FINAL REPORT

Use of sUAS/UAS to Cost Effectively Monitor Eagle Nesting

ESTCP Project RC18-5046

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Select Engineering Services

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Dugway Proving Ground (DPG), located in west-central Utah, is a U.S. Department of Defense (DoD) test site for chemical and biological defensive testing; it is also home to multiple breeding pairs of golden eagles (Aquila chrysaetos). The presence of an eagle nest has the potential to stop military testing and training due to potential nest disturbance. It is vital to DPG and similar DoD installations to fully understand the status of in-use eagle nests on military lands. Using Unmanned Aircraft Systems (UAS) and Small Unmanned Aircraft Systems (sUAS), it may be possible to obtain accurate status updates of eagle nests on DoD lands more efficiently than can be accomplished on foot. The DPG Team designed a blind study conducting weekly golden eagle nest surveys on DPG to compare the effectiveness of sUAS, UAS, and ground observers.

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ACRONYMS AND ABBREVIATIONS

AGATCS	Army Ground Aerial Target Control System
AWR	Airworthiness Release
BGEPA	Bald and Golden Eagle Protection Act
CIO	Chief Information Officer
COTS	Commercial Off The Shelf
DoD	Department of Defense
DPG	Dugway Proving Ground
ETP	Exemption to Policy
FAA	Federal Aviation Administration
HWI	HawkWatch International
MBTA	Migratory Bird Treaty Act
MRTFB	Major Range and Test Facility Base
NDAA	National Defense Authorization Act
PIC	Pilot in Command
POC	Point Of Contact
RIAC	Rapid Integration and Acceptance Center
SES	Select Engineering Services
SIPR	Secret Internet Protocol Router
sUAS	Small Unmanned Aircraft System
TSMO	Threat System Management Office
UAS	Unmanned Aircraft System
USFWS	US Fish and Wildlife Service
UXO	Unexploded Ordinance Training
VLOS	Visual Line-Of-Sight

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ABSTRACT

INTRODUCTION AND OBJECTIVES

Dugway Proving Ground (DPG), located in west-central Utah, is a U.S. Department of Defense (DoD) test site for chemical and biological defensive testing; it is also home to multiple breeding pairs of golden eagles (*Aquila chrysaetos*). The presence of an eagle nest has the potential to stop military testing and training due to potential nest disturbance. It is vital to DPG and similar DoD installations to fully understand the status of in-use eagle nests on military lands. Using Unmanned Aircraft Systems (UAS) and Small Unmanned Aircraft Systems (sUAS), it may be possible to obtain accurate status updates of eagle nests on DoD lands more efficiently than can be accomplished on foot. The DPG Team designed a blind study conducting weekly golden eagle nest surveys on DPG to compare the effectiveness of sUAS, UAS, and ground observers.

TECHNOLOGY DESCRIPTION

The DPG Team conducted weekly golden eagle nest surveys on DPG during the 2019 and 2020 nesting seasons, using a blind study design, to compare the effectiveness of three “survey systems”: 1) a ground-based human observer, 2) a commercially available small Unmanned Aircraft System *(sUAS; DJI Matrice M600 and E Mergent RC E900),* and 3) a military-grade UAS platform *(MQ-1C Gray Eagle).*

PERFORMANCE AND COST ASSESSMENT

No single platform was clearly superior across all seasons and periods of observation. During the 2019 season, the sUAS observation team proved the most efficient at locating in-use and unknown nests, but it was more expensive than the ground observer (annual operation cost of approx. $130k for the sUAS, versus $20k for the ground observer). The UAS team did not observe frequently enough to be directly compared but appeared to be most efficient observing well-known nests with lots of metadata to reference. UAS costs were not directly assessed, as they operate as part of a larger installation program. Results differed significantly during the 2020 season after the sUAS platform used in 2019 was prohibited from use under the FY19 National Defense Authorization Act (NDAA). In 2020, the sUAS team had trouble locating nests or identifying status due to the change in platform/payload and was not as efficient as the ground observer. The results indicate that the use of an sUAS is effective but may not yet be able to cost-effectively replace ground monitoring. For instances where the nests are too high or terrain too rugged, sUAS are especially effective. As the cost of the sUAS system is reduced and the policy surrounding flying sUAS in DoD airspace is streamlined, it may become cost-effective compared to on-the-ground monitoring.

IMPLEMENTATION ISSUES

A major implementation issue with the use of sUAS in DoD airspace involves obtaining an Airworthiness Release (AWR) and Exemption to Policy (ETP). Both approvals take time to develop, review, and obtain approval. Good metadata and a member of the team that has experience with eagle behavior and good knowledge of the territory is key to obtaining useful data. The UAS observation method was the most uncertain and it proved to be unreliable as a method of weekly nest observations due to scheduling and payload restrictions. If the nest location was well known, the UAS was by far the fastest and most efficient observation method. However, the nature of the platform’s flight and approach patterns made detailed nest metadata critical to the success of the survey.

EXECUTIVE SUMMARY

INTRODUCTION

Dugway Proving Ground (DPG), located in remote west-central Utah, serves as a Major Range Test and Facility Base (MRTFB) test site for chemical and biological defensive testing, battlefield smokes, and obscurants. In addition, DPG is home to multiple breeding pairs of golden eagles, which are protected under the Bald and Golden Eagle Protection Act (BGEPA) and the Migratory Bird Treaty Act (MBTA). Due to these regulatory drivers, the presence of an eagle nest has the potential to restrict military testing and training if military activity causes nest disturbance. It is therefore vital to the function of DPG and similar DoD testing and training ranges to fully understand the location and status of in-use eagle nests or territories on military lands.

Current survey techniques of nesting golden eagles on DPG and active DoD training properties require long-distance viewing of each nest from the ground at least weekly, which is both time-consuming, costly, and may not always provide a definitive status of nest changes *(Weissensteiner and Poelstra 2015)* due to limited visibility from the ground. Using both military-grade and commercial Unmanned Aircraft Systems (UAS)/Small Unmanned Aircraft Systems (sUAS), it is possible to obtain highly accurate locations and status updates of in-use golden eagle nests on DoD lands, data that is critical to maintaining open testing and training ranges for as much time as possible in the eagle nesting season *(Chabot and Bird 2015, Hodgson et al. 2016, Junda et al. 2015, Weissensteiner and Poelstra 2015)*. The sUAS/UAS can be used to detect new nests in areas that are difficult to see or access from the ground, as well as count nestlings and track nesting milestones in a less time-invasive manner not previously possible *(Weissensteiner and Poelstra 2015)*. All of this can be accomplished with greatly reduced disturbance to the nesting pairs *(through reduced time in the area)*, crucial to the success of sensitive nesters such as the golden eagle *(Chabot and Bird 2015, Scobie and Hugenholtz 2016, Weissensteiner and Poelstra 2015)*.

OBJECTIVES

Select Engineering Services (SES), in coordination with DPG, the Rapid Integration and Acceptance Center (RIAC), Threat Systems Management Office (TSMO), and HawkWatch International (HWI), hereinafter referred to as the DPG Team, developed this technology demonstration to demonstrate the use of sUAS/UAS as a cost-effective way to monitor golden eagles on military installations. Currently it takes approximately 960 hours to conduct on-the-ground monitoring of eagle nests for approximately six months *(based upon actual numbers provided by DPG and SES experience).* The primary objective was to reduce the total hours required to monitor the nests and evaluate the cost-effectiveness of using sUAS/UAS over in-person ground based monitoring. Other objectives of the demonstration included the following:

- Efficiencies of scale to monitor more nests in less time for a lower cost
- Demonstrated the effectiveness of sUAS/UAS versus on-the-ground observation
- Improved quality of still photos and videos for further analysis
- Demonstrated use of sUAS/UAS as safe and low disturbance to the eagles
- Demonstrated use of sUAS/UAS to enable greater access to the nest and ability to collect more detailed data

- Demonstrated use of sUAS/UAS as more efficient in finding nests in particular settings such as hidden/remote terrain

TECHNOLOGY DESCRIPTION

The DPG Team conducted weekly golden eagle nest surveys on DPG during the 2019 and 2020 nesting seasons to compare the effectiveness of three "survey systems": 1) a ground-based human observer, 2) a commercially available sUAS, and 3) one or more military-grade UAS platform(s). These nest surveys were conducted as a blind study; none of the three teams of observers encountered one another in the field. None exchanged information concerning the nest surveys, and none had any access to data generated by surveys conducted by any of the other teams.

sUAS/UAS Platform Descriptions

In the 2019 study season, a DJI Matrice sUAS platform was procured with an approved DoD software patch, through the Army Ground Aerial Target Control System (AGATCS), in partnership with the TSMO. DJI Zenmuse Z30 cameras were used as the operational payload, with 32x optical zoom allowing for long-range HD observations. This system was approved for use during the 2019 nesting season. However, in December 2019 the National Defense Authorization Act (NDAA) was signed which stated that DoD could not operate or enter into or renew a contract for the procurement of a covered unmanned aircraft system that is manufactured in a covered foreign country. Foreign country was defined as People's Republic of China. sUAS platforms by DoD programs except in the case of sUAS counter-defense testing. This language was strictly interpreted to prevent the use of the modified DJI Matrice that was used the previous year. This led the DPG Team to seek out another option. Through discussions with TMSO, an alternative sUAS was identified for use, the E Mergent RC E900 platform. The two E900s were integrated with Sony FCB-EV7520A camera payloads.

DPG is also home to the Rapid Integration and Acceptance Center (RIAC) which was established by the Project Manager Unmanned Aircraft Systems to create a single location where unmanned and manned aircraft could complete end-to-end testing and integration. DPG coordinated with RIAC to conduct monitoring flights when they were not conducting mission flights. RIAC identified a military UAS platform that would be most suitable for this type of flight plan: the MQ-1C Gray Eagle.

Survey Methods

The DPG Team conducted weekly golden eagle nest surveys on DPG during the 2019 and 2020 nesting seasons to compare the effectiveness of three "survey systems": 1) a ground-based human observer, 2) a commercially available small Unmanned Aircraft System, and 3) one or more military-grade UAS platform(s). The ground-observer was a single vehicle-based biologist; the sUAS system included three personnel *(commercial pilot, observer, and biologist for video monitoring)*; and the military UAS required three personnel *(military pilot, military camera operator, and civilian biologist for video monitoring)*. All three biologists associated with each survey approach had comparable familiarity with existing DPG eagle territories and previous eagle nest monitoring experience.

The DPG Team generated territory-specific data sheets that specify known nests within 11 known territories on DPG, nest survey order based on historic use patterns, and other detailed survey instructions. The UAS observation team conducted a separate territory and nest survey effort designed to test the platform's capabilities as a precision, on demand survey system for areas with little to no ground access. Two senior DPG environmental staff provided weekly oversight of data collected by all three survey systems and collated survey results to ascertain the weekly "benchmark" status of each territory, and to ensure survey protocols were properly followed. Camera data from a subset of nests were also used to provide retrospective verification and correction of weekly status.

Each annual survey was segmented into two time-periods: the "early season", defined as 10 February–14 April *(9–10 weeks)* and the "late season", defined as 15 April–30 June *(12 weeks)*. The primary goal of the early season surveys was to document "Occupied Territories" (pair of adults present), "In-Use Nests" (nest with eggs or young), and "Vacant Territories" (no in-use nests and no adult birds in territory), while the goal of late season surveys was to track In-Use Nest to "Success" *(at least one nestling surviving to 80% fledge age)* or "Failure" *(terms adapted from Steenhof et al. [2017]).* During the early season, all 11 territories were surveyed every two weeks *(e.g., 6 one week, five the next).* In contrast, late season surveys were restricted to In-Use Nests found during the early season surveys, plus any territories with unresolved status.

For ground and sUAS survey systems, independent teams attempted to survey each nest from outside an 800-m horizontal protective buffer *(as widely prescribed on public lands and suggested by Romin and Muck [2002]).* Biologists associated with each survey system recorded eagle response behavior *(i.e., any agitation or flushing observed while conducting nest surveys).*

Surveys conducted for each platform followed specific territory and nest survey protocols to ensure comparable methods were employed and to facilitate the capture of detailed time-keeping records associated with specific survey tasks. Biologists for each survey system recorded total daily "Survey Time", which began upon departure from English Village *(ground and sUAS)* or initiation of take-off from the DPG airfield (UAS) and continued until return to same location at the end of the survey effort. For each platform, "Territory Survey Time" was noted, starting when entering into a 2km buffer around known nests associated with each territory, and continuing until status was confirmed, and the survey was complete, or a 3-hr time limit was reached. Time spent within each territory involved in "Area Search" *(general scanning overall area for adult and nesting evidence),* "Nest Search" *(prescribed order survey of known nests),* and "Extended Search" *(searching for new or uncatalogued nests)* was also recorded. Surveyors used standardized terminology established in this document and photographic guides to age eagle nestlings *(Driscoll 2010, Hoechlin 1976).*

PERFORMANCE ASSESSMENT

Time to Early Season Status

The ground observer and the sUAS took roughly the same amount of time to determine early season territory occupancy each year, even with the change in sUAS platform in 2020. The UAS platform was rarely able to make definitive determinations within the given time allowed, and its data was subsequently not comparable to the other platforms. Most of the time required by both the sUAS and ground observer was taken by drive time between nests in a territory.

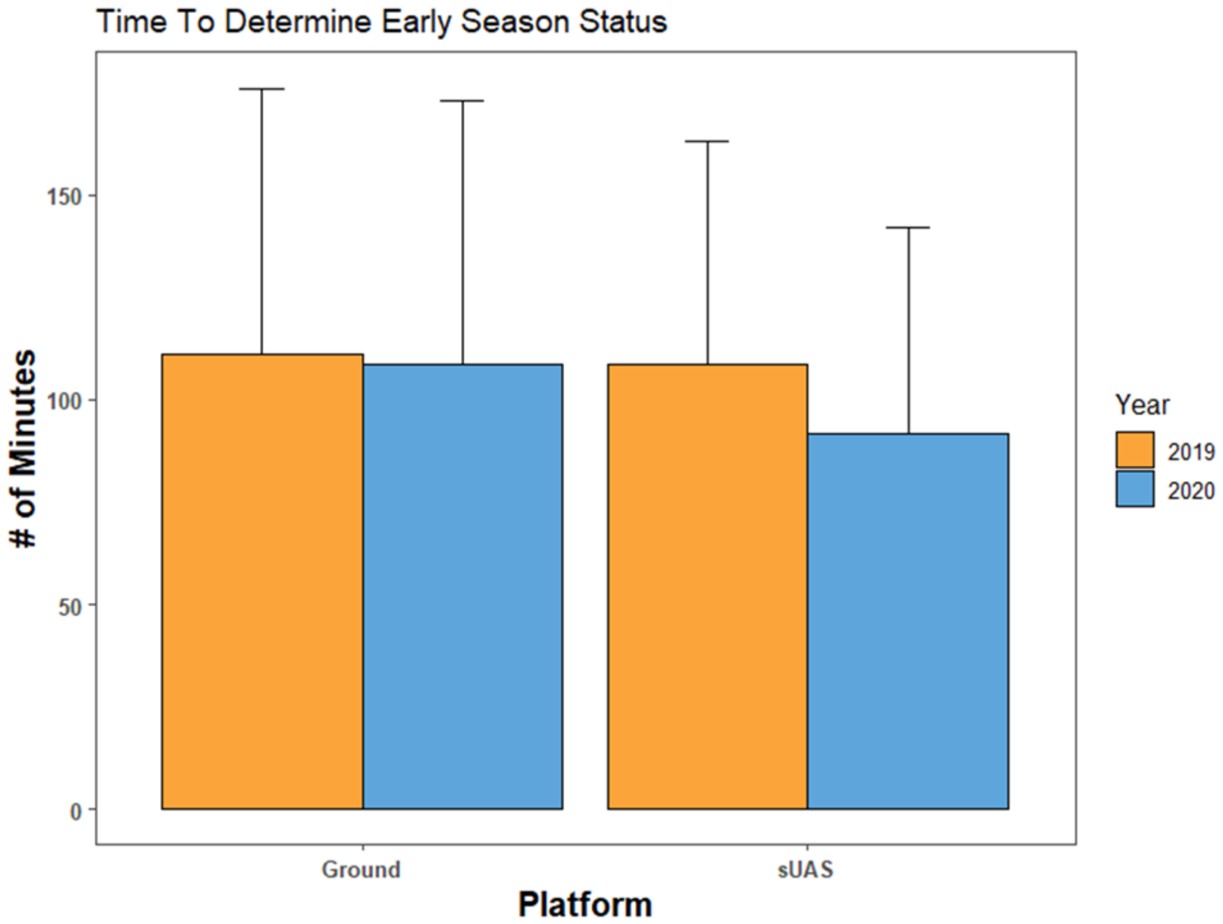


Figure ES-1. Chart Showing the Mean Time in Minutes (+SD) Each Platform Required to Determine the Early Season Occupancy of a Territory.

Date of In-Use Nest Identification

The sUAS platform was roughly equal with the ground observer at detecting in-use nests in 2019. The sUAS platform was able to survey almost every known nest in each assigned territory each week, making it more likely for the platform to detect an incubating eagle within a week of nesting initiation. The ground observer, on the other hand, was forced to rotate which nests were surveyed during each visit due to long hikes over rough terrain. The 2019 UAS was typically not able to identify nest activity due to the low resolution of its payload and the lack of precise nest metadata provided to its pilots and was not compared. In 2020 the sUAS was again roughly equal to the gound observer in nest detection time, despite the sUAS's drop in payload resolution. This indicates that the advantage of visiting more nests outweighed the disadvantage of poor payload resolution. In 2020, the UAS platform was forced to cease surveys before nests became in-use, removing it from this comparison.

