua Glazer was born in Indianapolis, IN. He received his B.S. in Aerospace Engineering from North Carolina State University in May of 2019. In the following fall semester, he began a M.S. in Aerospace Engineering at North Carolina State University. He worked with Dr. Larry Silverberg apart of the Namibia Wildlife Aerial Observatory working with unmanned aerial systems for anti-poaching.

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# INTRODUCTION

Poaching has decimated the populations of African species such as elephants and rhinos for decades (Western 1985; Douglas 1987). Even in protected African parks, poaching continues to be problematic. Expansive terrains in the savanna and limited road networks pose a challenge to law enforcement and anti-poaching units (APU). Poachers exploit the terrain by slipping by patrols and hiding in the bush. Law enforcement is currently limited to patrolling and interdiction by foot and ground vehicle. Manned aircraft are too expensive for regular use. This paper considers the employment of the unmanned aerial vehicle (UAV) as a practical day-to-day alternative to the manned aircraft.

Security professionals have long been following guiding principles for patrol and interdiction. Police regularly apply them in community settings and military personnel apply them in larger-scale conflicts. These principles drive practices in perimeter protection and interdiction in the presence of protective cover. This paper focuses on the impact of UAVs in an interdiction poaching scenario, a subject that has received limited attention in the scientific community.

Published research on the effectiveness of UAVs in anti-poaching in the savanna is in its early stages. Fixed-wing UAV effectiveness was studied in 20 trials over 13 farms in South Africa. These researchers studied image quality across three types of cameras during the day and night (Mulero-Pazmany, 2014). This helped establish a baseline for the study on how one can effectively spot poachers and animals from drones. Air-Shepard, a security group in southern Africa, used a fixed-wing UAV for anti-poaching at night. These researchers reported that rhino killings in the area ceased after deploying their UAVs, but they did not release their methods (Air Shepherd, 2018). The work by Air-Shepherd is an ongoing effort actively being pursued with anti-poaching units in South Africa, which indicates that UAS may hold promise in anti-poaching. In 2018, researchers studied the practicality and effectiveness of spotting human figures with fixed-wing and multirotor UAVs across 236 trials (van Vuuren et al., 2018). Their studies varied across different terrains with different levels of bush cover during day and night flights. The UAV operators spotted mock poachers more readily with their quadcopters than with their fixed-wing vehicles due to the multi-rotor's slower speeds and higher quality footage.

According to Olivares-Mendez 2015, "…it is estimated that a 10-minute delay [in response time] is sufficient for killing and de-horning a rhino." UAV presence may make the difference in saving an animal's life by increasing the time that the poacher is stuck in the field by preventing poacher movement when the UAV is nearby. Importantly, the increase in time may enable the APU ground team to perform a more informed and safer interdiction. The authors hypothesized that bush cover constitutes a key factor in UAV anti-poaching effectiveness. The authors expected bush cover and zone size to have a large effect on poacher movement and on the effectiveness of UAV surveillance, so we selected level of bush cover and zone size as the primary variables, and conducted the study in such a way that secondary factors could be identified and studied, too.

## METHODS

The focus of the study was on the effectiveness of the UAV by performing interdiction exercises with mock poachers and anti-poaching unit (APU) UAV operators, at the stage in which the location of the poachers was not yet determined. A balanced set of daytime and night-time exercises were conducted over a ten-week period. The effect of capture percentage *C* on two primary parameters were of interest - on bush cover percentage *B* and on zone size *S*. The secondary parameters, given that they were a priori unknown, were teased out of the study by the way the experiment was designed. The experimental design goal was to keep the interdictions competitive. The expectation was that we would be able to study the effect of bush cover and zone size more thoroughly in competitive exercises, recognizing that competition would create a data-rich, learning environment during which the strategies by the mock poachers and UAV operators would become more sophisticated over time. To increase the rate in which the players on both sides learn, we conducted the exercises in zones that were sufficiently large to practically accommodate the interdiction but not so large as to prohibitively increase the time required for an exercise. To maintain the competitiveness throughout the course of the exercises, we allowed some adjustments in the rules that govern the exercises to take place. Based on previous work (van Vuuren et al., 2018), we understood that, when poachers try to slip through patrol and hide, they hear incoming UAVs before seeing them and react accordingly and that UAV operators see the poachers before the poachers first see the UAVs. These factors and the responses of the behaviors of the mock poachers and the UAV operators guided the rule changes.

We performed the exercises in three 1000 m by 1000 m study zones and one 500 m by 500 m study zone over a 10-week period from August to October of 2019. As shown in Figure 1, each 1000m by 1000 m zone was divided into a 4 x 4 grid, further segmented into a 500 m by 500 m 2 x 2 grid and a 750 m by 750 m 3 x 3 grid. The purpose of segmenting the zones was to determine the effect of zone size on anti-poaching effectiveness.


**Figure 1:** Rectangular Study Zones of The Exercises

We estimated the level of bush cover in each zone as follows. First, we acquired satellite images of each study zone through Google Earth and Bing Maps and uploaded it into ImageJ. Next, we converted the images into an 8-bit grayscale. Using the threshold command, we highlighted the dark gray pixels, representing bush, adjusted the thresholds to isolate the bushes in the images, and finally calculated their percent area. In the process, we adjusted the threshold command and made corrections by erasing any dark gray pixels that were observed *not* to be bush cover (See Figure 2).

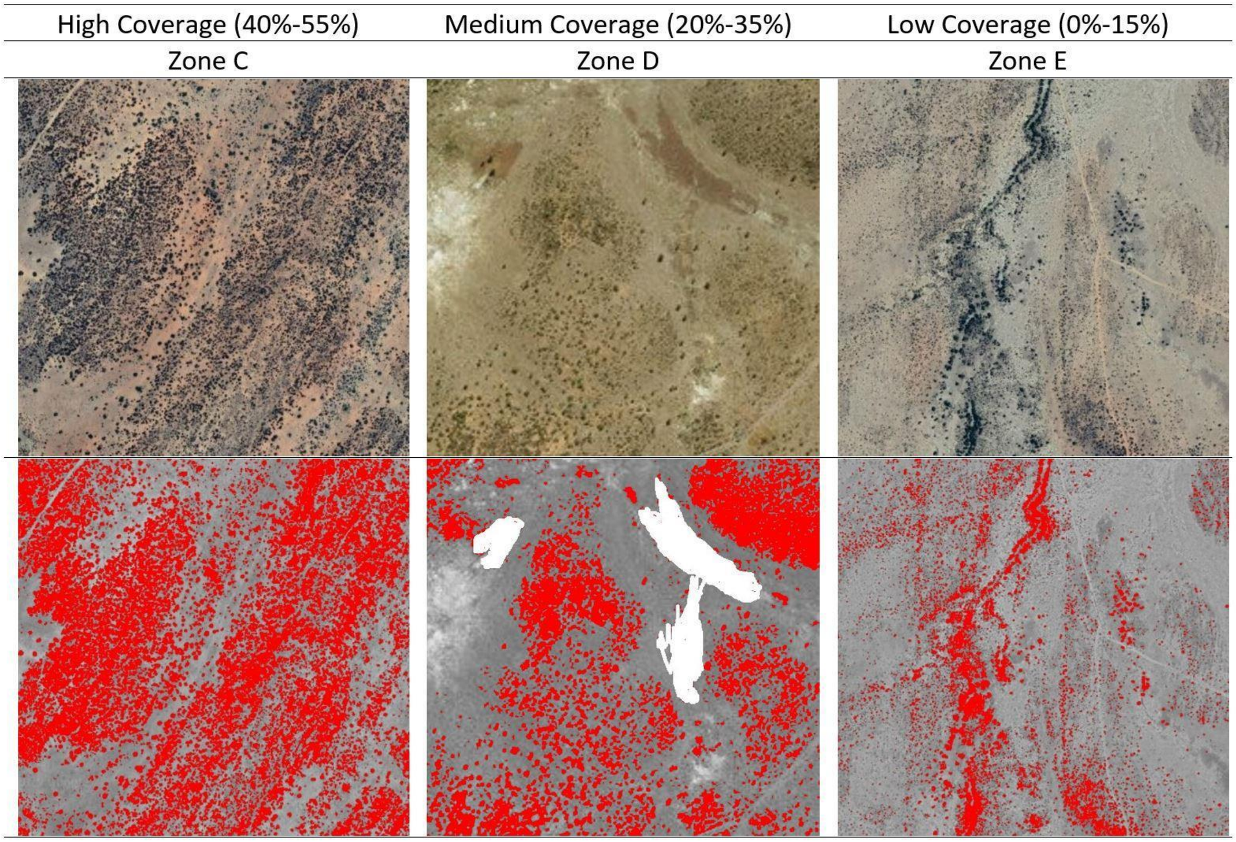


**Figure 2:** Bush Cover

We divided the levels of bush cover in to ranges, labeled as high (*B* between 40% and-55%), medium (*B* between 20% and 35%), and low (*B* between 0% and 15%). Each exercise involved two teams: four mock poachers and an anti-poaching unit (APU). The APU was composed of a flight team and a ground team. Participants rotated through each role for randomization. The mock poachers' main goal was to retrieve a red flag representing an animal and escape undetected. The red flag was hidden in a bush within 100 meters of a last known location. The last known location, specified by GPS coordinates, reflected the poacher's studied understanding of the animal movements within the property. The poachers' last known location was selected such that the poaching team would need to cover most of the zone.

The objective of the APU was for the flight and ground team to find the poachers. The APU flight team's objective was to find the poachers using the UAV and relay it to the ground team, if assisting the APU. When the ground team was present, the poachers had no time limit. Otherwise, poachers had a one-hour time limit to achieve their objective. The time limit was selected on the basis of the ability of the onsite anti-poaching team to fully sweep an area within an hour. The poachers did not know whether a ground team was tracking them. The ground team consisted of one person, who was an experienced onsite game tracker. When employing the ground team, the flight and