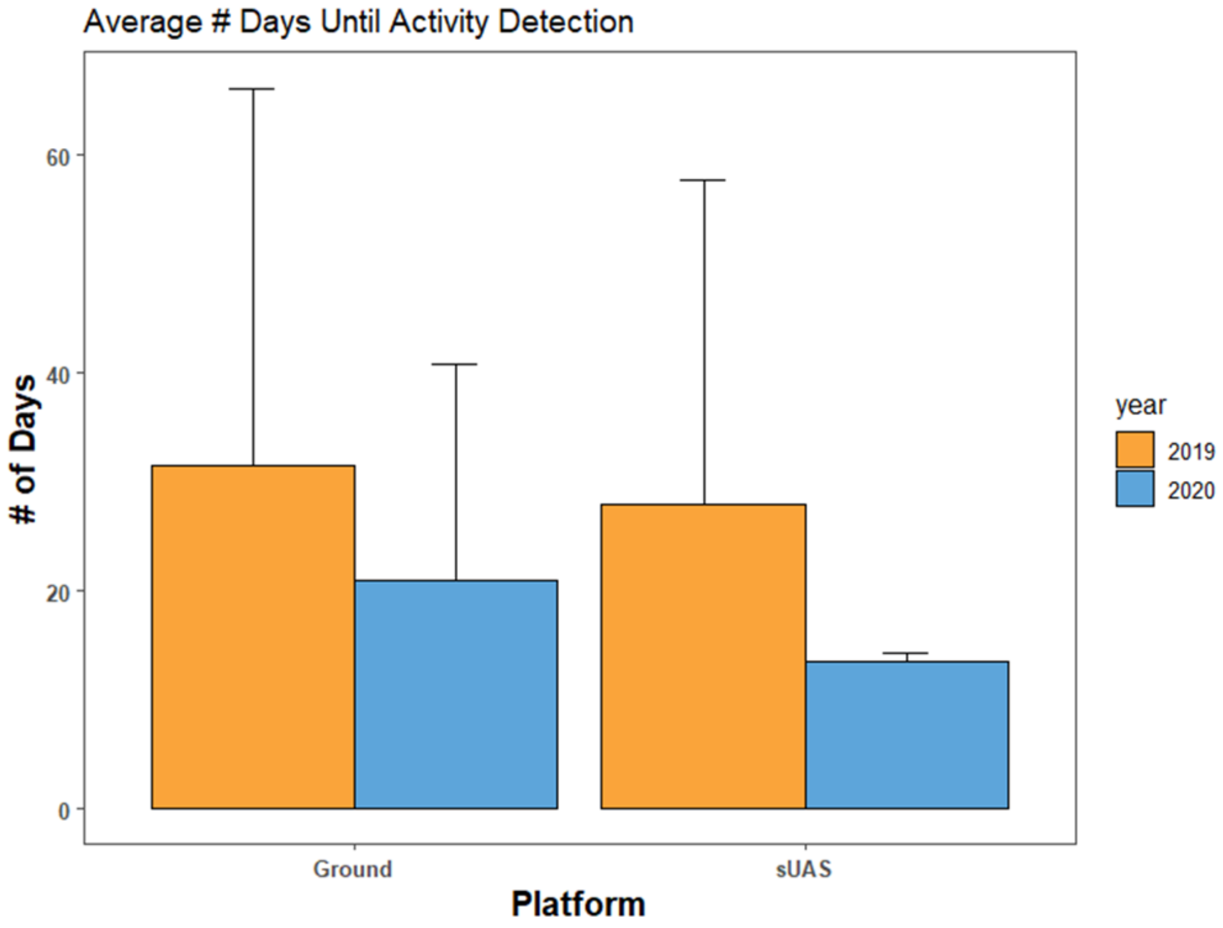
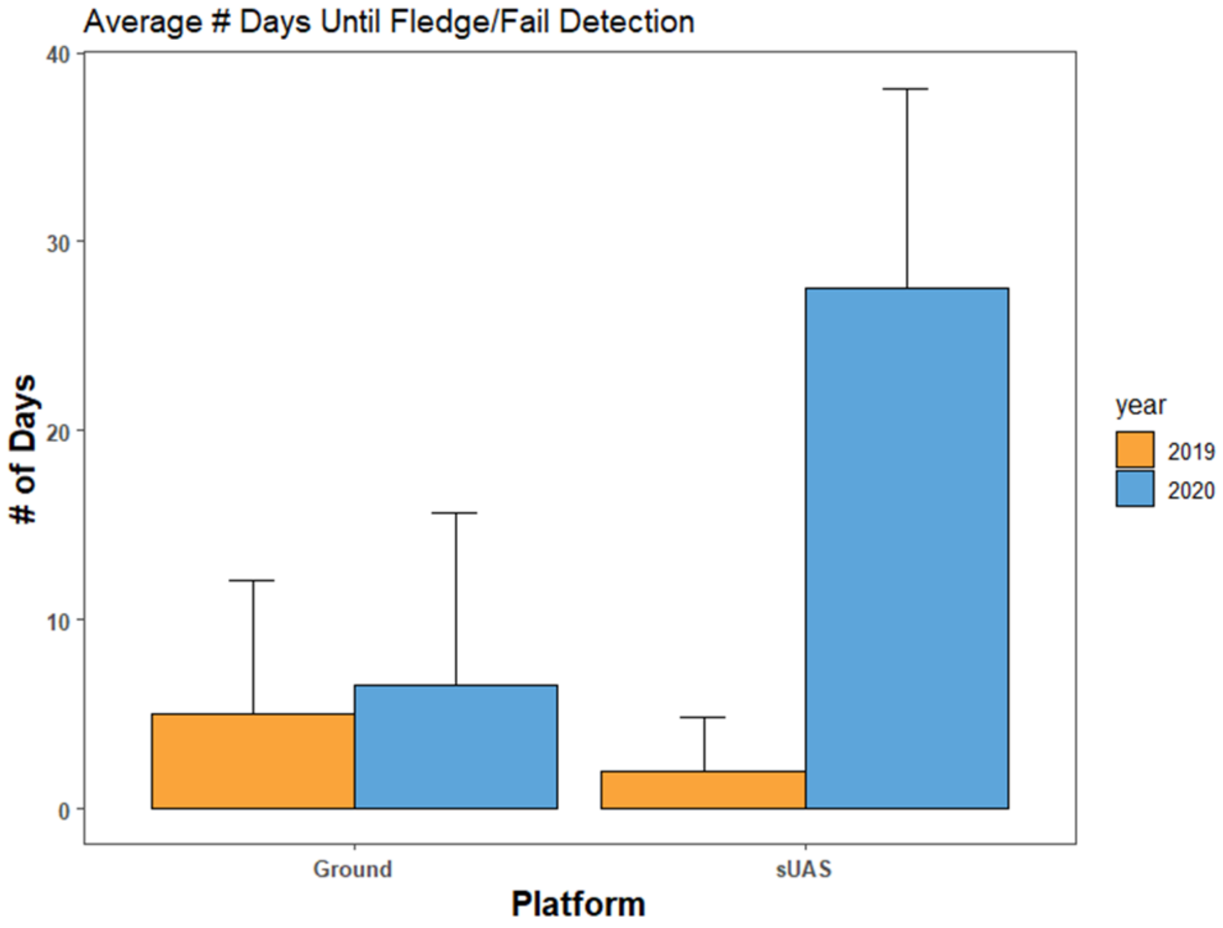


Figure ES-2. Chart Showing the Mean Number of Days (+SD) from Nest Initiation to Activity Detection by Each Platform.

Date of Nest Failure or Fledge Identification

In 2019, the ground observer and sUAS platforms very nearly tied for speed at detecting nest failure or fledge. Both had sufficient quality optics and visitation rates to detect the lack of chicks in a nest almost immediately. The UAS was not compared due to lack of data. By contrast, the ground observer was much faster to detect nest failure or fledge in 2020 than the sUAS. The sUAS's loss of payload resolution made it difficult for the platform to identify the presence or absence of small chicks in a nest. Again, the UAS was forced to cease surveys before nests became in-use, removing it from this comparison.



ES Figure ES-3. Chart Showing the Mean Number of Days (+SD) from Nest Failure or Fledge to Detection by Each Platform.

Time to Nest Status Update

These models illustrate the differences in nest observation efficiency both between platforms and between years. In 2019, the sUAS displayed a clear efficiency advantage over the ground observer, requiring much less observation time to make a nest status determination, especially in the early nesting season. This is because of the sUAS's ability to view directly into a nest bowl, eliminating the need to wait for a possible incubating eagle to stand or stretch in order to come into view from the ground. As the nesting season went on and chicks got larger, they were easier to see from below, decreasing the advantage of the sUAS. In 2020, the sUAS retained a small advantage over the ground observer, but the poor resolution of the payload meant that the platform had to observe each nest for much longer in order to determine if an object perceived to be in the nest was actually an eagle or if it was simply a pixilation artifact. In addition, the ground observer in 2020 took more time on average as the season went on, mostly due to the fact that one of the in-use nests was located in a high, partially obscured cliff cavity, preventing easy observation at any time.

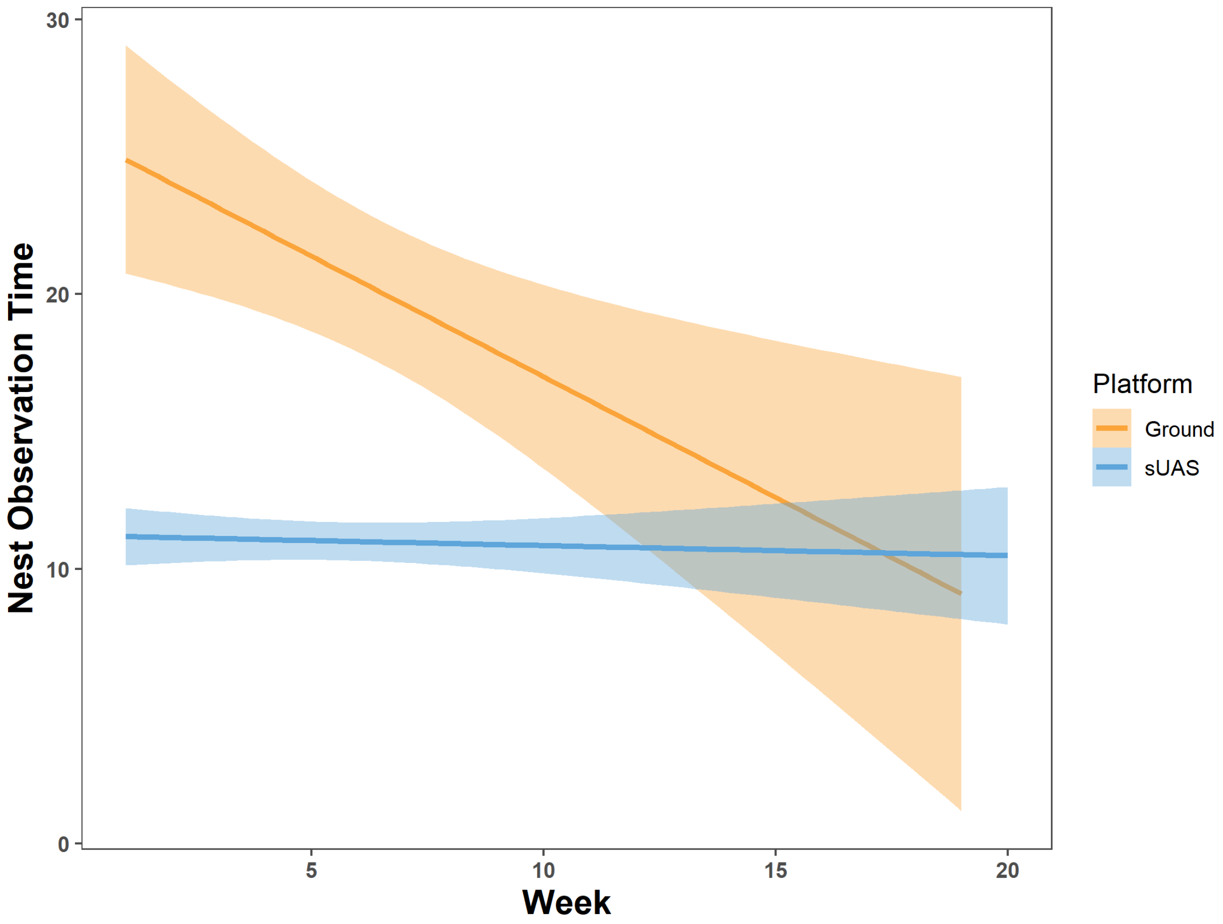


Figure ES-4. Comparison of the Efficiency of a Ground Observer in Minutes (± 95% Confidence Intervals) vs an sUAS at Determining Any Given Nest's Status During 2019.

The sUAS took vastly less time to determine status during early season, while the ground observer gained efficiency as unused nests were eliminated from the survey round.

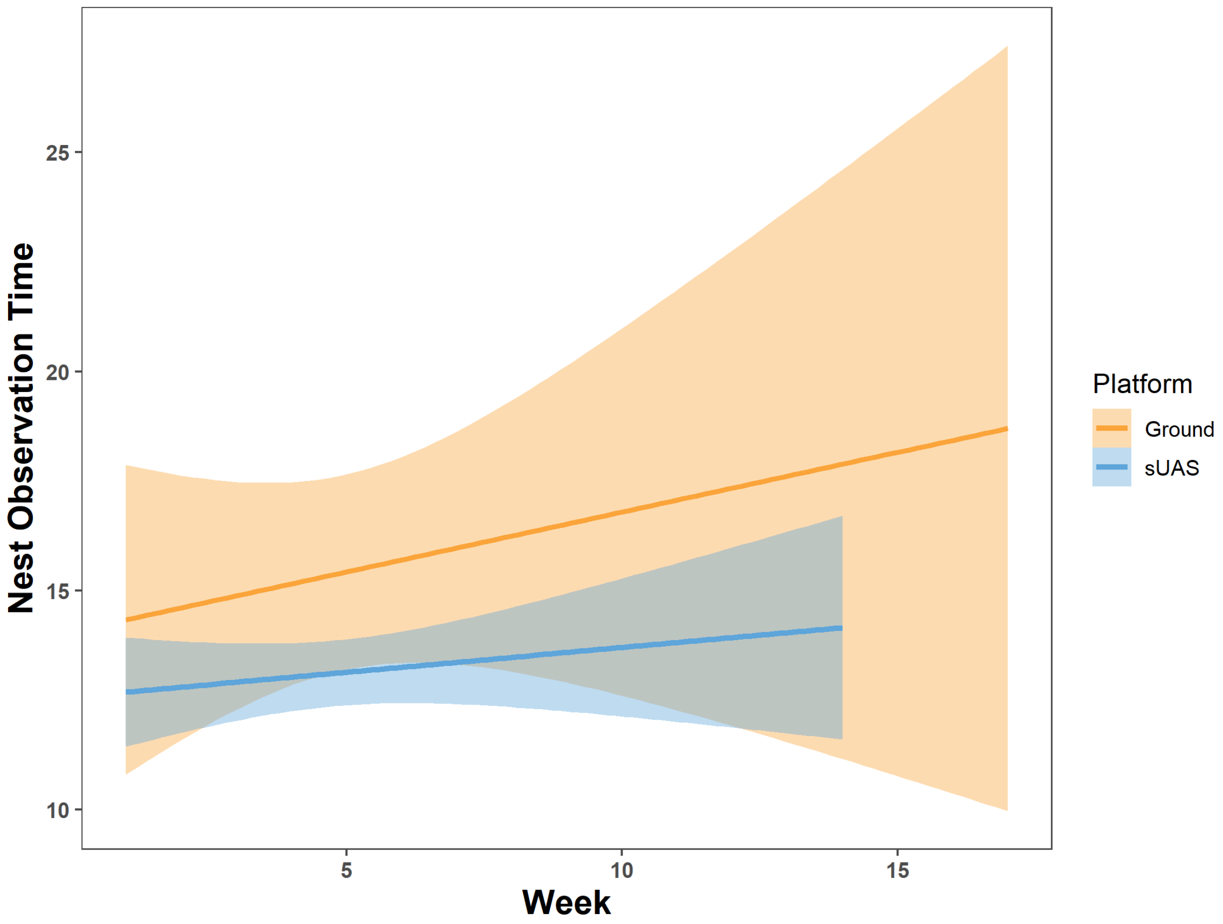


Figure ES-5. Comparison of the Efficiency of a Ground Observer in Minutes (± 95% Confidence Intervals) vs an sUAS at Determining Any Given Nest's Status During 2020.

The sUAS took less time to determine status on average, but the sUAS's efficiency advantage was much less pronounced than during 2019.

Hypothetical Mission Impact in Days

The hypothetical mission impact of nest area closures and openings is a measure of the precision of each platform in detecting nest status changes. Ideally, an in-use nest will be detected, and an area closure enacted immediately *(within one week or survey period)* upon the start of incubation, and the area opened again immediately upon the failure or fledge of the nest. This minimizes potential mission impacts of unnecessary range closures as well as protecting the nest against potential disturbance.

In 2019, both the ground observer and sUAS platform were slow to detect the activity of RN315, leaving it unprotected for several weeks, although the sUAS was one week quicker in detecting the nest's activity. In addition, the ground observer designated RN315 as fledged prematurely by one week. This resulted in the sUAS being cumulatively more precise in designating range closures in 2019 than the ground observer.

In 2020, the data is complicated by the fact that both the ground observer and the sUAS monitored nests that the other platform was not capable of reaching, leaving only one nest for direct comparison. The ground observer was slow to detect the activity of RN248A by several weeks but caught the fledge of the nest immediately. The rough terrain and lack of road access in RN248A's territory required the ground observer to ration which nests received a survey visit each week, which resulted in the in-use nest going undetected for several weeks. The sUAS detected the activity of RN029 immediately but was slow to confirm the failure of the nest by several weeks. The low resolution of the platform payload in 2020 made it much more difficult to identify the presence or absence of young chicks from the nest bowl than the presence or absence of an incubating adult. Both platforms were equally precise at determining the status of RN321.

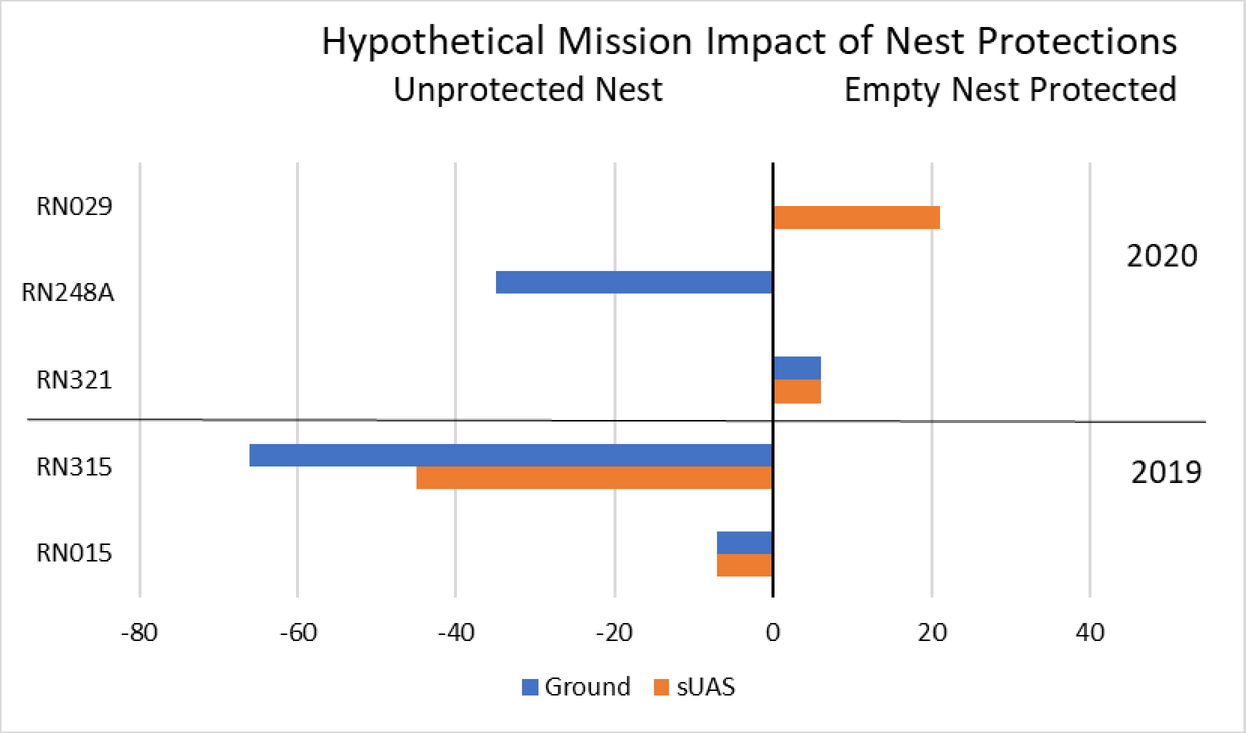


Figure ES-6. Chart Showing the Hypothetical Impact of Nest Area Closures/Openings by Platform and Year.

Quality of Photo/Video Documentation

The DPG Team conducted a qualitative evaluation of how well each platform was able to document nest status in both 2019 and 2020. In 2019, the sUAS platform delivered high resolution video and photo documentation of all nests viewed, as well as footage of the surrounding cliffs for the team to search for previously unknown nests. The photo/video documentation allowed the data managers to confirm nest status before putting range closures in place. By contrast, the UAS platform in 2019 was equipped with a low-resolution payload that hampered the observer's ability to identify nests with confidence. The UAS's thermal imaging capability did allow the observer to spot chicks in in-use nests, however. In 2020, the imaging capabilities of the sUAS and UAS platforms were reversed. The replacement sUAS platform had a downgraded payload resolution due to downlink limitations.

In addition, it did not have onboard data recording capabilities; the observation team had to record footage from the ground station, and as a result encountered significant issues with poor reception and signal corruption. These limitations resulted in the sUAS team requiring more time on site to determine nest status, and in many cases prevented the team from calling a certain nest status at all. On the other hand, the UAS platform received a significant upgrade to its payload systems, allowing for HD image recording. Unfortunately, the UAS team was forced to cease survey operations after only 2 weeks of monitoring due to the COVID-19 crisis, and the observation team was unable to obtain enough data to present a significant image comparison.

Figure ES-7. A Photo of RN315 As Taken by the sUAS Platform in 2019

(DJI Matrice 600 Pro with Zenmuse Z30 payload).

The photo shows an adult golden eagle sheltering a chick less than a week old.

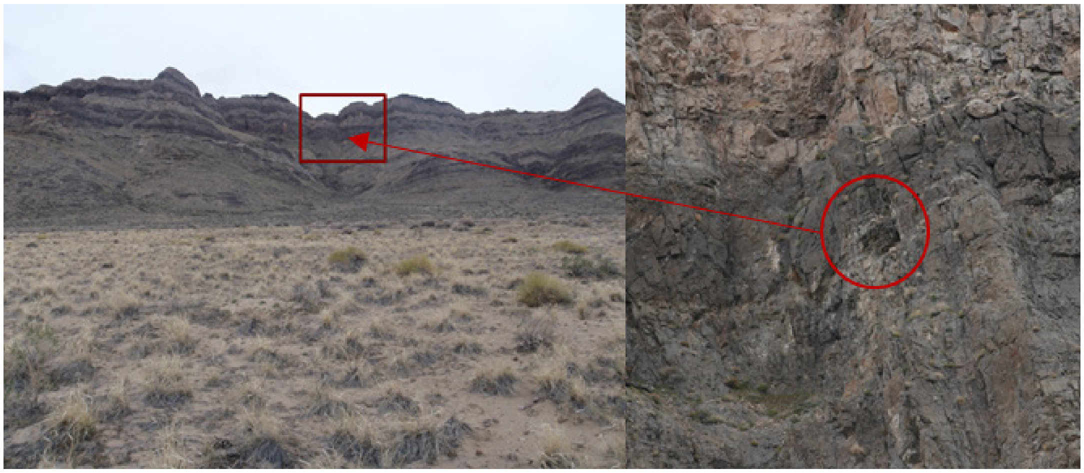


Figure ES-8. A Series of Two Photos Taken by a Ground Observer at Two Different Zoom Levels of RN046.

The first photo shows the distance the observer must view the nest from, as well as the height of the nest on the cliff face. The second photo shows how the ground observer must view the nest from below, even at high zoom.

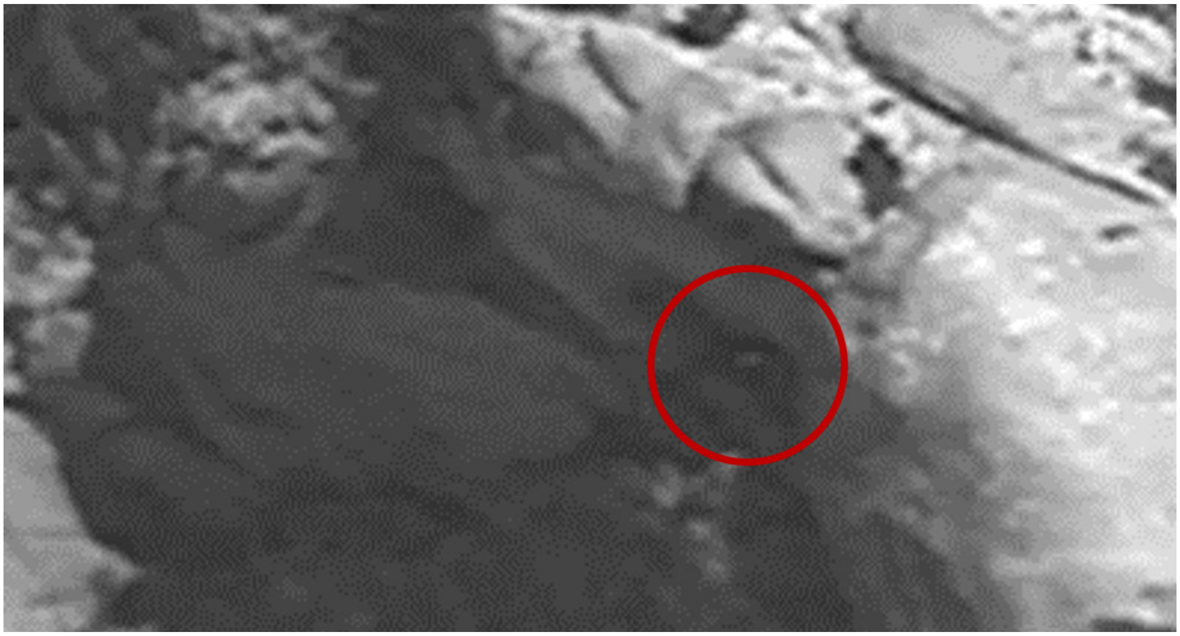


Figure ES-9. A Video Still Taken from the Footage of the UAS Observer Using Thermal Imaging in 2019, Showing RN315 with a Nearly 9-week-old Chick.

The chick is shown as a pale (warm) shape in the middle of a cool cliff face. This image shows the challenges the UAS observer faced with low resolution imagery, and how thermal imaging was able to partially compensate in the late nesting season.

Figure ES-10. A Video Still Taken from the Footage of the sUAS Observer in 2020 (E900 with Sony FCB-EV7520A), Viewing Nest RN248.

The photo shows the low resolution and video artifacts that inhibited the sUAS's ability to make accurate nest activity identifications in 2020.

Additional Metrics for Success

The results of the mixed-effect logistic regression models indicate that the ground observer and sUAS platform had essentially equal *(high)* accuracy in determining the status of any given nest in 2019. Both platforms were more than 85% likely to determine nest status accurately and confidently in the early season, growing to more than 95% accurate in the late season. This can be attributed to the experience and skill of the ground observer, as well as the ability of the sUAS platform to take high quality documentation photos and video for review. In 2020, the sUAS platform suffered greatly from the drop in payload resolution. It began strongly and was still confidently able to determine when nests were not in-use. However, it struggled to accurately identify when nests were in-use and to determine the difference between an incubating nest and a nest with chicks. The ground observer, on the other hand, displayed almost the same results as in 2019.

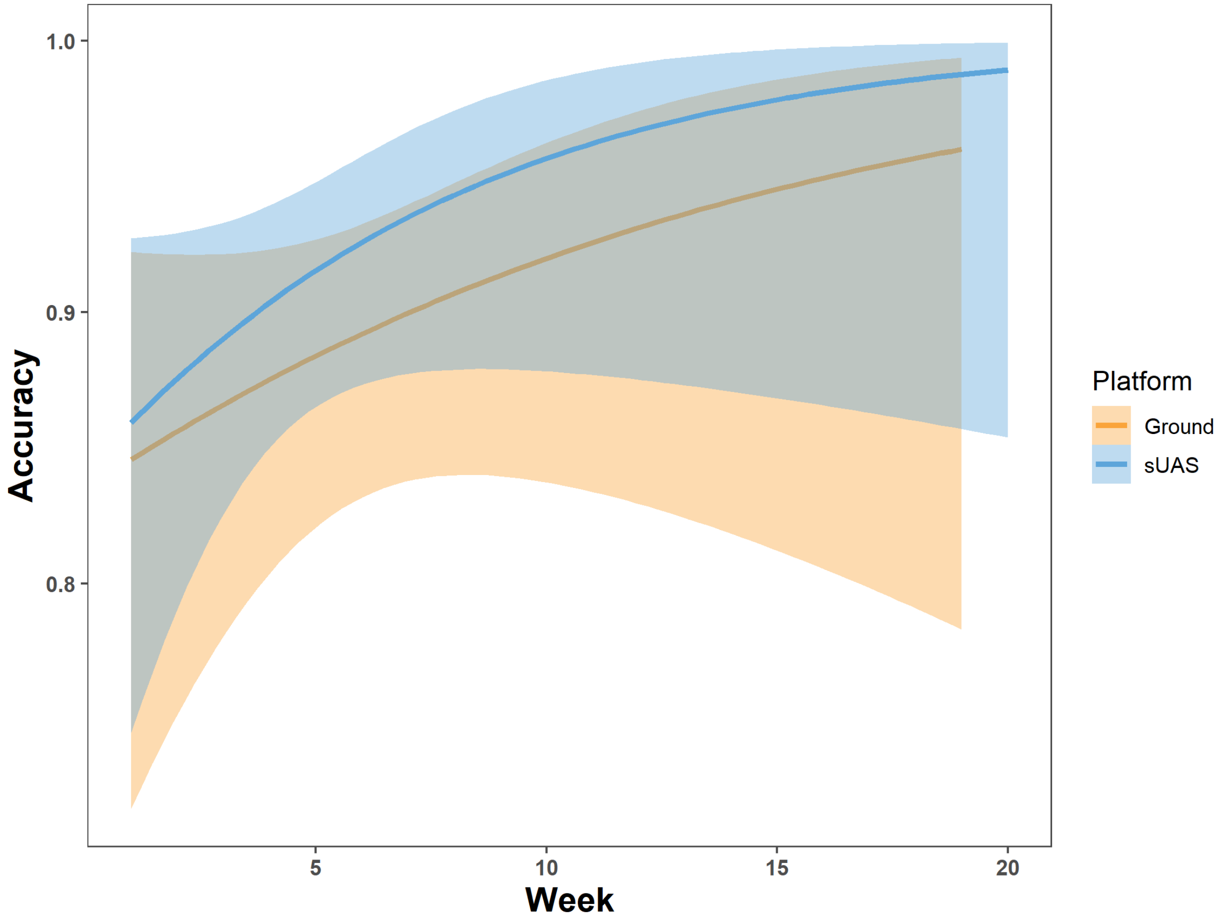


Figure ES-11. Comparison of the Accuracy of a Ground Observer (± 95% Confidence Intervals) vs an sUAS at Determining Any Given Nest's Status During 2019.

Both platforms gained accuracy as the season went on, remaining roughly equal in accuracy. Error margins represent 95% confidence intervals.

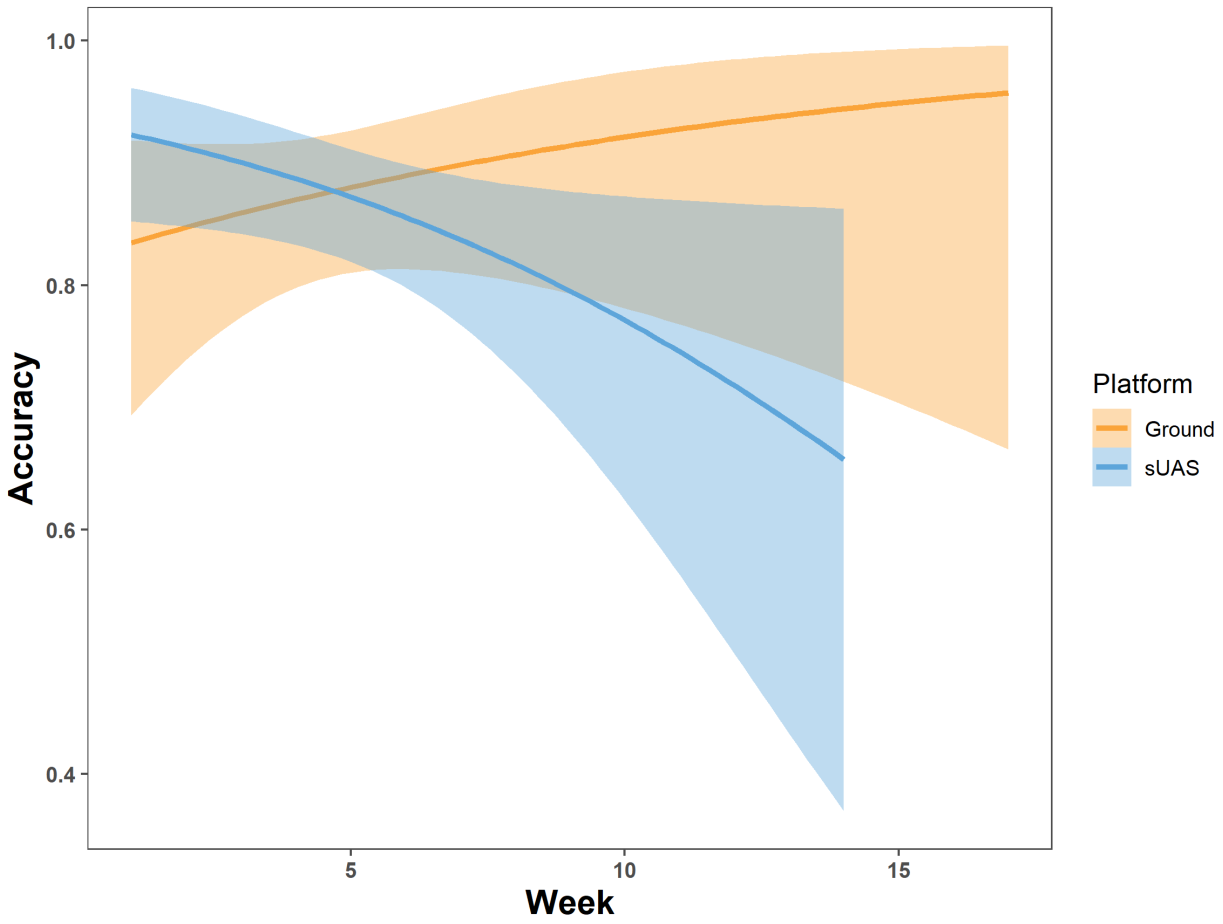


Figure ES-12. Comparison of the Accuracy of a Ground Observer (± 95% Confidence Intervals) vs an sUAS at Determining Any Given Nest's Status During 2020.

The ground observer gained accuracy during the season, mirroring 2019, while the sUAS lost accuracy. This represents the challenges of identifying an in-use nest's status with a low-resolution payload. Error margins represent 95% confidence intervals.

When determining which platform is most efficient and cost-effective, it is important to take total territory coverage into account, especially in the early nesting season when looking to identify in-use nests. The sUAS platform was able to survey approximately twice as many nests each week than the ground observer in both 2019 and 2020. This grants the sUAS more confidence in accurately calling the occupancy status of early season territories, as well as giving it an advantage in locating in-use nests promptly. This played out in 2019 as the sUAS located one in-use nest a full week before the ground observer. The ground observer had to rotate which nests to observe each week due to time pressure and the lengthy hikes needed to cover some territories. By being unable to cover all known nests each week, the ground observer was slower to identify an in-use nest, leaving it potentially vulnerable to disturbance.

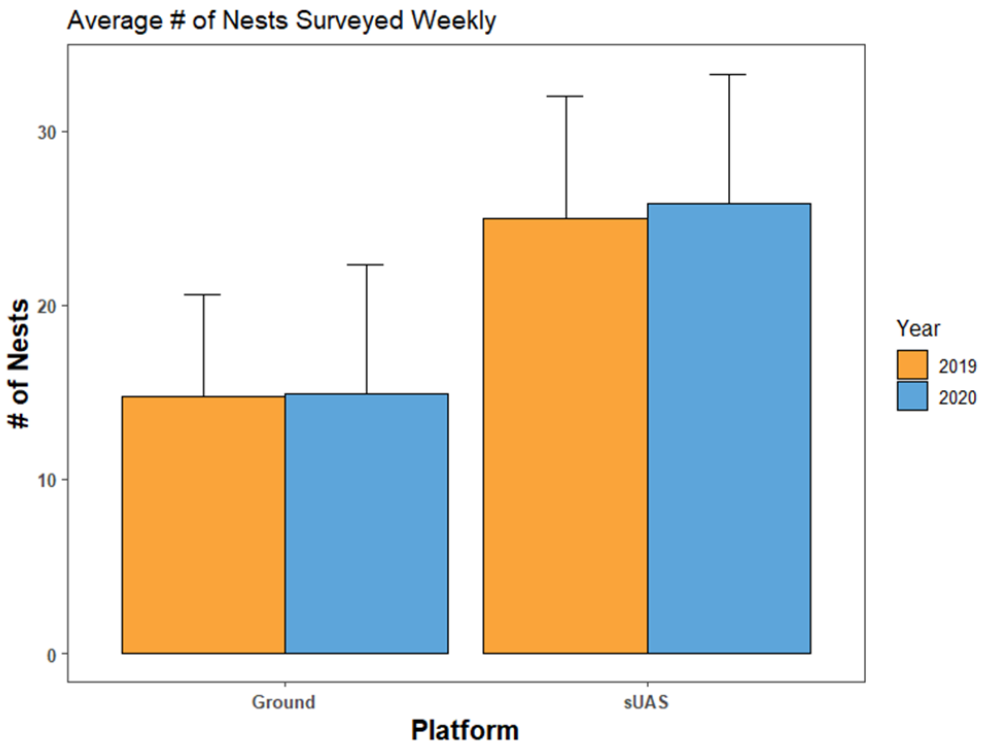


Figure ES-13. Chart Showing the Mean Number of Nests (+SD) Surveyed Each Week During the Early Season.

COST ASSESSMENT

The table below provides a side-by-side comparison of the two sUAS, UAS, on-the-ground monitor and helicopter. Due to the unique circumstances faced during this demonstration, it is assumed that the additional cost for Government support for waiver and oversight would not be necessary for future projects.

Table ES-1. Cost Comparison of Methods with Government Support for Waiver

Cost Elements	sUAS-DJI Matrice	sUAS- E900	UAS	On-The-Ground	Helicopter
Platform	$ 18,139	$ 5,500	NA	NA	$ 216,000
Payload	NA	$ 5,895	NA	NA	NA
Batteries/Chargers	$ 1,528	$ 1,651	NA	NA	NA
Binoculars, scope	$ -	$ -	NA	$ 2,000	$ 2,000
Transportation *(to-from observation locations)*	$ 3,000	$ 3,000	NA	$ 3,130	
Maintenance/Repair	$ 256	$ 893	NA		
Monitoring Labor	$ 55,346	$ 48,840	$ 10,910	$ 14,715	$ 8,640
Waiver Development (*contractor*)	$ 7,000	$ 7,000	NA	NA	
*Govt. waiver prep and sponsor/training/oversight of flights	$ 79,557	$ 61,249	NA	NA	NA
Total	**$ 164,826**	**$ 134,028**	**$ 10,910**	**$ 19,845**	**$ 226,640**

** Cost specific to this project as a result of DoD Memo banning COTS sUAS and FY19 NDAA prohibiting the procurement or operation of Chinese made sUAS.*

The most significant cost driver is DoD Army sUAS policy. The platform/payload must meet Department of Army cyber security requirements. Each platform must undergo an evaluation and provide an Exemption to Policy (ETP) also referred to as a waiver, to operate in restricted airspace. The cost associated with obtaining an ETP includes labor to develop the ETP application package *(Standard Operating Procedures, System Safety Management Plan, and Memos),* upload through SIPR, and track through the system. The waivers are only for six months. In addition, each sUAS must have an Airworthiness Release.