ground teams-maintained radio contact throughout the exercise. If the ground team spotted the poachers or their footprints, the ground team would direct the flight team to that location. If the flight team identified the poachers first, the flight team would direct the ground team to that location. The exercise ended when the APU team or the poaching team achieved its objective. If the poachers had not achieved their objective within an hour, we assumed that the poachers were hindered long enough for the ground team to have caught them, so those cases were counted as a success for the APU.

We conducted the exercises during the day and at night. Table 1 shows the specifications of each. As shown, we used the DJI Phantom 3 Professional in the daytime exercises and the modified FLIR DJI Phantom 3 Professional in the nighttime exercises.

**Table 1:** Quadcopter Technical Descriptions

| | **DJI Phantom 3 Professional** | **Modified DJI Phantom 3 Professional** |
|---|---|---|
| Aircraft Type | Quadcopter | Quadcopter |
| Camera | RGB | 9Hz FLIR Thermal |
| Resolution | 4K / 12MP | 336 x 256 |
| Flight Speeds | 0 - 15 m/s | 0 - 15 m/s |
| Endurance | 20 min | 20 min |
| Noise Levels at 100 m | 56 dBa | 56 dBa |
| Width | 0.29 m | 0.29 m |
| Length | 0.29 m | 0.29 m |
| Live Video Feed | HD video on smartphone | SD video on 7” LCD |

In all of the exercises, the poachers consisted of two pairs of personnel – a note taker and a timer, and a pair of poachers individually equipped with a GPS and a radio. The note taker recorded important events, such as when they first heard the quadcopter, when it was seen, when the pair of poachers took cover, when the flag was found, and whether escape was achieved. The timer provided the times of these events. The note taker and timer roles were separated because it had proven difficult for a single individual to record everything while the pair of poachers were moving through the bush. The pair of poachers were responsible for navigating the group through the study zone.

The flight team consisted of a pilot, a co-pilot, a note taker, and a timer. The pilot set-up and controlled the UAV while the co-pilot assisted the pilot and monitored the screen for potential poacher sightings. The note taker recorded when these potential sightings took place, when the quadcopter came back for a battery change, and whether the poachers were caught. The timer recorded the times of these events. The roles were rotated after each exercise to give each person equal experience with the different roles of the poachers and the APU, and for randomization.