The prohibition on foreign made sUAS impacts costs because the U.S. market is still developing and has not yet produced a cost competitive commercial sUAS to compete with foreign made sUAS. As the U.S. market matures and purchases increase, this will begin to bring the costs down.

Costs were not directly assessed for much of the UAS platform team, as the operation of the UAS platforms are part of a larger installation program and were made available for the study on a non-interference basis.

Costs are based on golden eagle monitoring on a MRTBF with vast distances between nests and rugged terrain. Breeding season begins in February and goes through June, allowing for a range of temperatures and weather conditions.

The cost comparison assumes that both the sUAS and on-the-ground monitoring start and return from the same location. The time to survey nests and return to the starting location has been recorded.

Industry data on life expectancy of an sUAS is between one and two years or ~200 flights. When first envisioning this project, it was thought that the sUAS would be most cost-effective and could replace the current approach of on-the-ground monitoring. The results from the demonstration show that the use of an sUAS is a good tool to have available but may not yet be able to cost-effectively replace on-the-ground monitoring. However, the sUAS provides benefits over that of the on-the-ground monitor such as photos which can be used to study and accurately age the chicks. The sUAS can also cover more territory than an on-the-ground monitor and access nests that are too high or at a difficult angle to see from the ground. In addition, some of the costs associated with this demonstration can be reduced or eliminated in future use cases, such as costs associated with government waiver oversight. As the cost of the sUAS system is reduced and the policy surrounding flying the sUAS in DoD airspace is streamlined or eliminated, it may become cost-effective compared to on-the-ground monitoring. The use of sUAS compared to helicopter use is cost competitive.

IMPLEMENTATION ISSUES

A major implementation issue with the use of sUAS in DoD airspace involves obtaining an AWR and Exemption to Policy (ETP). This policy seeks to prevent the use of foreign made sUAS based on cybersecurity vulnerabilities. Both approvals take time to develop, review, and obtain approval. Under the 2019 DoD Army policy, a modified DJI Matrice 600 was used to monitor golden eagles after obtaining an ETP. However, because of the FY 2020 NDAA, Section 848 Prohibition on Operation or Procurement of Foreign-Made Unmanned Aircraft Systems, the procurement or use of Chinese made sUAS was prohibited. This led to the use of a different sUAS platform. Each change of platform requires a new AWR and ETP. The ETP can only be granted for six months at a time and the time to obtain an approval may take 45-60 days minimum.

The sUAS platform used for observation and data collection has real potential for becoming a quick, cost-effective way to monitor the progress of nesting birds in hard-to-reach places. For this platform to work efficiently and in a manner that collects the best data, some points described below had been found over the past two years to help improve the use of this platform.

Good metadata and a member of the team that has experience with eagle behavior and good knowledge of the territory is key to obtaining useful data. A trained eye for these sUAS platforms was able to compensate for finding nests with sometimes less than ideal video streaming quality or lighting situations. A profile containing pictures from multiple angles and distances and GPS coordinates of known nest in the territory was critical to confirming nest locations and to reduce the time that the sUAS team spent locating nests during a flight.

The UAS observation method was the most uncertain upon the start of the 2019 nesting season, and it proved to be unreliable as a method of weekly nest observations due to scheduling and payload restrictions. RIAC allowed the use of their students and platforms on an as-available basis, and other missions, weather concerns, or maintenance frequently bumped nest observations off the schedule. In addition, the sections of airspace the students were scheduled for were often not over the desired areas of range containing eagle nests to be surveyed. It became clear to the DPG Team that rather than using the UAS as a stand-alone observation method, it would be more useful as a precision tool for obtaining rapid nest observations in areas with no ground access or with critical range use planned within the next two weeks.

If the nest location was well known, the UAS was by far the fastest and most efficient observation method due to lack of drive and hiking time between observation points. However, the nature of the platform's flight and approach patterns made detailed nest metadata critical to the success of the survey. UAS platforms must determine an approach angle and loiter point for a territory observation from several kilometers away, requiring the observation team to have precise knowledge of the nest's location reference data, elevation, aspect, bearing from the ideal viewpoint, and topographical inclusion before the nest can be found. The UAS observation team found that landscape level photos combined with detailed descriptions of a nest's location were sufficient to allow for a successful survey.

1.0 INTRODUCTION

1.1 BACKGROUND

Dugway Proving Ground (DPG), located in remote west-central Utah, serves as a Major Range Test and Facility Base (MRTFB) test site for chemical and biological defensive testing, battlefield smokes, and obscurants. In addition, DPG is home to multiple breeding pairs of golden eagles, which are protected under the Bald and Golden Eagle Protection Act (BGEPA) and the Migratory Bird Treaty Act (MBTA). Due to these regulatory drivers, the presence of an eagle nest has the potential to restrict military testing and training if military activity causes nest disturbance. It is therefore vital to the function of DPG and similar DoD testing and training ranges to fully understand the location and status of in-use eagle nests or territories on military lands.

Current survey techniques of nesting golden eagles on DPG and active DoD training properties require long-distance viewing of each nest from the ground at least weekly, which is both time-consuming, costly, and may not always provide a definitive status of nest changes from incubation to hatching, number of nestlings, nestling condition, etc. *(Weissensteiner and Poelstra 2015)* due to views from the ground. Finding new nests is driven by bird behavior, luck, or significant amounts of time and effort spent traversing rugged terrain on foot. Currently, ranges are required to err on the side of caution if the status of an eagle nest is uncertain, which may lead to increased range closure times. Using both military-grade and commercial Unmanned Aircraft Systems (UAS)/Small Unmanned Aircraft Systems (sUAS), it is possible to obtain highly accurate locations and status updates of in-use golden eagle nests on DoD lands; data that is critical to maintaining open testing and training ranges for as much time as possible in the eagle nesting season *(Chabot and Bird 2015, Hodgson et al. 2016, Junda et al. 2015, Weissensteiner and Poelstra 2015).* The sUAS/UAS can be used to detect new nests in areas that are difficult to see or access from the ground, as well as count nestlings and track nesting milestones in a noninvasive manner not previously possible *(Weissensteiner and Poelstra 2015).* All of this can be accomplished with greatly reduced disturbance to the nesting pairs *(through reduced time in the area),* crucial to the success of sensitive nesters such as the golden eagle *(Chabot and Bird 2015, Scobie and Hugenholtz 2016, Weissensteiner and Poelstra 2015).*

1.2 OBJECTIVE OF THE DEMONSTRATION

Select Engineering Services (SES), in coordination with DPG, the Rapid Integration and Acceptance Center (RIAC), Threat Systems Management Office (TSMO) and HawkWatch International (HWI), hereinafter referred to as the DPG Team, developed this technology demonstration to demonstrate the use of sUAS/UAS as a cost-effective way to monitor golden eagles on military installations. Currently, it takes approximately 960 hours to conduct on-the-ground monitoring of eagle nests for approximately six months *(based upon actual numbers provided by DPG and SES experience).* Much of this time is spent traveling to and from remote sites either by foot or truck. The primary objective was to reduce the total hours required to monitor the nests and evaluate the cost-effectiveness of using sUAS/UAS over in-person ground-based monitoring. Other objectives of the demonstration included the following:

- Efficiencies of scale to monitor more nests in less time for a lower cost
- Demonstrated the effectiveness of sUAS/UAS versus on-the-ground observation

- Improved quality of still photos and videos for further analysis
- Demonstrated use of sUAS/UAS as safe and low disturbance to the eagles
- Demonstrated use of sUAS/UAS to enable greater access to the nest and ability to collect more detailed data
- Demonstrated use of sUAS/UAS as more efficient in finding nests in particular settings such as hidden/remote terrain

1.3 REGULATORY DRIVERS

Golden eagles are protected under BGEPA and the MBTA. These protections require eagles to be protected against "take," defined as "[to] pursue, shoot, shoot at, poison, wound, kill, capture, trap, collect, molest or disturb." In addition, the protections against "take" extend to the nests and eggs of eagles, as well as the adult birds. The conservation status of the golden eagle is currently stable globally, but declining regionally, in both western and eastern U.S. populations *(Hoffman and Smith 2003, Katzner et al. 2012, Smith 2008)*. Additionally, a recent review by the U.S. Fish and Wildlife Service (USFWS) upheld concern over the population status of the golden eagle *(USFWS 2016a),* leading to a "no net loss" standard in the recent revision to the "Eagle Rule" *(USFWS 2016b).* This standard essentially prohibits any "take" of golden eagles or their nests without offsetting such take through the permitting framework. To prevent accidental take of golden eagles, DPG is obligated to monitor its existing population of nesting golden eagles and avoid disturbance, except in cases of specific permitted activities. As DPG can monitor its golden eagle population more effectively and efficiently, the installation will be able to operate with minimal concerns for incurring accidental take.

2.0 TECHNOLOGY/METHODOLOGY DESCRIPTION

2.1 TECHNOLOGY/METHODOLOGY OVERVIEW

The DPG Team conducted weekly golden eagle nest surveys on DPG during the 2019 and 2020 nesting seasons to compare the effectiveness of three "survey systems": 1) a ground-based human observer, 2) a commercially available sUAS, and 3) one or more military-grade UAS platform(s). These nest surveys were conducted as a blind study; none of the three teams of observers encountered one another in the field. None exchanged information concerning the nest surveys, and none had any access to data generated by surveys conducted by any of the other teams.

Golden eagle nest surveys are typically performed by one observer that travels to 11 territories to observe and note status of nesting. A second observer is sometimes used for safety if the terrain/location warrant it. Equipment includes high power binoculars/scope. All observations are documented, on paper, but no pictures or videos are taken. On-the-ground observers are required to undergo unexploded ordinance training (UXO) administered by Dugway range safety officers as well as basic coordination, navigation, and radio ops training specific to DPG.

The sUAS platform DJI Matrice 600 *(Figure 1)* was originally proposed for this project. However, the 23 May 2018 DoD Memo, "Unmanned Aerial Vehicle Systems Cybersecurity Vulnerabilities" was issued, suspending the use of Commercial Off-the-Shelf (COTS) sUAS. In response, a DJI Matrice was procured with an approved DoD software patch, through the Army Ground Aerial Target Control System (AGATCS), in partnership with the Threat System Management Office (TSMO). DJI Zenmuse Z30 cameras were used as the operational payload, with 32x optical zoom allowing for long-range HD observations. This system was approved for use during the 2019 nesting season.

Figure 1. DJI Matrice 600 Pro

However, in December 2019 the National Defense Authorization Act (NDAA) was signed which called for a complete ban on the procurement and/or use of Chinese made sUAS platforms by DoD programs except in the case of sUAS counter-defense testing *(Appendix 2)*. This language was strictly interpreted to prevent the use of the modified DJI Matrice that was used the previous year. This led the DPG Team to seek out another option. Through discussions with TMSO, an alternative sUAS was identified for use, the E Mergent RC E900 platform *(Figure 2)*. The two E900s were integrated with Sony FCB-EV7520A camera payloads.

Figure 2. E Mergent RC E900

Table 1 below provides a comparison of the two platforms. The two payloads were technically comparable but the Matrice was designed as an integrated system whereas the E900 was integrated with a camera payload after manufacture. The primary differences between the two were the transmission distances, operating frequencies, and the SD card which was in the camera on the Matrice and in the controller tablet of the E900. These differences led to a significant degradation of photo quality from the E900.

Table 1. A Comparison of the Two sUAS Platforms:
The Modified DJI Matrice 600 in 2019 and the E900 Used in 2020

	DJI Matrice 600	**E900**
Max Transmission Distance	3.1 miles	1.5 miles
Frequency	5.8 GHz	2.4 GHz
Payload Specifications	30x Optical Zoom + 6x Digital zoom 2.13 Mp 1080p Tablet Tap Zoom supported	30x Optical zoom + 12x Digital zoom 2.13 Mp 480p *(functional resolution)* Separate controller for camera
Camera and Interface Abilities	Auto/Manual – Focus, Shutter Priority, Bright Compensation SD card Supported	Auto/Manual - Focus, Shutter priority, Bright Compensation SD card in controller tablet
Batteries	6x 5700 mAh	1x 6S 2200 mAh battery Battery weight – 2490 g *(+/-20g)*
Estimated Flight Time (minutes)	~25 min	~20 min
Max Takeoff Weight (payload capacity)	15.5 kg Payload Capacity - 5.5 kg	10.5 kg Payload Capacity – 4.5 Kg
Max Wind Resistance	18 mph	20 mph

The sUAS team consisted of a pilot-in-command, operator, and observer who was also an ornithologist with in-depth knowledge of the Dugway range and eagles in the area. All three members of the team completed training before the study began consisting of UAS flight theory, platform components, flight controls, operation, troubleshooting techniques, and supervised flight training administered by TSMO. All members of the team underwent unexploded ordinance training (UXO) administered by Dugway range safety officers as well as basic coordination, navigation, and radio ops training specific to DPG.

DPG is also home to the Rapid Integration and Acceptance Center which was established by the Project Manager Unmanned Aircraft Systems to create a single location where unmanned and manned aircraft could complete end-to-end testing and integration. DPG coordinated with RIAC to conduct monitoring flights when they were not conducting mission flights. RIAC identified a military UAS platform that would be most suitable for this type of flight plan. There are approximately 24 Continental United States Army installations with UAS that could potentially be used for monitoring of raptors or other natural resources as part of their ongoing training of UAS pilots.

The UAS was operated by UAS pilots, supported by an ornithologist who provided coordinates and identification/analysis of nests.

2.2 TECHNOLOGY/METHODOLOGY DEVELOPMENT

The DPG Team's technical approach was to demonstrate the cost-effective use of sUAS/UAS to monitor golden eagles by a direct blind comparison between on-the-ground monitoring and sUAS/UAS overflights. A flow diagram for the methodology proposed can be found in Appendix 3, and a detailed overview of the methodology developed can be reviewed in section 5.4 *(Field Testing).*

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY/ METHODOLOGY

Currently, on-the-ground monitoring includes one observer visiting each of the 11 territories once or more per week until occupancy is established, the in-use nest is identified, or sufficient monitoring and time of year eliminates the possibility of initiation of nesting activity. In-use nests are tracked with in-person visits once per week for the duration of the breeding season until nest fledge or demonstrable failure. This method is relatively reliable with repeated visits, but is time-consuming, costly, and may not always provide a definitive status on a given day of observation. Also, the changes in nest status are not immediately available, which can cost the military valuable operation days on closed ranges.

The demonstration studied two different sUAS platform/payload systems: a DJI Matrice 600 Pro with a Zenmuse Z30 payload in the 2019 nesting season, and an E Mergent RC E900 prototype with a Sony FCB-EV7520A payload in the 2020 nesting season. The two platforms performed very differently during each nesting season, and each showed its own strengths and limitations.

The DJI Matrice is a commercial off-the-shelf product, and as such was well designed and easy to use. The Matrice was stable and reliable in the field, with robust trouble-shooting procedures and documentation. The integrated Zenmuse camera system provided HD on-board photo and video recording of nests over distances of over 800 meters. The Matrice maintained flight control and video transmission over distances of up to 3 miles, far greater than typical line of sight limits, allowing for remote or obscured nests to be observed efficiently. However, the bulky battery system and low tolerance for temperature extremes limited the Matrice in particularly rugged conditions. The Matrice is also manufactured in China, and as such it is currently restricted from use in DoD restricted airspace except for use in counter-sUAS defense applications. Therefore, this system is no longer available for use in DoD restricted airspace.

The E Mergent RC E900 is a prototype sUAS platform developed for custom DoD applications in partnership with TSMO. The main advantage of the E900 over the commercial DJI Matrice is that it is American made, and as such is currently eligible for consideration of the DoD issued flight waiver. It is also highly customizable to a specific project's needs and can be modified and repaired at will with sufficient technological expertise. However, the E900 is not a fully realized commercial product, and as such it was less refined and reliable than the Matrice. The E900 also lacked the ease of use of the DJI payload controls and software. It was determined that the current iteration of the E900 used for the demonstration lacked the long-range transmission capabilities required, as well as possessing inadequate video stabilization and control operations. Integrating a third-party payload into the E900 system resulted in limited video resolution and recording capabilities. The after-manufacture integration of the camera onto the platform created some photo quality issues. The SD card was located in the controller tablet instead of on the camera, therefore photos/videos would be transmitted to the SD card, which required the images to be reduced from 1080p to 480p.

Furthermore, both sUAS platforms have risk minimization features. Both platforms include user friendly, intuitive flight controls with programmable altitude restrictions, horizontal geofencing, and GPS hold mode to insure platform stability in windy weather. An added GPS failsafe includes a return to home/auto land switch on the controller that initiates an autopilot to land the platform at its original takeoff location with no input from the pilot. Both platforms include real time information such as distance from controller, heading indicator, altitude above takeoff location, and battery performance all on one display. This heads-up information allows separation from nesting areas to help prevent "take" of the birds, or to stay clear of restricted airspace.

The MQ-1C Gray Eagle was also used when available for nest monitoring in both the 2019 and 2020 nesting seasons *(Figure 3)*. The Gray Eagle fleet on DPG underwent a significant upgrade to their payload systems during the fall of 2019, resulting in much higher resolution video for the 2020 season. This is the first time a military UAS platform has been used to monitor nesting raptors. It was theorized that the high speed and very long observation ranges of the platform would allow it to survey many territories both quickly and thoroughly, with no impact to ground operations in the area. The thermal imaging capabilities of the Gray Eagle platform were also intriguing as a method of detecting chicks *(before they develop insulating adult plumage)*. It was also theorized that student pilots training with RIAC would benefit from the high difficulty of locating eagle nests in cryptic terrain, especially given a mission structure mimicking what they would encounter in theater. Because the Gray Eagle was not always available for monitoring, it was difficult to obtain comparable data.

Figure 3. MQ-1C Gray Eagle

Although not specifically included in the demonstration, helicopters can also be used to monitor nests. This method, as with the other surveying techniques, has its pros and cons. The greatest advantage of using a helicopter as an observation platform is its ability to move quickly from territory to territory. With a trained spotter on board and with the use of optics, nest status can be quickly recorded from an advantageous perspective in hard to reach places. A trade-off of the helicopters speed and mobility is the noise of the aircraft increasing the potential for nest and eagle disturbance.

These disturbances may skew the data as disruptions of a nesting pair of eagles may result in failure of a nest in a worst-case scenario, especially when monitoring frequently throughout a season as required by DPG's ongoing range activities. The higher perspective and fast movement of the helicopter may also limit the observer's ability to search the area for eagles when first entering a territory, which makes determining early season occupancy difficult. This practice of using optics to search an area when first entering a territory has proven effective in the past of helping an observer's ability to track an eagle to its nest. Furthermore, from a logistical standpoint, the scheduling availability of range airspace for the helicopter to be cleared to fly would be inconsistent at best, as the nesting period of the eagles fall during a typically busy time for range operations. As a final consideration, there is a significant risk to human health and safety when monitoring eagle nests via a helicopter, due to the inherent dangers of flying close to cliff faces and low through rugged terrain. The very high cost of both pilot and helicopter needs to be taken into consideration when contemplating using a helicopter for territory observations and data collection.