In preparation for the exercises, we paired study zones with mock poacher starting points and APU flight-team takeoff locations. We selected different terrains and other aspects of the exercises in consultation with the on-property anti-poaching unit to mimic a real interdiction situation. We required the mock poachers' starting points to be out of view of the flight team, at the edge of the research area and not far from a road or a border to reflect where an actual poacher might enter and exit the property. The flight team's takeoff locations required a clearing for take-off and landing, to be located just outside of the research area, and not have a view of the rest of the research zone, which meant it was located in thicker bush cover or over a hill. We positioned the previously known coordinates and exit points so that the poachers would need to cover most of the zone. We changed the coordinates in each exercise to prevent the poacher team from having an unfair advantage.

Before each exercise began, the APU would set-up the quadcopter and the poachers would travel to their starting position. Both teams would synchronously begin their stopwatch. Then the poachers would start making their way to the radius of the last known position, and the flight team would take off. After takeoff, the pilot would manually maneuver the UAV in search of the poachers. Once in the radius, the mock poachers normally split into two groups to cover more ground. When a poacher found a flag, they would display it. This rule reflected that poachers cannot hide most animal parts from view.

Finally, note that we first gave the poachers a head start depending on the area of the study zone. The head start gave them a chance to get further from their starting points and hide, giving added realism to the study. In real interdiction, the poachers will break in before the anti-poaching unit knows of their presence. The head start times were as follows: In the 500m x 500m areas the poachers were given 1 minute, in the 750m x750m areas they were given 2 minutes, and in the 1km x 1km areas they were given 3 minutes. Next, we randomized the exit point to prevent the experienced flight team members from flying over the exit points, whose locations were known.

## RESULTS & DISCUSSION

We conducted a total of 58 exercises over a ten-week period. The daytime exercises were conducted between the hours of 9:00 and 17:00 and the night flights between 20:00 and 1:00 local time. Overall, the success rate of capture of the APU varied with bush cover more than with zone size. The success rate also varied week by week as the poachers and flight team increased their skills. After several weeks, as the rates of learning on both sides leveled out, so too did the success rate of capture level out to about 75%. More details are given in Figure 3.

The strategies employed by the poachers evolved over the course of the study. The changes in the day and night strategies were different because of the significant differences between them. During the day, a common strategy gained the name “follow the leader” or “inchworm.” The strategy consisted of a poacher with a GPS moving to one bush ahead of a next poacher in line. This strategy then evolved into “bush hopping,” in which a general heading would first be pointed out by either of the GPS users followed by everyone selecting their own sequence of bushes. The whole team would move quickly between bushes to remain undercover for the maximum amount of time as the quadcopter sought to catch poachers in the open. Additionally, poachers would take advantage of the 5-minute downtime of the drone when it would have to return to its base for a battery change. Later in the exercises, we gave the mock poachers a second radio. The radio allowed them to communicate more and separate from one another when looking for the flag. The use of the second radio, low volume shouting, and hand signals improved communication at a distance and group coordination overall.

Night mock poaching exercises started halfway through the research period. The APU flight team already had improved its flying skills and the poachers had already become familiar with the terrain. The new nighttime experience caused difficulties for both teams. The camera on the APU's quadcopter was not gimballed, putting them at a disadvantage when trying to spot poachers. The poachers, having lost their long-distance sight and ability to see the quadcopter, could not plan their routes as before. These factors forced each team to change its strategy. The poachers had to learn what bush cover works against the APU and the flight team had to relearn what a person looks like with a thermal camera. The most significant strategy changes for the poachers went from using the day strategy of focusing on movement and balling up under dense branch cover, to listening for the direction of the quadcopter and immediately hiding by laying down under dense vegetation.

The poachers started with the advantage of a shorter learning curve. The group first hid upon hearing the quadcopter, but quickly devised ways to continue moving while staying hidden. Over time, the group learned the terrain by having to maneuver through it when looking for cover as a quadcopter flew near them. Communication and knowledge of the terrain aided them, but as the poachers learned, the flight team also continued to adapt. The flight team took longer to improve because they had to learn the terrain, how to pilot the quadcopter, and what to look for on the small screen to find the images of poachers. The APU also had to learn all of the functions displayed on the screen – altitude, the live video feed from the UAV, GPS position, direction from flight team, cardinal directions, and direction the UAV is currently facing. On the other hand, the APU could employ many different strategies. Pilots could select different altitudes and forward speeds to trade off resolution and coverage, could orbit to survey an area, could check under suspicious trees, fly backwards, and try to trick the poachers with false battery changes. As the exercises continued, the competing teams improved, and a new set of rules were implemented to prevent one team from having an unfair advantage over the other.