3.0 PERFORMANCE OBJECTIVES

The following performance objectives were developed as the primary criteria by which the DPG Team could assess the success of the sUAS/UAS platforms as nest monitoring tools. The specific benchmarks identified are focused on reduction of time required to monitor nests, increase in number of nests surveyed, and increase in precision of results, all in comparison to the standard ground observer.

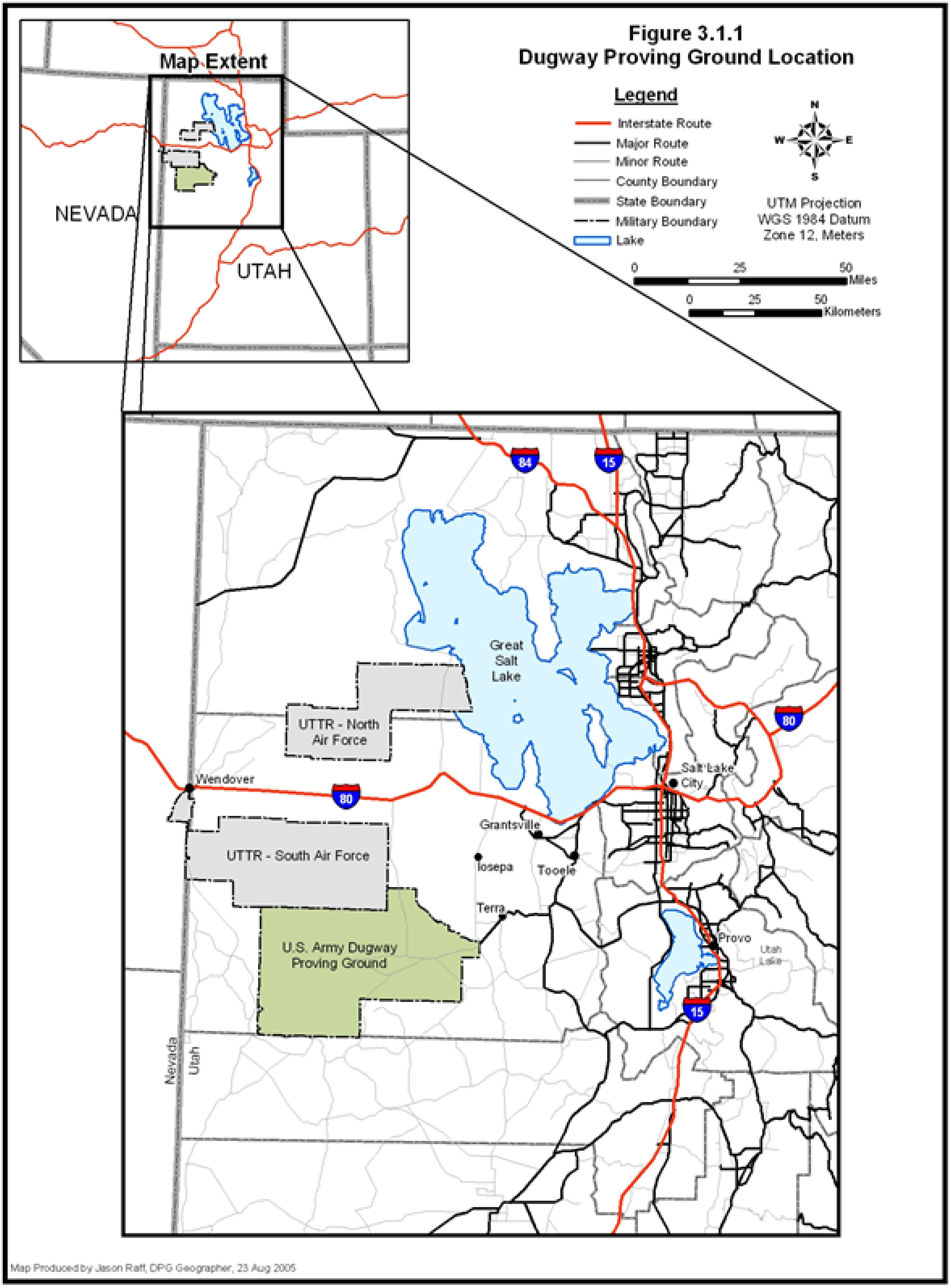
Table 2. Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria
Quantitative Performance Objectives			
Total amount of time necessary to determine the early season status of all known nests	Amount of time necessary for the method of observation to determine early season status of all known nests	Exact start and ending times of daily survey for each method of observation	sUAS/UAS time to determine early season status < or = in-person time to determine status
Total number of in-use nests identified	Number of in-use nests the method of observation is able to identify	Weekly report of nest activity status for each known territory by each method of observation	Total number of nests identified by sUAS/UAS > or = number of nests identified in-person
In-use nest date of identification	Accuracy of the method of observation in determining nest activity	Dates of territory visits recorded in conjunction with nest status for each method of observation	Date of identification the same or earlier for sUAS/UAS than in-person
Nest failure date of identification	Accuracy of the method of observation in detecting nest failure	Dates of territory visits recorded in conjunction with nest status for each method of observation	Date of identification the same or earlier for sUAS/UAS than in-person
The total amount of time necessary to update the status of in-use nests	Amount of time necessary for the method of observation to update the status of a known in-use nest	Exact start and ending times for territory and nest visits for each method of observation	sUAS/UAS total time spent to update nest status < or = time spent in-person
The number of previously unknown alternate eagle nests found within the 11 territories	Ability of the method of observation to detect new or previously unknown eagle nests	Each new nest observed recorded by each method of observation	Total number of new nests found by sUAS/UAS > or = number of nests found in-person
Differences in hypothetical mission impact *(in days)* and nest protection based on restrictions imposed and lifted due to monitoring	Precision of the method of observation in determining dates of activity and failure/fledge	• Dates of perceived activity and failure/ fledge recorded by each method of observation • True dates of nest activity and failure/ fledge recorded by camera equipment directly observing nest	• sUAS/UAS indicated days of mission impact < or = in-person indicated days of mission impact • sUAS/UAS indicated days of nest protection most similar to days of actual nest activity
Qualitative Performance Objectives			
Quality of video/photos to document occupancy and status	Ability of the method of observation to gather proof of nest activity status	Photo/video documentation of each in-use nest by sUAS/UAS and in-person observers	sUAS/UAS gather higher quality video and photos to document nest activity than in-person observers

4.0 SITE DESCRIPTION

4.1 SITE LOCATION AND HISTORY

Dugway Proving Ground is located on the southern end of the Great Salt Lake Desert and covers 798,214 acres, serving as a test site for chemical and biological defensive testing, battlefield smokes and obscurants *(Figure 4)*. DPG was activated for military use in 1942 to serve as a proving ground for the testing of chemical weapons. Chemical, biological, and explosives testing have been conducted within DPG. Open air testing of chemical and biological agents was conducted until 1969, after which all chemical and biological warfare testing was confined to sealed chambers. Open-air testing of decontamination methods, contamination avoidance, and evaluation of threat dissemination methods, including the use of biological and chemical simulants in place of biological and chemical agents, has been done at DPG since 1969. In addition, DPG was first opened to Army Reserve Component training in 1969. Ground training on DPG includes a wide variety of activities at DPG, ranging from 12-soldier weekend activities to 3,000- to 4,000-soldier tactical exercises lasting up to several weeks.



Map Produced by Jason Raff, DPG Geographer, 23 Aug 2005

Figure 4. Map of DPG Showing Location Within UT

4.2 SITE CHARACTERISTICS

DPG is within the Great Basin subdivision of the Basin and Range Physiographic Province. The Basin and Range Physiographic Province includes parts of Idaho, Oregon, Nevada, Utah, California, Arizona, New Mexico, and northern Mexico. This province is characterized by a series of mostly isolated north-south trending mountain ranges that are separated by wide desert plains *(Press and Siever 1982)*.

Most of DPG lies within the Great Salt Lake Desert, with mountains and low-lying basin areas covering remaining portions of DPG. DPG is bordered to the northeast by the Cedar Mountains and to the south by a series of ranges and valleys, the closest of which is the Dugway Range. The Onaqui Mountains and Davis Mountain lie to the east of DPG. The Deep Creek Range lies to the west and marks the boundary of the Great Salt Lake Desert. The Stansbury Mountains lie to the northeast of the Cedar Mountains.

Relatively extensive basin areas are broken by the topographic relief of the Cedar Mountains, Little Davis Mountain, Simpson Buttes, Camels Back Ridge, Wig Mountain, Granite Peak, and Sapphire Mountain. There are no large perennial surface water bodies that lie within or border DPG. However, two large playas are located in the western and southern portions of DPG, the DPG Playa, and the Downwind Grid Playa. Vegetated and non-vegetated sand dunes are also located in the eastern and central portions of DPG and along DPG's northern and western boundaries.

DPG is in a semi-arid, continental, steppe region, or high desert known as the Great Basin Desert. This region is often referred to as a cold desert due to its mid-latitude location. Typically, winters are cold; summers are hot and dry with a high evaporation rate; and most precipitation falls in the spring *(Dugway Proving Ground 2003a)*.

Other weather characteristics typical of the DPG area include frequent electrical storms and occasional dust storms in summer and temperature inversion conditions in winter. Temperature inversion conditions occur when cold Arctic air spills into the area, wind speed is low, and contrary to the normal pattern, air temperature increases with height above the ground surface. Surface airflow is reduced and any tendency toward reduced air quality is aggravated under these conditions *(Dugway Proving Ground 2003a)*.

Weather patterns at DPG are influenced by terrain. Most of DPG is relatively flat because it consists of a former lakebed *(the former Lake Bonneville of which the Great Salt Lake is a small remnant)*. Interspersed in the flat terrain are abrupt, often pinnacle-like mountains, which are cooler and receive more precipitation than surrounding flatlands. They influence local weather patterns by channeling winds and promoting up- and down-slope conditions in mornings and evenings, respectively *(Dugway Proving Ground 2003a)*.

Local wind patterns are governed by differential heating and cooling of higher elevations relative to flatlands and by regional weather. These patterns usually include the onset of southeasterly or southerly downslope flow at night that persists into morning, which transitions into northwesterly through northerly flow with daytime heating. There are two periods of relative atmospheric stability in early morning and early evening hours. These patterns are marked in summertime but weak or absent in winter, due to differences in the amount of heat in the form of solar radiation received seasonally and the tendency of snow to reflect solar radiation away during winter *(Dugway Proving Ground 2003a)*.

Monthly average temperatures for the Ditto Technical Center for the period 1950 to 1998 range from 77.9° F in July, which is the hottest month, to 27° F in January, which is the coolest. Daily extremes for each month show a substantial range. For example, for July the daily extreme high is 109° F and the extreme low is 37° F. Similarly, the daily extreme range for January is 91° F. Large temperature fluctuations recorded between day and night and seasonally are typical of the area's arid continental climate *(Dugway Proving Ground 2003a).*

Precipitation data for the Ditto Technical Center for the period 1950 to 1998 show that mean annual precipitation is about 8 inches with a low of about 3 inches and a high of about 15 inches. Wettest months are March, April, and May, followed by October. Snowfall occurs November through March; however, snow may persist at mountain elevations for much longer periods than on flatlands *(Dugway Proving Ground 2003a).*

The average warmest month is July, and January is the average coldest month. The highest recorded temperature was 109° F in 1998, and the lowest recorded temperature was -29° F in 1989. May is the average wettest month.

Unusual or severe weather conditions, such as fog and cloud ceilings, which limit visibility, occur most often during winter. Thunderstorms or electrical storms occur during summer *(Dugway Proving Ground 2003a).*

The map below *(Figure 5)* shows the 2018 known eagle nest territories. These territories are significant distances between them and cover a wide range of terrain and are limited by road access.

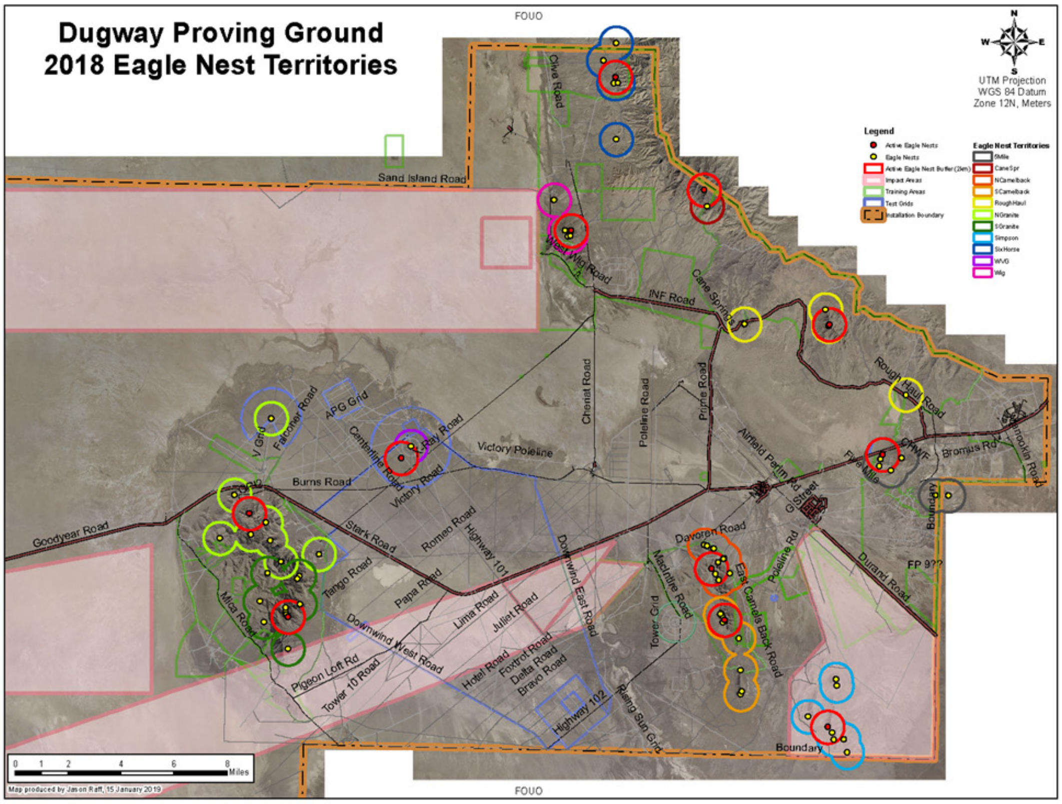


Figure 5. Map of Golden Eagle Nests and Territories at DPG

5.0 TEST DESIGN

5.1 CONCEPTUAL TEST DESIGN

The DPG Team conducted weekly golden eagle nest surveys on DPG during the 2019 and 2020 nesting seasons to compare the effectiveness of three "survey systems": 1) a ground-based human observer, 2) a commercially available small sUAS, and 3) one or more military-grade UAS platform(s). The ground-observer was a single vehicle-based biologist; the sUAS system included three personnel *(commercial pilot, observer, and biologist for video monitoring);* and the military UAS required three personnel *(military pilot, military camera operator, and civilian biologist for video monitoring).* All three biologists associated with each survey approach had comparable familiarity with existing DPG eagle territories and previous eagle nest monitoring experience.

The DPG Team generated territory-specific data sheets that specify known nests within 11 known territories on DPG *(Figure 5),* nest survey order based on historic use patterns, and other detailed survey instructions. The ground observer and the sUAS observation team attempted to survey the same 11 territories relatively close in time, but the biologists associated with each survey system remained blind to each other's findings. The UAS observation team conducted a separate territory and nest survey effort designed to test the platform's capabilities as a precision, on demand survey system for areas with little to no ground access. Two senior DPG environmental staff provided weekly oversight of data collected by all three survey systems and collated survey results to ascertain the weekly "benchmark" status of each territory, and to ensure survey protocols were properly followed. Camera data from a subset of nests were also used to provide retrospective verification and correction of weekly status. Generally, all surveys conducted by the ground and sUAS observation teams occurred on Monday and Tuesday of each week, with Wednesday available as a weather or other make-up day, and Thursday for data review by senior staff. Individual territory surveys by the ground observer and sUAS were staggered to avoid overlap in time. The military UAS observation team conducted surveys as available. Each survey round of co-monitored territories *(i.e., territories "shared" between survey systems, which may vary based on stage of season and performance of individual systems)* were completed by all three platforms within 36 hours of each other, unless weather delays or other unforeseen issues occurred for one or more platform.

Each annual survey was segmented into two time-periods: the "early season", defined as 10 February–14 April *(9–10 weeks)* and the "late season", defined as 15 April–30 June *(12 weeks).* Survey seasons were selected based on 12 February–19 March "core" egg laying dates *(i.e., 90% of observed values, with 5% tails removed)* back-dated from 1,038 Utah desert nests *(K. Keller, unpublished data).* The early season end date was set to allow at least two survey rounds after the latest likely lay date based on past data. Similarly, the late season end date was set to encompass 80% fledge age based on the latest likely egg laying date. The primary goal of the early season surveys was to document "Occupied Territories", "In-Use Nests", and "Vacant Territories", while the goal of late season surveys was to track In-Use Nest to "Success" *(at least one nestling surviving to 80% fledge age)* or "Failure" *(terms adapted from Steenhof et al. [2017]).* During the early season, all 11 territories were surveyed every two weeks *(e.g., six one week, five the next).* In contrast, late season surveys were restricted to In-Use Nests found during the early season surveys, plus any territories with unresolved status.

For ground and sUAS survey systems, independent teams attempted to survey each nest from outside an 800-meter horizontal protective buffer *(as widely prescribed on public lands and suggested by Romin and Muck [2002])*. If topography prevented clear viewing at that distance, these survey systems were authorized to approach to within 400 meters of a nest, but only as close as necessary to confirm nest status. The "incursion" view distance was recorded. Closer approaches to confirm inactive nests were allowed to facilitate area nest searching. Biologists associated with each survey system recorded eagle response behavior *(i.e., any agitation or flushing observed while conducting nest surveys).*

Surveys conducted for each platform followed specific territory and nest survey protocols to ensure comparable methods were employed and to facilitate the capture of detailed time-keeping records associated with specific survey tasks. Biologists for each survey system recorded total daily "Survey Time", which began upon departure from English Village *(ground and sUAS)* or initiation of take-off from the DPG airfield *(UAS)* and continued until return to same location at the end of the survey effort. For each platform, "Territory Survey Time" was noted, starting when entering into a 2-km buffer around known nests associated with each territory, and continuing until status was confirmed, and the survey was complete, or a 3-hr time limit was reached. Time spent within each territory involved an "Area Search" *(general scanning overall area for adult and nesting evidence),* "Nest Search*" (prescribed order survey of known nests),* and "Extended Search*" (searching for new or uncatalogued nests)* was also recorded. Surveyors used standardized terminology established in this document and photographic guides to age eagle nestlings *(Driscoll 2010, Hoechlin 1976).* The specific protocols associated with each survey period and specific survey tasks are detailed in the following section. These approaches were further reinforced by complementary flow charts *(Appendix 3),* and territory-specific data sheets.