The flight teams' initial success resulted from taking advantage of certain rules initially put in place to limit the poaching team's capacity while the flight team was learning. The need to revoke those rules became apparent. Figure 3 shows the success percentage of the flight team over the ten-week period.

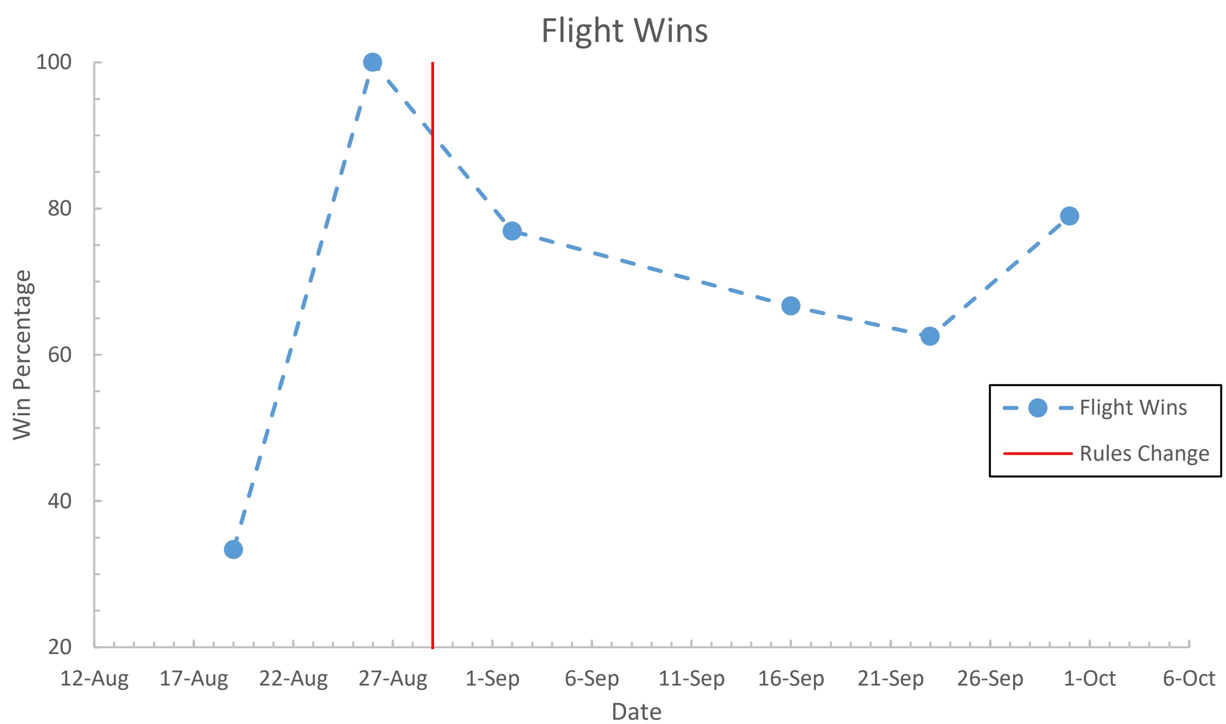


**Figure 3:** Flight Team Wins (Successful Captures) Over Time.

As shown, the flight team initially learned quickly. They took advantage of the rules that limited poacher success. After changing the rules, the flight team's success became steadier and more balanced with the mock poachers' skills. Before the changes, the APU caught the poachers 66.7% of the time, after the changes 73.1% of the time and overall the APU caught the poachers 72.41% of the time.

Table 3 shows how zone size and bush cover affected capture percentage and Table 4 shows how zone size and bush cover affected time to capture. The success rate of capture depended strongly on the bush cover in each study zone, where it was more difficult to spot the poachers in the zones with high bush cover. The success rate in the study zones with the highest bush cover (*B* between 40% and 55%) was about 65% with an average capture time of about 39 minutes. Study zone D had medium bush cover (*B* between 20% and 35%). Its success rate was about 63% with an average capture time of about 22 minutes. Study Zone E, which had low bush cover (*B* between 0% and 15%), had the highest success rate of about 90% with an average capture time of about 21 minutes.