5.2 BASELINE CHARACTERIZATION AND PREPARATION

Three surveyors with high levels of previous experience surveying golden eagle nests for this study were selected. One ground observer had 7 years of golden eagle nest survey experience in the West Desert prior to the start of this study, including 4 years surveying nests on DPG. The sUAS observer had 4 years of golden eagle nest survey experience, all conducted on DPG. The UAS observer possessed 6 years of golden eagle nest survey experience in the West Desert, overlapping with 4 years surveying in other parts of Utah, and 1 year of experience in southern Idaho before this study. Prior to the start of each field season, each observer reviewed the data collection protocols and held a briefing to discuss field procedures and relevant survey details associated with individual territories. Datasheets included territory and nest maps to aid all observers in locating nests *(Table 3).* At the end of year one, a debriefing was held to discuss survey issues encountered by each observer. It was found that high angle, distant views from the UAS platforms and limited UAS observer experience with DPG nests seriously limited nest locations in year one. As a result, "mission packets" were created prior to the start of year two, which included recommended UAS approaches, viewing angle, nest elevation offset, and nest photos, where available.

Table 3. Status of Golden Eagle Territories on DPG

2015–2018. Nest status was determined by ground observers using binoculars and 60x spotting scopes, equipped with maps showing nest locations and photos of a sub-sample of nests. Territories were considered to contain an "In-Use Nest" if observers detected evidence of a breeding attempt (an adult eagle in incubating posture on a nest, or nestlings), or occupied if a pair of eagles were present in the territory.

Territory Name	# of nests*	2015	2016	2017	2018
Six Horse pass	6	Occupied	**In-Use Nest**	Occupied	Occupied
Cane Springs	2	Occupied	Occupied	Occupied	**In-Use Nest**
North Camelback	12	**In-Use Nest**	**In-Use Nest**	**In-Use Nest**	Occupied
North Granite	8	**In-Use Nest**	**In-Use Nest**	**In-Use Nest**	**In-Use Nest**
Roughhaul Rd	5	**In-Use Nest**	Vacant	Vacant	Occupied
South Camelback	15	Occupied	**In-Use Nest**	Occupied	**In-Use Nest**
South Granite	13	Occupied	Occupied	Vacant	Occupied
Simpson Butte	8	Unknown**	**In-Use Nest**	**In-Use Nest**	Unknown**
West Vertical Grid	4	**In-Use Nest**	**In-Use Nest**	**In-Use Nest**	**In-Use Nest**
Wig Mountain	6	**In-Use Nest**	**In-Use Nest**	**In-Use Nest**	Occupied
Five Mile Hill	7	Vacant	Vacant	Occupied	Occupied

* The number of nest location records is approximate, and includes all documented nest locations, which may include some that have collapsed and no longer exist, or some duplicate nest records.

** Ground observers were not permitted to access Simpson Butte due to unexploded ordnance in the vicinity during 2015 and 2018.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY AND METHODOLOGY COMPONENTS

This project was designed to compare the cost-effectiveness and technical capability of the ground monitor versus the sUAS versus the UAS when monitoring nesting golden eagles. The hypothesis was that sUAS would provide a cost-effective means of monitoring eagles over the traditional ground monitoring due to the amount of area that can be covered in a short amount of time, as well as the use of HD cameras that are able to be positioned at various altitudes and angles to provide the best look into the nest. The sUAS is also a relatively inexpensive, easy to operate platform. Figure 6 below shows the 11 territories that were monitored each season.

The methodology used was based on best practices in the eagle monitoring arena to ensure a blind study with verifiable results. All results were analyzed in conjunction with costs to determine the most cost-effective solution.

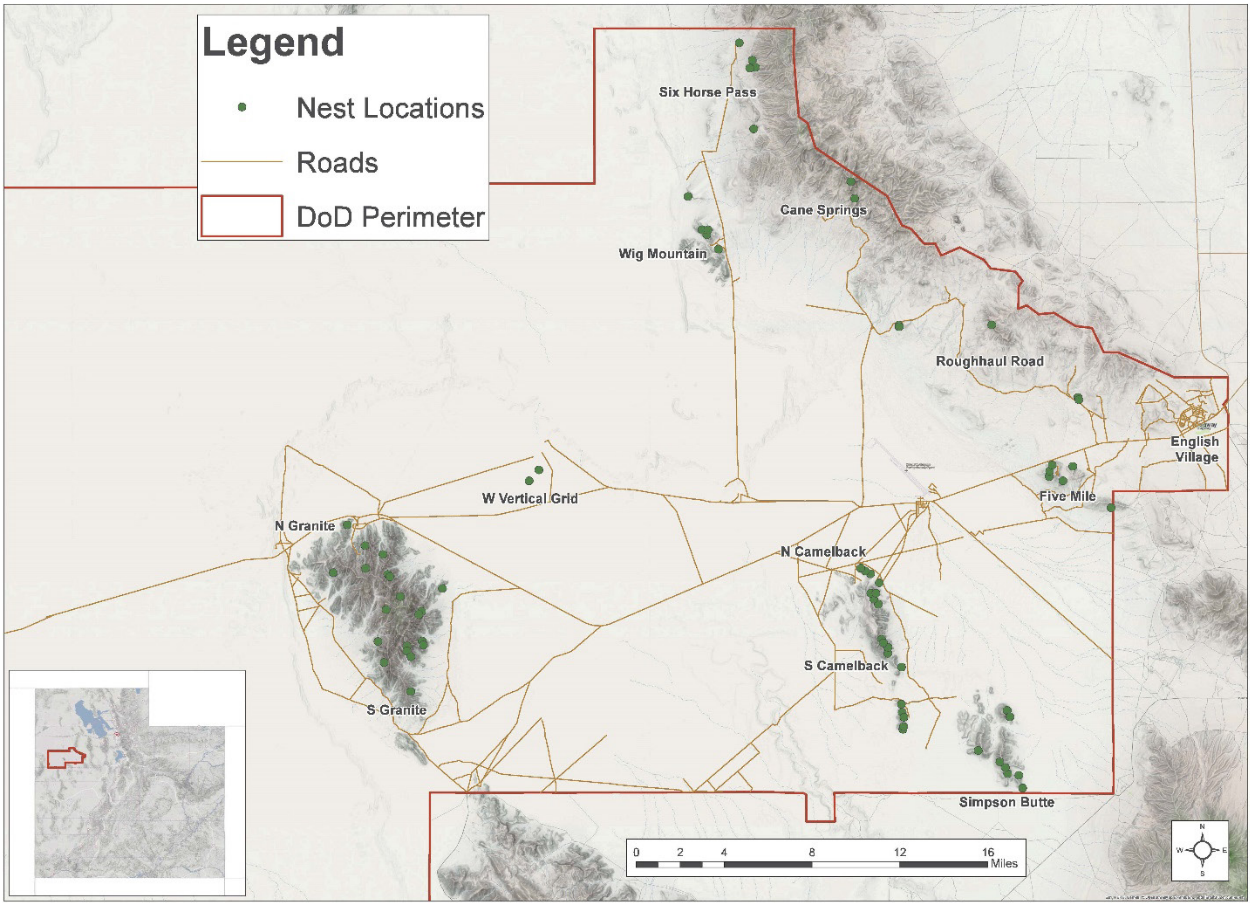


Figure 6. Known Golden Eagle Nest Locations Associated With 11 Territories on DPG

5.4 FIELD TESTING

The following instructions were provided to the observers to guide field observations, in addition to the simplified flow chart of methods provided in Appendix 3.

Early Season: Surveyors will attempt to search all 11 territories every two weeks, with 6 and 5 territories surveyed on alternating weeks, utilizing up to 2 survey days per week, and up to 3 hours search time per territory. Territories will be grouped by location and the ground observer and sUAS team will alternate territory groups between days. Territory survey order within each group will be based upon DPG identified priority areas and optimal time of day viewing conditions. Surveyors will follow strict survey protocols detailed below and visualized by flowcharts in Appendix 3.

Step 1: Determine necessary survey effort level at each territory:

- If first territory survey, or no In-Use Nest found during previous survey(s), attempt complete search below *(Step 2–7)* until territory status is determined or 3-hour time limit is reached for that territory.
- If In-Use Nest present on previous visit, complete Steps 2–4, and then proceed to "In-Use Nest" protocol. This includes nests for which the previous status was "previously In-Use unknown" *(see description in "In-Use Nest" protocol),* until status is resolved.

- If an In-Use Nest in this territory was previously determined as "failed", do not survey.

Step 2: Record daily "Survey Start Time" when leaving English Village *(Ground/sUAS)* or upon take-off *(UAS).*

Step 3: Record individual "Territory Survey Start Time" when within 2-km buffer around known nests.

Step 4: Navigate to within 800 m+ or adjusted viewing location of first ranked nest(s) *(order prescribed based on survey history).*

Step 5: "Area Search": record stationary time spent searching for free-flying eagles within territory or on ridges *(up to 15 mins).* Time does not include approach drive/fly time to stationary point, but adults observed during approach are noted *(please indicate if observed on approach).*

- No adults seen, proceed to "Nest Survey".
- One adult seen, proceed to "Nest Survey", but adjust nest survey order to begin with known nest(s) within 250 m of adult, survey all other nests in prescribed order.
- Two adults seen off-nest, search any known nest(s) and substrate visible within 250 m of adults for signs of nest tending/eggs. If both eagles remain off-nest for 15 mins, territory survey ends, with times noted, and territory status will be recorded as "Territory Occupied, no In-Use Nest".

Step 6: "Nest Survey": attempt to search all known nests in pre-determined order, with visit-specific modifications as warranted. Each nest is viewed until status is confirmed *(i.e., "In-Use" [adult, egg, or young on nest], "inactive" [not In-Use, based on clearly visible nest bowl/platform, or condition inadequate for nesting], "Unknown" [30 mins viewing viable nest, status unresolved], "Time expired" [territory survey end time reached before status confirmed], or "Not Surveyed").* Evidence of tending/greenery is noted. Record all nest survey time undifferentiated by nest but note if full 30 mins required for individual nests.

- Attempt to survey all known nests in prescribed order (based on nest histories, but adjusted if presence of adult(s) detected during this or previous survey, or recent evidence of tending), until "In-Use Nest" (eggs/nestling/incubating adult) found, two adults seen off-nest, all nests surveyed, or 3 hr time limit reached. If all nests were not surveyed during a previous survey due to time expiration, resume from previous position.
- Up to 5 mins may be spent scanning nearby cliff faces and ridgetops upon arrival at each new viewpoint.
- If an In-Use Nest is found, proceed to "In-Use Nest" protocol (survey ends there, with end times noted). Territory status will be recorded as "Occupied-In-Use Nest".
- If two adults seen off-nest, go to protocol under "Two adults seen", under "Step 5: Area Search" (survey ends there, with end times noted).
- If all nests surveyed without detecting an In-Use Nest, and a single adult has been seen on this or any previous survey, record end of Nest Survey time and proceed to "Extended Search".

- If all nests surveyed without detecting an In-Use Nest, and no eagles were detected in the territory, record territory status as "Vacant Territory", record end of Nest Survey time and proceed to next territory.

Step 7: "Extended Search": attempt to find new nests when only one adult seen and known nests are not In-Use. Record search time, including time hiking if relevant, and indicate area searched on map.

- Search potential nest substrate and ridges within 250 m of previous adult sightings(s) for potential alternate nests, until an In-Use Nest is found *(go to "In-Use Nest" protocol),* two adults are seen off-nest, the area surrounding the sighting has been adequately searched *(may include hiking for ground observer),* or time expires. Add any new nests found to the end of next territory visit search order unless evidence of tending.
- If an In-Use Nest is found, proceed to "In-Use Nest" protocol *(survey ends there, with times noted).*
- If two adults seen off-nest, go to protocol under "Two adults seen", under "Step 5: Area Search" *(survey ends there, with end times noted).*

Step 8: Record "Territory Survey End Time" when leaving 2-km buffer around each territory (NOTE: 3 hr territory limit begins upon entering 2-km threshold, but may expire during nest survey, extended search, or In-Use Nest monitoring).

Step 9: Repeat Steps 3-8 until all territories allotted for survey in a given day are visited. Ground and sUAS may not survey territories allotted for other survey days to maintain separation of survey platforms.

Step 10: Record daily "Survey End Time" on return to English Village or runway.

Late Season: Surveyors will attempt to visit all In-Use Nests identified in early season every week, plus any carryover territories with ambiguous status until resolution is reached, utilizing up to two survey days per week, and up to a time limit specific to each territory (between 1 and 4 hrs). Territories will be grouped by location and the ground observer and sUAS team will alternate territory groups between days. Territory survey order within each group will be based upon DPG identified priority areas and optimal time of day viewing conditions. Surveyors will follow strict survey protocols, detailed below, and visualized by flowcharts in Appendix 3.

Step 1: Determine necessary survey effort level at each territory:

- If In-Use Nest present on previous visit, complete Steps 2–4, and then proceed to "In-Use Nest" protocol. This includes nests for which the previous status was "previously In-Use unknown" *(see description in "In-Use Nest" protocol),* until status is resolved.
- If an In-Use Nest in this territory was previously determined failed, do not survey.
- If early season surveys found no adults in the territory *(i.e., "Vacant Territory"),* or produced two or more separate sightings of two off-nest adults *(i.e., "Occupied Territory, no In-Use Nest"),* do not survey.

- If early season surveys found only one adult and no In-Use Nest, additional surveys may or may not be warranted. If all known nests were surveyed definitively on at least two separate visits, and at least one "Extended Search" was conducted of substrate within 250m of any adult sighting(s), no additional survey is necessary. Otherwise, follow Early Season protocol until these criteria are met or In-Use Nest is found.

Step 2: Record daily "Survey Start Time" when leaving English Village *(Ground/sUAS)* or runway *(UAS).*

Step 3: Record individual "Territory Survey Start Time" when within 2-km buffer around known nests.

Step 4: Approach first nest viewing location of In-Use Nest and proceed to "In-Use Nest" protocol.

Step 5: Record "Territory Survey End Time" when leaving 2-km buffer around each territory, or when time expires *(NOTE: 3-hr territory limit begins upon entering 2km threshold but may expire during survey).*

Step 6: Repeat Steps 2-5 until all territories allotted for survey in a given day are visited. Ground and sUAS may not survey territories allotted for other survey days to maintain separation of survey platforms.

Step 7: Record daily "Survey End Time" on return to English Village or runway.

"In-Use Nest" Protocol *(to be used with both "Early Season" and "Late Season" surveys)*: Surveyors will determine status of newly or previously found In-Use Nest by watching for up to 60 mins *(but ended sooner if definitive status is reached sooner, or maximum 4-hour territory time expires).*

- For newly discovered "In-Use Nest", 60-minute clock begins when nest first verified used (e*.g., may exclude up to 30 mins of survey while still "unknown"*); for all others, time begins with arrival at view coordinate.
- If two adults seen on the nest, watch until confirmation of incubation/brooding, eggs, nestlings, fledglings, or *failure (proceed to those statuses below),* or list as "adults on nest-unknown" if status unresolved after 60 mins or when time expires.
- Incubation/brooding: if adult seen in incubating/brooding posture, record status and end nest survey.
- Egg(s): if egg(s) seen, record number, presence of adult(s), other circumstances, and end nest survey.
- Nestling(s): if nestling(s) seen after March 24, spend up to 60 mins attempting to count and age to nearest half-week. Surveys may be ended sooner without a count of nestlings when all-downy eaglet(s) *(<4 weeks)* seen. Note presence of adults, feeding events, etc. List as "unknown" age and/or count if unresolved after 60 mins or time expires *(or note if not attempted due to pre-March 24 date).* If age is determined to be 7 weeks or older (80% fledge age), proceed to "fledgling" protocol below.

- Fledgling(s): spend up to 60 mins attempting to determine total number of fledglings reaching at least 80% fledge age *(7 or more weeks).* Annual nest survey effort is complete when fledge age reached and confident fledgling count achieved *(may require subsequent week visit).*
- Failure: nest confirmed as empty of adults, eggs, or nestlings, after previous visit confirmed In-Use *(excluding "adults on nest-unknown"),* or status of previously confirmed In-Use Nest cannot be verified after two consecutive weeks of 60 min survey.
- Previously In-Use-unknown: status cannot be verified after 60 mins of watching, despite activity confirmed during a previous survey. Two consecutive nest surveys with this status results in assigning failure.

5.5 SAMPLING PROTOCOL

Laboratory samples were not collected during this demonstration. Field survey methods are addressed in section 5.4.

5.6 SAMPLING RESULTS

Laboratory samples were not assessed during this demonstration. Field survey results are addressed in section 6.0.

6.0 PERFORMANCE ASSESSMENT

The demonstration team successfully completed two full seasons of eagle nest monitoring on DPG during 2019 and 2020 *(Table 4)*. However, eagle nesting initiation and success rates were very low across the entire Utah West Desert region during both years *(HawkWatch International 2019)*. Eagle nesting initiation is currently thought to be a function of available food supply, namely black-tailed jackrabbits for the West Desert population of golden eagles *(Steenhof et al. 1997)*. Jackrabbit populations in Utah are currently at a low in their population cycle, resulting in a few years of depressed golden eagle nest initiation and success *(HawkWatch International 2019)*. Eagle nesting success may begin to trend upwards as soon as next year *(2021)* as rabbit populations rebound *(Bedrosian et al. 2017)*. It may be that better eagle nesting success during monitoring would allow for a larger dataset and more robust conclusions regarding the abilities of each monitoring platform.

6.1 STATISTICAL ANALYSIS

As a result of the low nesting initiation and success rates on DPG during both monitoring seasons, the demonstration team was not able to collect enough independent data points to support a robust mixed effect regression model to assess platform success as we had proposed. The large number of variables involved in our proposed model demand a large set of independent nest observations, and a large number of replications of those observations. We only observed two in-use nests in 2019, and 3 in 2020 *(although only one nest in 2020 survived to fledging age)*. Instead, the DPG Team developed a simplified version of the proposed model focusing on general nest observations and status assessment. Survey platform was treated as a fixed effect with the binary response variable being correct or incorrect weekly nest status classification within each territory based on the “true” weekly status. Territory, survey week, and period *(early/late)* were treated as random effects. Mixed effect modeling allowed us to assess whether the survey platform influenced the odds of correctly classifying weekly statuses, outside the random effects of time and territory. In addition, the DPG Team created a logistic regression model to assess the effects of survey platform on the amount of time required to determine nest status. Survey platform was treated as a fixed effect with the number of minutes required to determine each nest status as the response. We included territory, survey week, and nesting period as additional variables. We ran two separate runs of both models for each year, as the differences in sUAS platforms greatly affected the results from year to year.

The initial proposal was to compare military UAS platforms to the sUAS and ground observer teams directly. However, it was determined in the first season of operation *(2019)* that flight schedules for the military UAS platforms were too sporadic to support regular nest monitoring. The military UAS were only able to monitor nests on an as-available basis, and other missions, weather, and maintenance concerns frequently bumped nest observations off the schedule. In addition, the COVID-19 crisis in 2020 resulted in the UAS observer being barred from conducting nest observations within the UAS control box due to health and safety concerns. Due to a lack of repeated observations on the same scale as the ground observer and sUAS, the military UAS platform was not included in the comparison models.