We found that the study zones with high bush cover resulted in a higher degree of difficulty when it came to locating the poachers with the quadcopter. The ground team also had a much shorter line of sight, making it more difficult to track poachers. As shown, bush cover influenced the success rates and capture times more than zone size.

**Table 2:** Capture Percentage Per Different Sized Zones

| **Average Capture Rate (%)** | | | | | **Average %** |
|---|---|---|---|---|---|
| **Zone Coverage** | **A&C 40-55%** | 44.44 | 83.33 | 66.67 | 64.81 |
| | **D - 20-35%** | 20.00 | 85.71 | 83.33 | 63.02 |
| | **E - 0-15%** | 100.00 | 85.71 | 85.71 | 90.48 |
| **Zone Size** | | **500m** | **750m** | **1000m** | |

**Table 3:** Capture Time Per Different Sized Zones

| Average Time to Catch Poachers (Minutes) | | | | | Average |
|---|---|---|---|---|---|
| Zone Coverage | A&C 40-55% | 36.00 | 41.60 | 38.50 | 38.70 |
| | D - 20-35% | 34.00 | 15.17 | 17.80 | 22.32 |
| | E - 0-15% | 14.40 | 29.83 | 18.67 | 20.97 |
| Zone Size 500m | | 500m | 750m | 1000m | |

We observed an inverse trend by combining the data (See Fig. 4). The capture percentage decreased with bush overage while the time to capture increased with bush cover.