Table 4. Nest Monitoring Results of Both Survey Years, Broken Out by Year and Platform, and Including "True" Nest Statuses and Dates as Determined by Backdating and Remote Cameras Placed in In-use Nests

Metric	Year	"TRUE"	Ground	sUAS	UAS	Comment
# Territories	2019	11	11	11	6	
	2020	11	10	11	NA	
# Occupied Territories	2019	11	10	11	1	
	2020	6	6	6	NA	
# Nests Surveyed	2019	85	59	63	11	
	2020	85	47	62	NA	
Average Weekly Nests Surveyed	2019	NA	16	27	1	
	2020	NA	15	26	NA	
# In-Use Nests	2019	2	2	2	1	
	2020	3	2	2	0	
# Fledglings	2019	2	2	2	1	
	2020	2	2	0	NA	
% Success	2019	100%	100%	100%	100%	
	2020	33%	50%	0%	NA	
Fledglings/Adult Pair	2019	1	1	1	NA	
	2020	0.33	0.33	0	NA	
Territory Occupancy Sample Units	2019	NA	34	32	1	Total number of early season territory surveys in which definitive territory occupancy *(excluding In-Use Nests)* documented
	2020	NA	33	31	NA	
In-Use Nest Sample Units	2019	NA	21	21	2	Total number of territory surveys in which definitive In-Use Nest documented
	2020	NA	13	6	NA	
% correct closure	2019	100%	81%	89%	25%	% of In-Use Nest survey dates correctly assigned closure
	2020	100%	93%	83%	NA	
% incorrect closure	2019	0%	19%	11%	75%	% of nest survey dates incorrectly assigned closure *(too early/too late)*
	2020	0%	7%	17%	NA	
Field Survey Man-Hours	2019	NA	8:39	18:00	1:22	Average weekly driving/flight and survey hours *("Survey Time" x number of personnel)*
	2020	NA	7:47	20:09	NA	
Territory Survey Man-Hours	2019	NA	1:38	4:09	0:25	Average time within 2-km geofence x number of personnel
	2020	NA	1:47	3:54	NA	
Nest Survey Time	2019	NA	0:17	0:09	0:07	Average weekly time needed to determine nest status
	2020	NA	0:20	0:11	NA	
New Nests Found	2019	NA	1	3	0	Number of previously unknown nests identified
	2020	NA	1	3	NA	

6.2 TIME TO EARLY SEASON OCCUPANCY STATUS

The ground observer and the sUAS took roughly the same amount of time to determine early season territory occupancy each year, even with the change in sUAS platform in 2020. The ground observer took a mean time of 111 minutes to determine occupancy in 2019 (SD = +-64) and 108 minutes in 2020 (SD = +- 64). The sUAS observer took a mean time of 108 minutes in 2019 (SD = +- 54) and 91 minutes in 2020 (SD = +- 50). The UAS took vastly less time to make a territory determination in 2019, although this is mostly due to the limited available flight time the platform had to work within. The UAS platform was rarely able to make definitive determinations within the given time allowed and was removed from the comparison. Most of the time required by both the sUAS and ground observer was taken by drive time between nests in a territory *(Figure 7).*

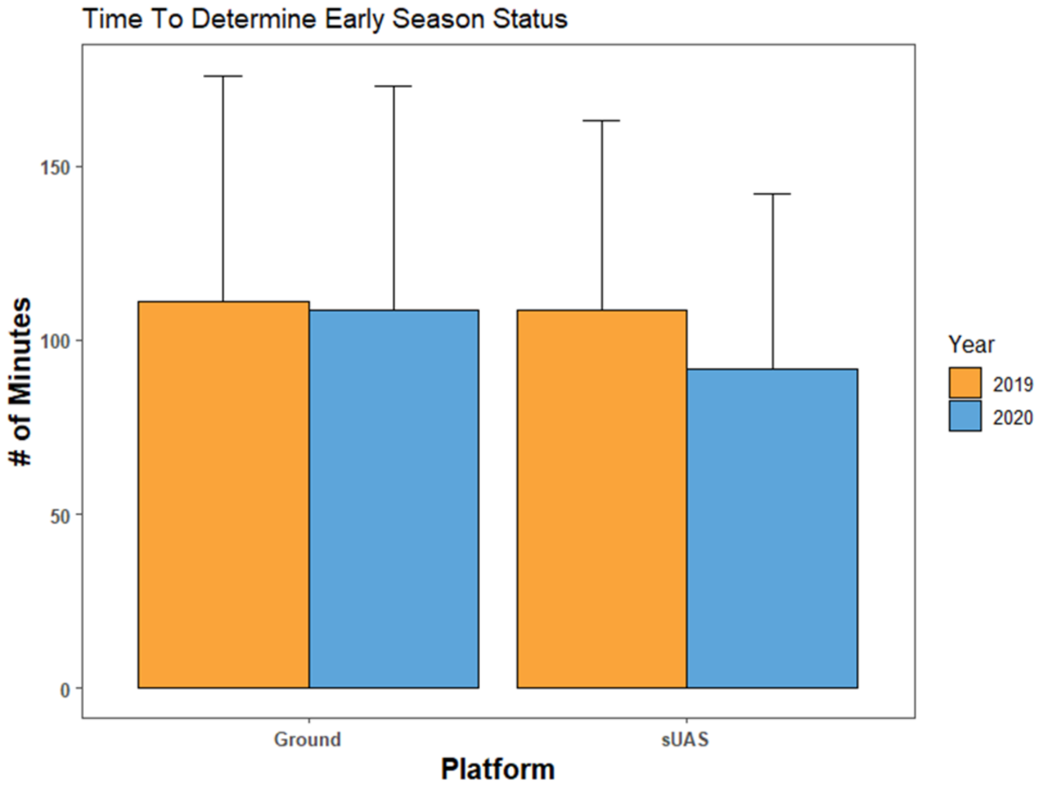


Figure 7. Chart Showing the Mean Time in Minutes (+SD) each Platform Required to Determine the Early Season Occupancy of a Territory.

6.3 NUMBER OF IN-USE NESTS IDENTIFIED

Both the ground observer and the sUAS found the same number of in-use nests each nesting season, while the UAS was unable to locate one of the in-use nests in 2019 *(the UAS was forced to cease operations before in-use nesting in 2020 due to COVID-19).* An interesting point to be considered is that in 2020, there were actually 3 in-use nests. The ground observer located one in-use nest that the sUAS was unable to observe due to territorial aggression against the platform by the eagle pair, while the sUAS located an in-use nest that the ground observer was unable to survey due to lack of ground access in an Impact Area. This illustrates the fact that both survey methods have strengths and weaknesses that the other can supplement *(Figure 8).*

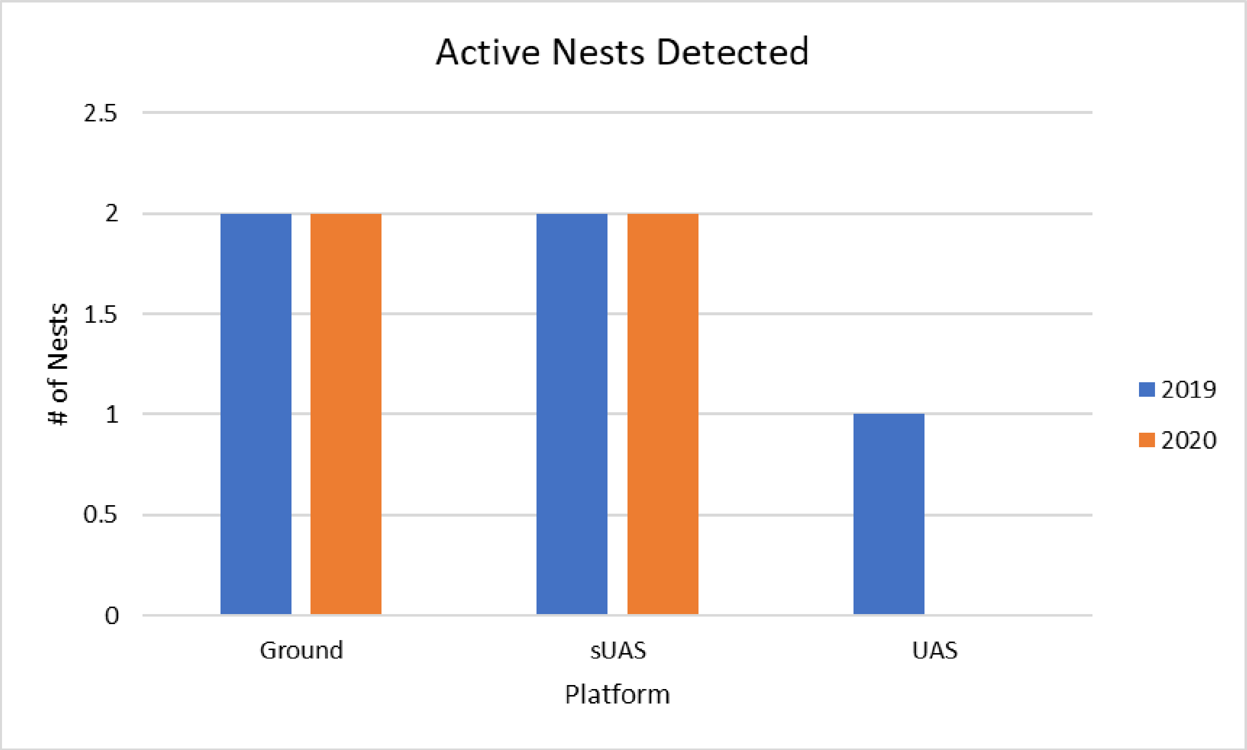


Figure 8. Chart Showing the Number of In-use Nests Each Platform Identified During Each Breeding Season.

6.4 DATE OF IN-USE NEST IDENTIFICATION

The sUAS platform was roughly equal with the ground observer at detecting in-use nests in 2019. The sUAS platform was able to survey almost every known nest in each assigned territory each week, making it more likely for the platform to detect an incubating eagle within a week of nesting initiation. The ground observer, on the other hand, was forced to rotate which nests were surveyed during each visit due to long hikes over rough terrain. The 2019 UAS was typically not able to identify nest activity due to the low resolution of its payload and the lack of precise nest metadata provided to its pilots and was not compared. In 2020 the sUAS was again roughly equal to the gound observer in nest detection time, despite the sUAS's drop in payload resolution. This indicates that the advantage of visiting more nests outweighed the disadvantage of poor payload resolution. In 2020, the UAS platform was forced to cease surveys before nests became in-use, removing it from this comparison *(Figure 9)*.

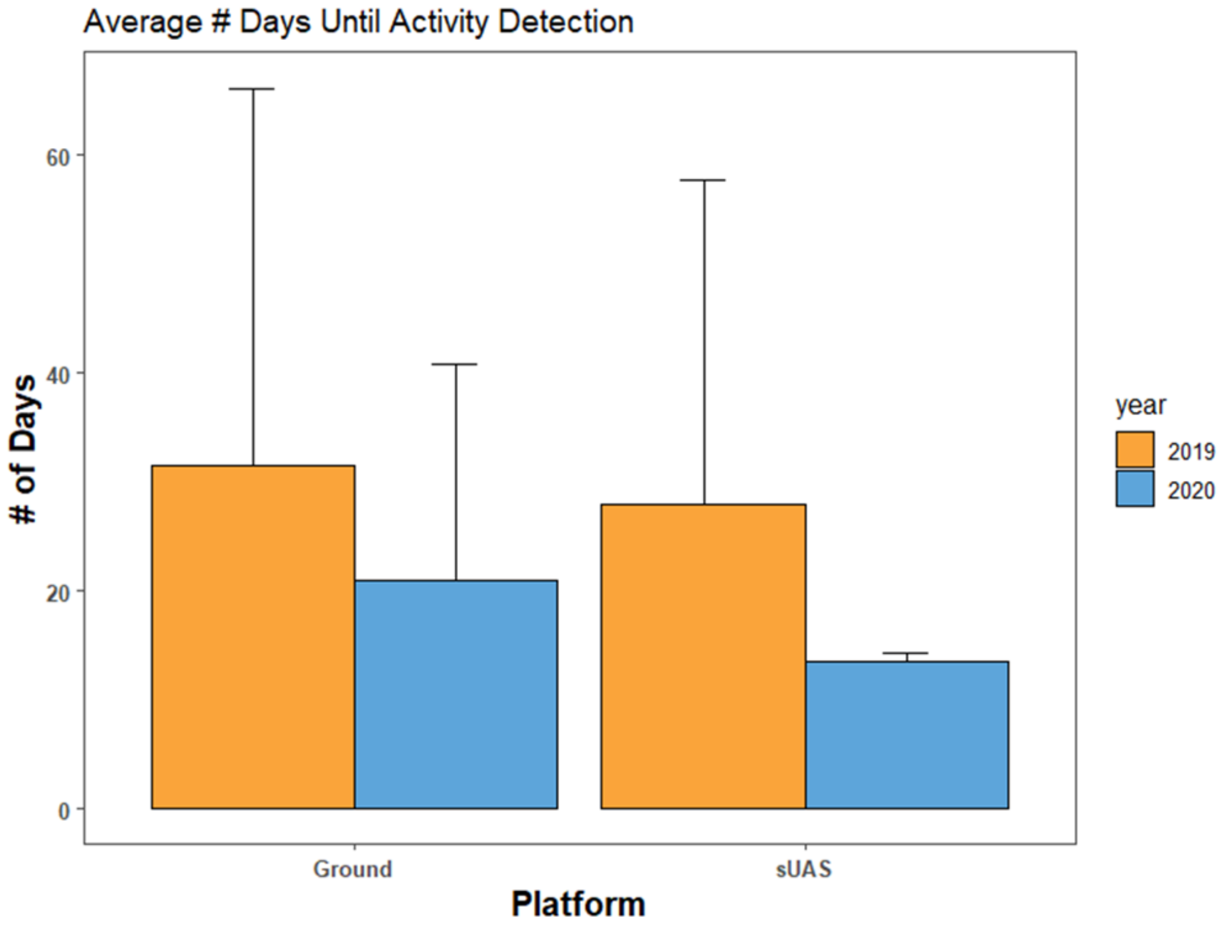


Figure 9. Chart Showing the Mean Number of Days (+SD) from Nest Initiation to Activity Detection by Each Platform.

6.5 DATE OF NEST FAILURE OR FLEDGE IDENTIFICATION

In 2019, the ground observer and sUAS platforms very nearly tied for speed at detecting nest failure or fledge. Both had sufficient quality optics and visitation rates to detect the lack of chicks in a nest almost immediately. The UAS was not compared due to lack of data. By contrast, the ground observer was much faster to detect nest failure or fledge in 2020 than the sUAS. The sUAS's loss of payload resolution made it difficult for the platform to identify the presence or absence of small chicks in a nest. Again, the UAS was forced to cease surveys before nests became in-use, removing it from this comparison *(Figure 10)*.

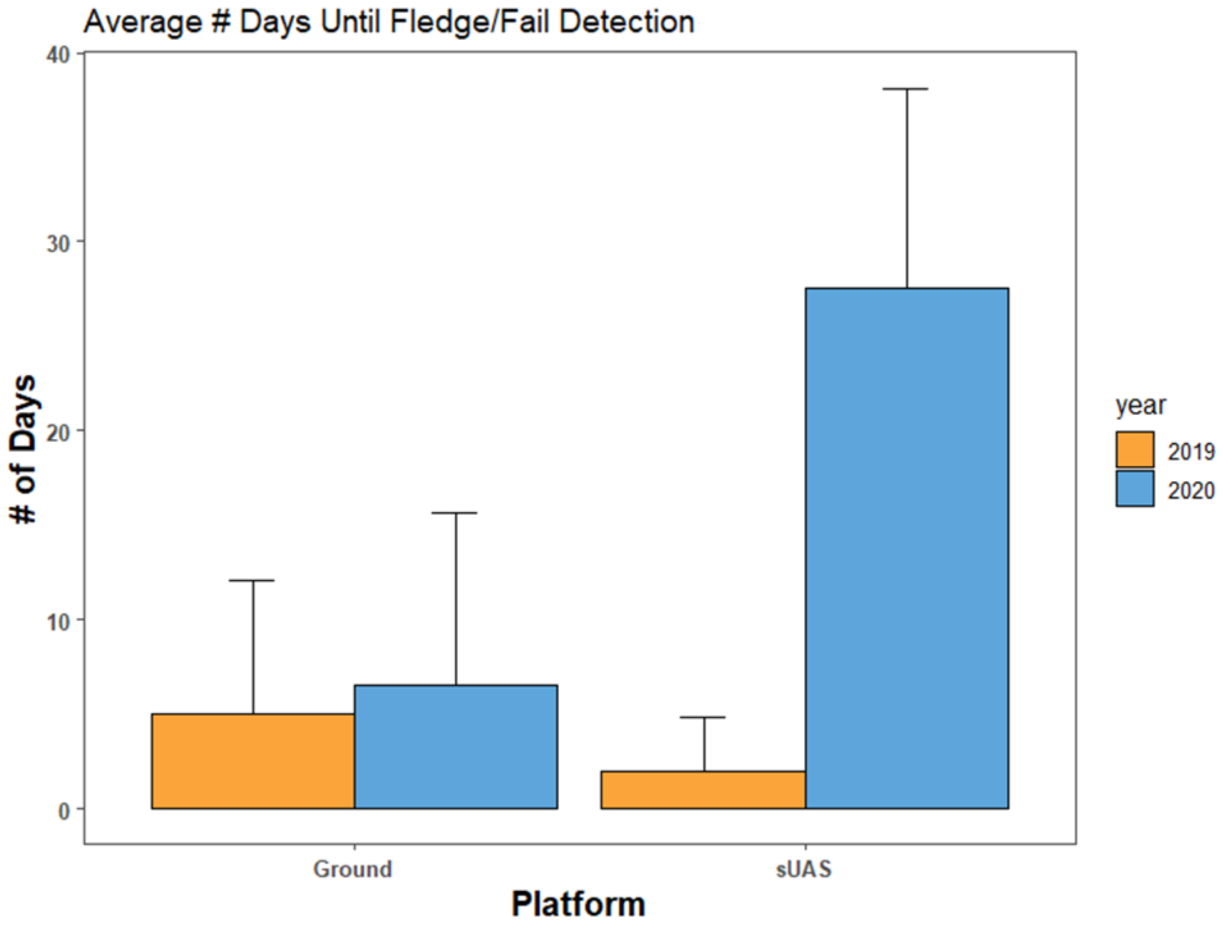


Figure 10. Chart Showing the Mean Number of Days (+SD) from Nest Failure or Fledge to Detection by Each Platform.

Error bars represent standard deviation.

6.6 TIME TO NEST STATUS UPDATE

The following logistic regression models illustrate the differences in nest observation efficiency both between platforms and between years. In 2019, the sUAS displayed a clear efficiency advantage over the ground observer, requiring much less observation time to make a nest status determination, especially in the early nesting season. This is because of the sUAS's ability to view directly into a nest bowl, eliminating the need to wait for a possible incubating eagle to stand or stretch in order to come into view from the ground. As the nesting season went on and chicks got larger, they were easier to see from below, decreasing the advantage of the sUAS. In 2020, the sUAS retained a small advantage over the ground observer, but the poor resolution of the payload meant that the platform had to observe each nest for much longer in order to determine if an object perceived to be in the nest was actually an eagle or if it was simply a pixilation artifact. In addition, the ground observer in 2020 took more time on average as the season went on, mostly due to the fact that one of the in-use nests was located in a high, partially obscured cliff cavity, preventing easy observation at any time.