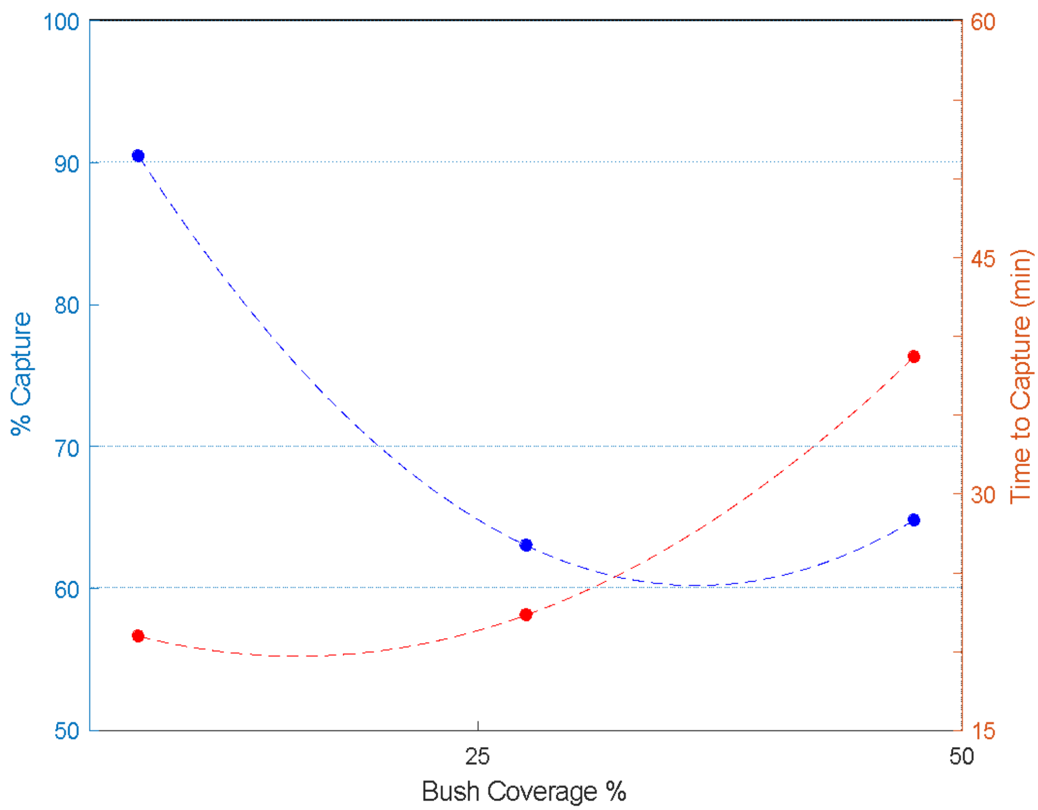


**Figure 4:** Bush Cover vs Capture and Time.

Using the combined data from Table 3, we can also determine the relationship between zone size and bush cover. Figure 5 shows a co-plot of bush cover versus capture percentage and zone size versus capture percentage. Using these points and looking at the $R^2$ values for each data set, we obtained a strong correlation between bush cover and capture percentage, but a weaker correlation between area size and capture percentage.

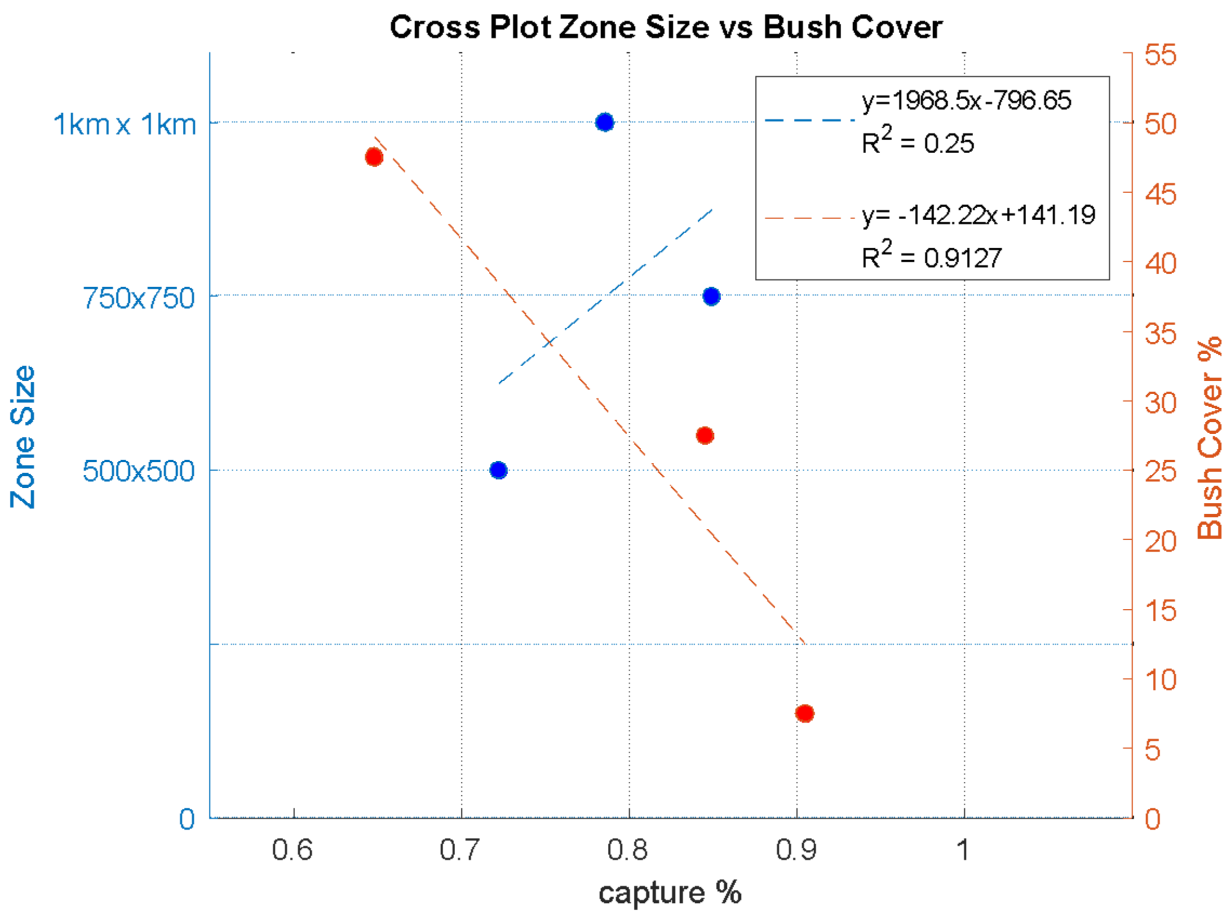


**Figure 5:** Cross Plot of Bush Cover And Area Size

We conducted 30 poaching exercises during the day and 28 at night. The thermal camera provided a few advantages to the APU including the ability to penetrate thin bush cover that could block the Phantom Professional camera during the day. However, the thermal camera was not well suited to investigating cover with thick branches that radiate heat because the branches block the thermal signatures at night while these same branches may provide little to no cover from the quadcopter during the day. The flight team's success rate for daytime exercises was 73.33% and at night was 71.43%.

One of the challenges in night exercises was false sightings of poachers that resulted from the high number of animals in the area and the lack of detail in the thermal video feed. However, once it was determined that a sighting was incorrect the exercise resumed. Note that the number of these false sightings would be expected to decrease with a higher resolution thermal image, which would also be expected to result in decreasing the time to spot a suspicious subject.

During the day, the average capture time was 28 minutes. While the APU success rates for both day and night exercises were determined to be similar, the night exercises were slightly faster. The average difference in time to capture poachers during the day and during the night was 20 minutes. What is key from this is that when APUs are planning out how to integrate UAVs into their operations, the bush cover of the area is 3 times more impactful than the zone size.

## SUMMARY & CONCLUSIONS

A total of 58 anti-poaching exercises were conducted, of which the APU team caught the mock poachers in 43 (72.41%) of the exercises. We conducted the exercises in zones that were 500m by 500m, 750m by 750m, and 1km by 1km, and with levels of bush cover that were low (0-15%), medium (20-35%), and high (40-55%). In the exercises conducted, we found that bush cover contributes overall to capture success more than zone size ($R^2$ = 0.91 for bush cover, $R^2$ = 0.25 for zone size). In the low bush cover zones, the poachers were caught about 90% of the time over an average time of 21 minutes. In the medium bush cover zone, the poachers were caught 63% of the time over an average time of 22 minutes. In the high cover zone, the poachers were caught about 65% of the time over an average time of 39 minutes.

In the study, we identified several important secondary variables. First, we identified the amount of time that the poachers sustain visual contact with a quadcopter to be important. In the exercises, the mock poachers routinely used the sound of the quadcopter to home in on and spot the quadcopter. This occurred at night, too, because battery lights on the quadcopter penetrated through the electrical tape placed over them. Spotting the UAV helped the poachers although it did not guarantee success because the UAVs flew in full manual mode, with the ability to rapidly adjust flight patterns. Also, spotting the UAV only assisted the poachers in knowing when to hide but they could still be caught when hiding. Next, we identified the effect of wind As an important secondary variable. The wind could mask the sound of the UAV, which enabled the APU quadcopter to sneak up on the poachers, giving them little time to hide. On days with more wind, the mock poachers became more cautious, utilizing bush cover more frequently.

Based on the findings, the following scenarios could potentially increase APU effectiveness:

(1) Employ two UAVs in the ground team. Multiple UAVs allows for an area to be searched at an increased rate. With multiple UAVs and a staggered battery change, a minimum of one vehicle would be in the air at all times, preventing poachers from exploiting battery changes.

(2) Consider flying a fixed wing UAV together with a quadcopter. The fixed-wing UAV would fly transects over low bush cover areas, particularly areas that poachers would need to cross, while delivering a live video feed. At the same time, a quadcopter would more effectively fly over the areas of high bush cover.

(3) Use a larger screen to increase the ability to spot poachers. On a standard cellphone screen, the poachers are more difficult to spot, especially when they are moving towards the top of the screen. The smaller screen also causes eye strain.

Scientific research in the wildlife conservation community of the anti-poaching problem is almost non-existent. This article reported on one such study. Pertaining to the role of the UAV in anti-poaching, future work may consider focusing on the effectiveness of communications between the APU ground team and its UAV team, and the trade-offs between strategies employing multi-rotor and quadcopter UAVs. In addition to interdiction studies, future research could focus on patrol studies, such as the development of no-pass zones, and on search studies, such as the spotting of poachers on look-out.

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