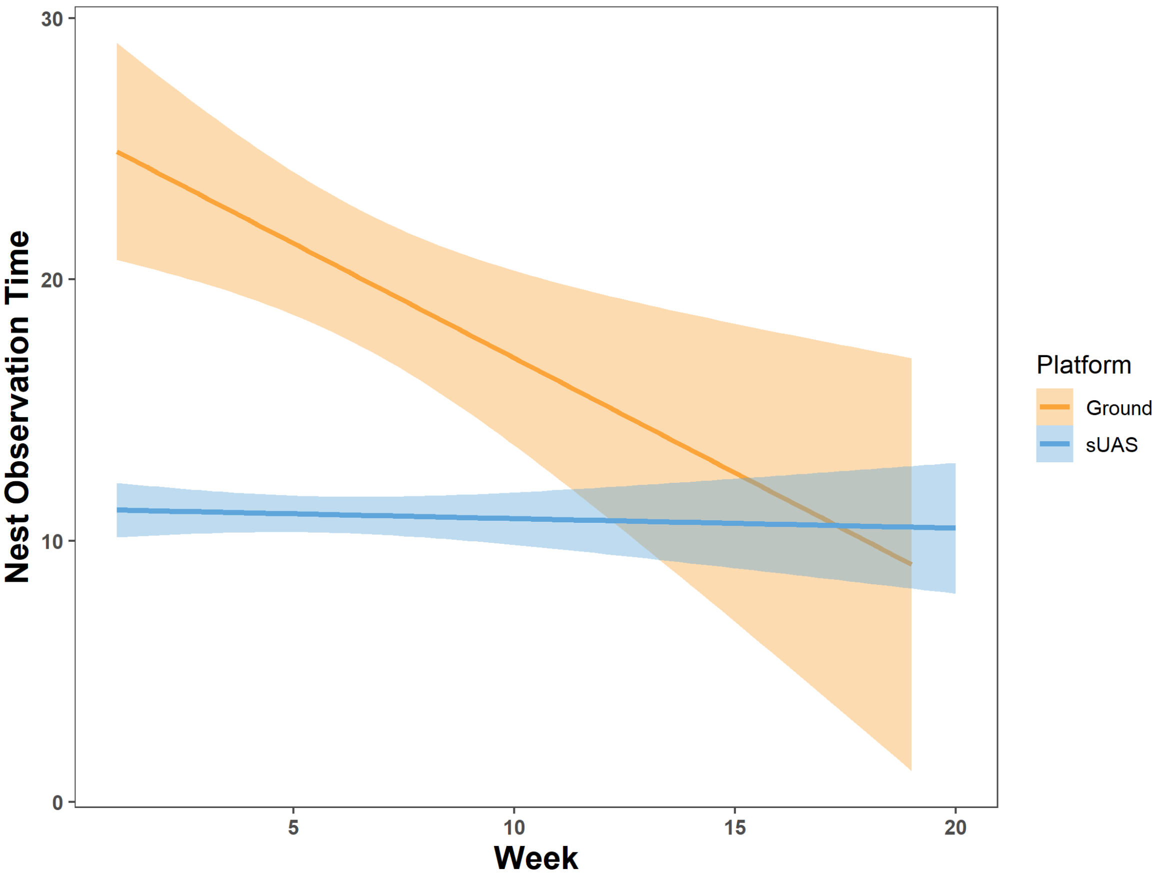


Figure 11. Comparison of the Efficiency of a Ground Observer in Minutes (± 95% Confidence Intervals) vs an sUAS at Determining Any Given Nest's Status During 2019. *The sUAS took vastly less time to determine status during early season, while the ground observer gained efficiency as unused nests were eliminated from the survey round.*

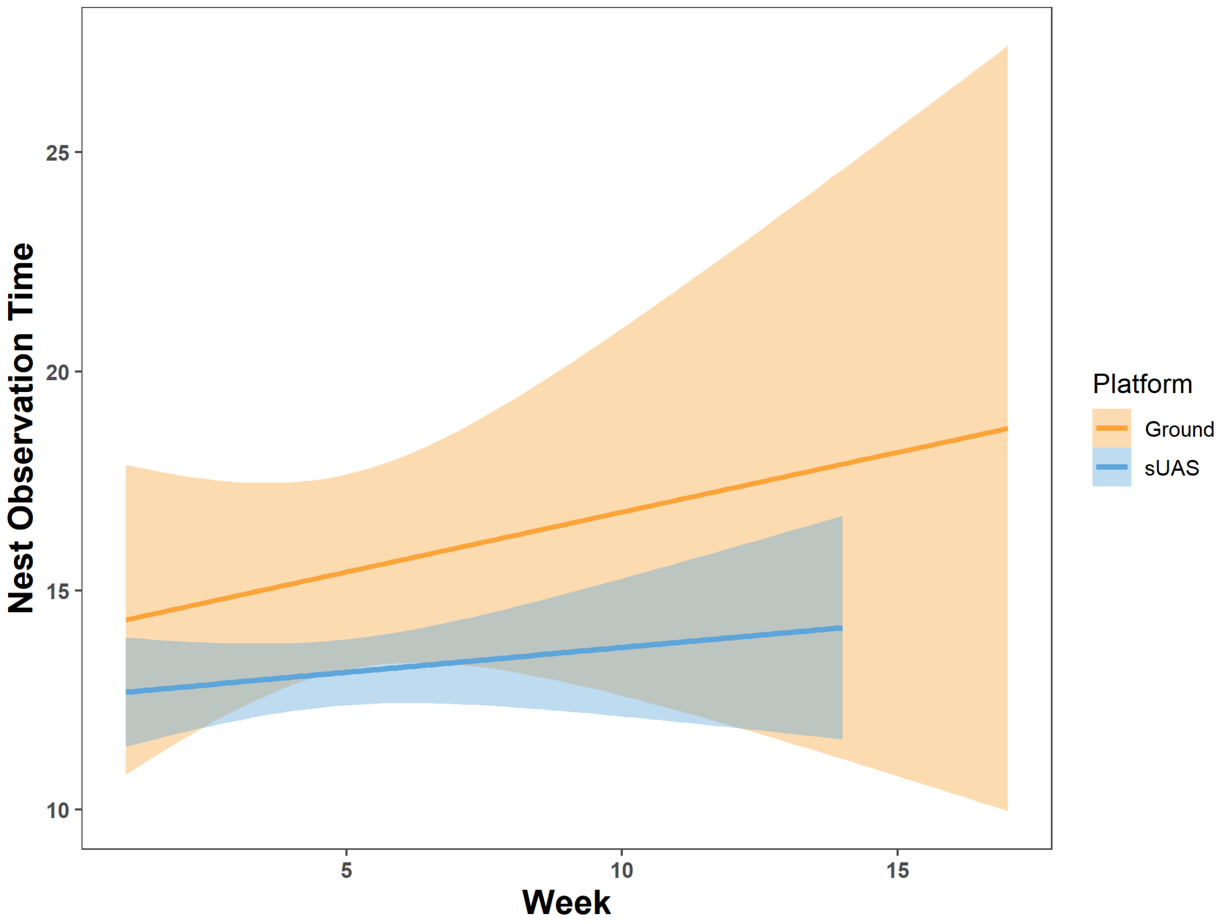


Figure 12. Comparison of the Efficiency of a Ground Observer in Minutes (± 95% Confidence Intervals) vs an sUAS at Determining Any Given Nest's Status During 2020. *The sUAS took less time to determine status on average. The sUAS's efficiency advantage was much less pronounced than during 2019.*

6.7 NUMBER OF NEW NESTS FOUND

In both 2019 and 2020, the sUAS outcompeted the ground observer and the UAS at finding previously undescribed nests. The sUAS had the advantage of covering a great deal of territory quickly, while also taking photos and video of terrain to be later analyzed for potential nests. The ground observer was unable to visit as much of each territory and had to focus on observing already known nests, preventing the observer from spending much time scanning for new nests. The UAS was unsuited to locating new nests due to the complications of approach angle and low payload resolution in 2019 and did not have enough survey time to draw a comparison in 2020 *(Figure 13).*

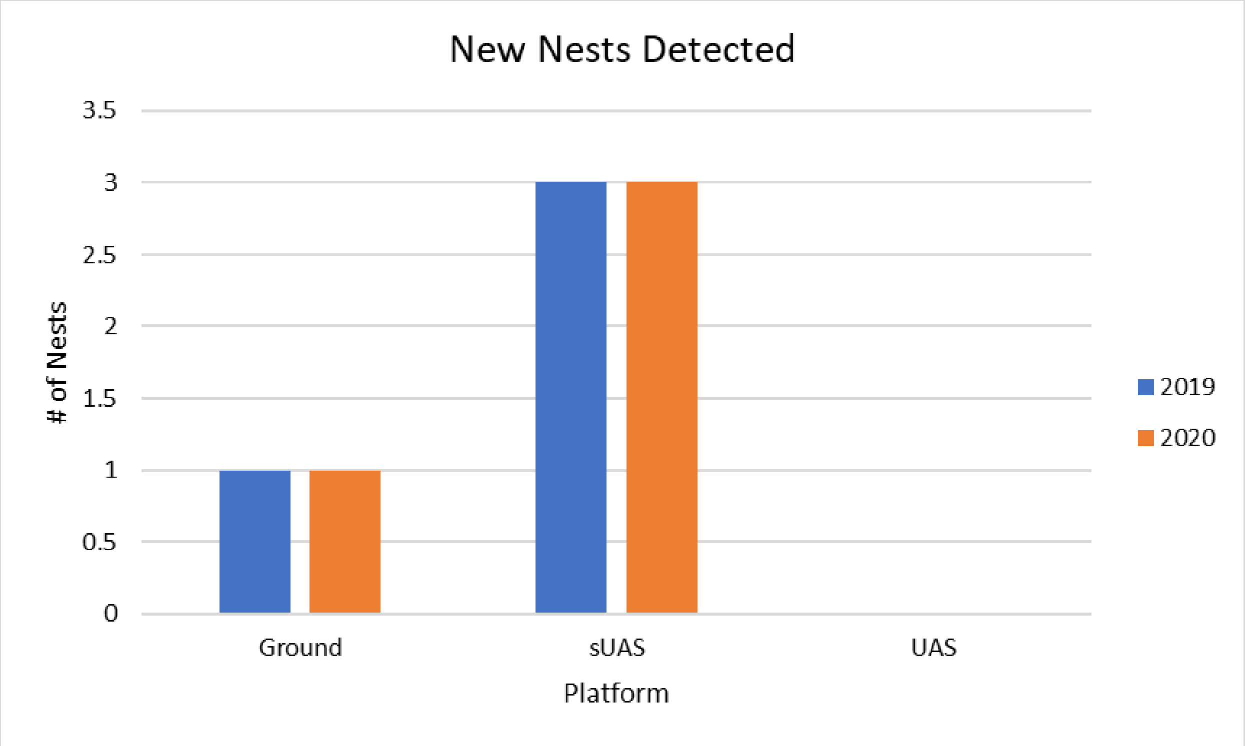


Figure 13. Chart Showing the Number of New Nests Each Platform Located During Each Season.

6.8 HYPOTHETICAL MISSION IMPACT IN DAYS

The hypothetical mission impact of nest area closures and openings is a measure of the precision of each platform in detecting nest status changes. Ideally, an in-use nest will be detected, and an area closure enacted immediately *(within one week or survey period)* upon the start of incubation, and the area opened again immediately upon the failure or fledge of the nest. This minimizes potential mission impacts of unnecessary range closures as well as protecting the nest against potential disturbance *(Figure 14)*.

In 2019, both the ground observer and sUAS platform were slow to detect the activity of RN315, leaving it unprotected for several weeks, although the sUAS was one week quicker in detecting the nest's activity. In addition, the ground observer designated RN315 as fledged prematurely by one week. This resulted in the sUAS being cumulatively more precise in designating range closures in 2019 than the ground observer.

In 2020, the data is complicated by the fact that both the ground observer and the sUAS monitored nests that the other platform was not capable of reaching, leaving only one nest for direct comparison. The ground observer was slow to detect the activity of RN248A by several weeks but caught the fledge of the nest immediately. The rough terrain and lack of road access in RN248A's territory required the ground observer to ration which nests received a survey visit each week, which resulted in the in-use nest going undetected for several weeks. The sUAS detected the activity of RN029 immediately but was slow to confirm the failure of the nest by several weeks.

The low resolution of the platform payload in 2020 made it much more difficult to identify the presence or absence of young chicks from the nest bowl than the presence or absence of an incubating adult. Both platforms were equally precise at determining the status of RN321.

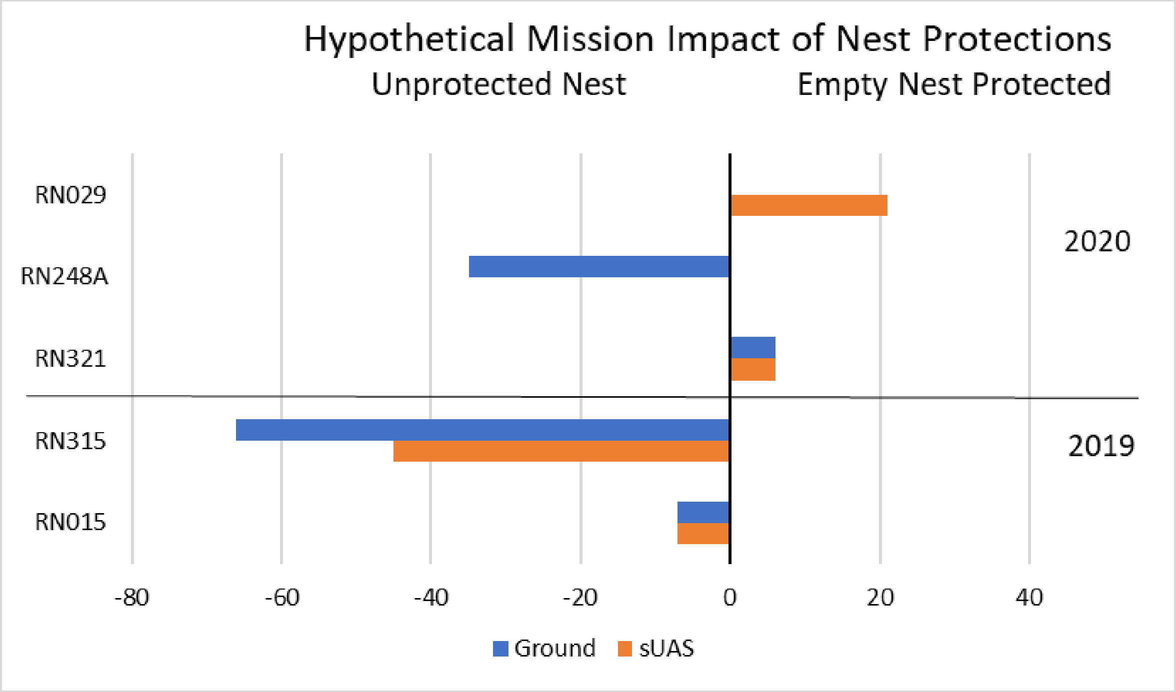


Figure 14. Chart Showing the Hypothetical Impact of Nest Area Closures/Openings by Platform and Year.

The 0 line represents no deviation from actual nest use, i.e., the desired perfect protection.

6.9 QUALITY OF PHOTO/VIDEO DOCUMENTATION

The DPG Team conducted a qualitative evaluation of how well each platform was able to document nest status in both 2019 and 2020. In 2019, the sUAS platform delivered high resolution video and photo documentation of all nests viewed, as well as footage of the surrounding cliffs for the team to search for previously unknown nests. The photo/video documentation allowed the data managers to confirm nest status before putting range closures in place. By contrast, the UAS platform in 2019 was equipped with a low-resolution payload that hampered the observer's ability to identify nests with confidence. The UAS's thermal imaging capability did allow the observer to spot chicks in in-use nests, however. In 2020, the imaging capabilities of the sUAS and UAS platforms were reversed. The replacement sUAS platform had a downgraded payload resolution due to downlink limitations. In addition, it did not have onboard data recording capabilities; the observation team had to record footage from the ground station, and as a result encountered significant issues with poor reception and signal corruption. These limitations resulted in the sUAS team requiring more time on site to determine nest status, and in many cases prevented the team from calling a certain nest status at all. On the other hand, the UAS platform received a significant upgrade to its payload systems, allowing for HD image recording. Unfortunately, the UAS team was forced to cease survey operations after only 2 weeks of monitoring due to the COVID-19 crisis, and the observation team was unable to obtain enough data to present a significant image comparison.

The photos below show the images taken from the two sUAS and the one UAS *(Figures 15-18)*.

Figure 15. A Photo of RN315 as Taken by the sUAS Platform in 2019.

(DJI Matrice 600 Pro with Zenmuse Z30 payload). The photo shows an adult golden eagle sheltering a chick less than a week old.

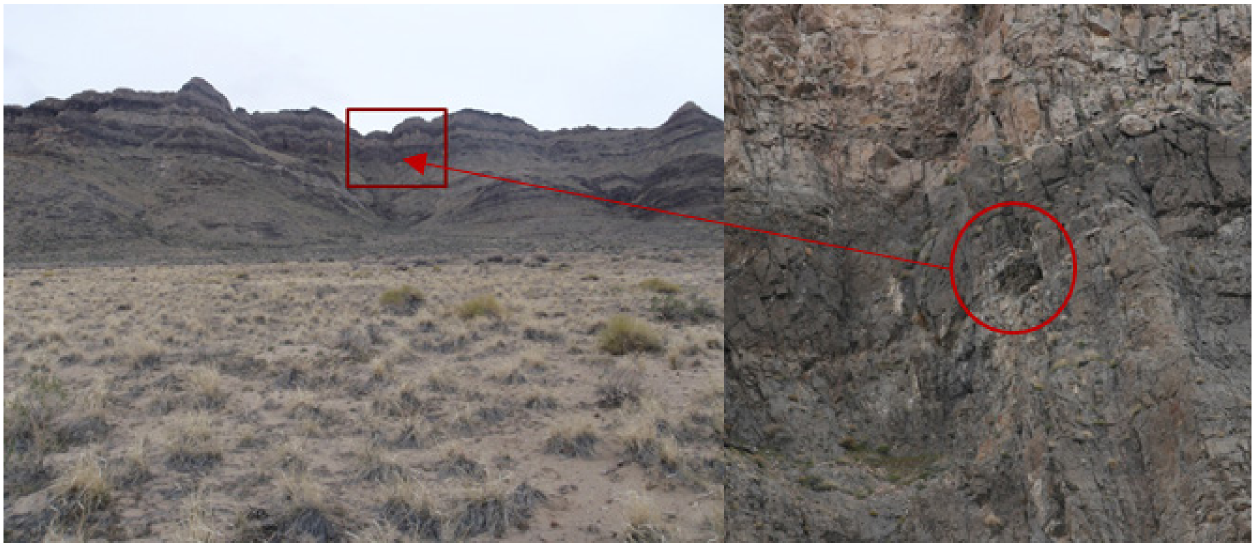


Figure 16. A Series of two photos taken by a ground observer at two different zoom levels of RN046.

The first photo shows the distance the observer must view the nest from, as well as the height of the nest on the cliff face. The second photo shows how the ground observer must view the nest from below, even at high zoom.

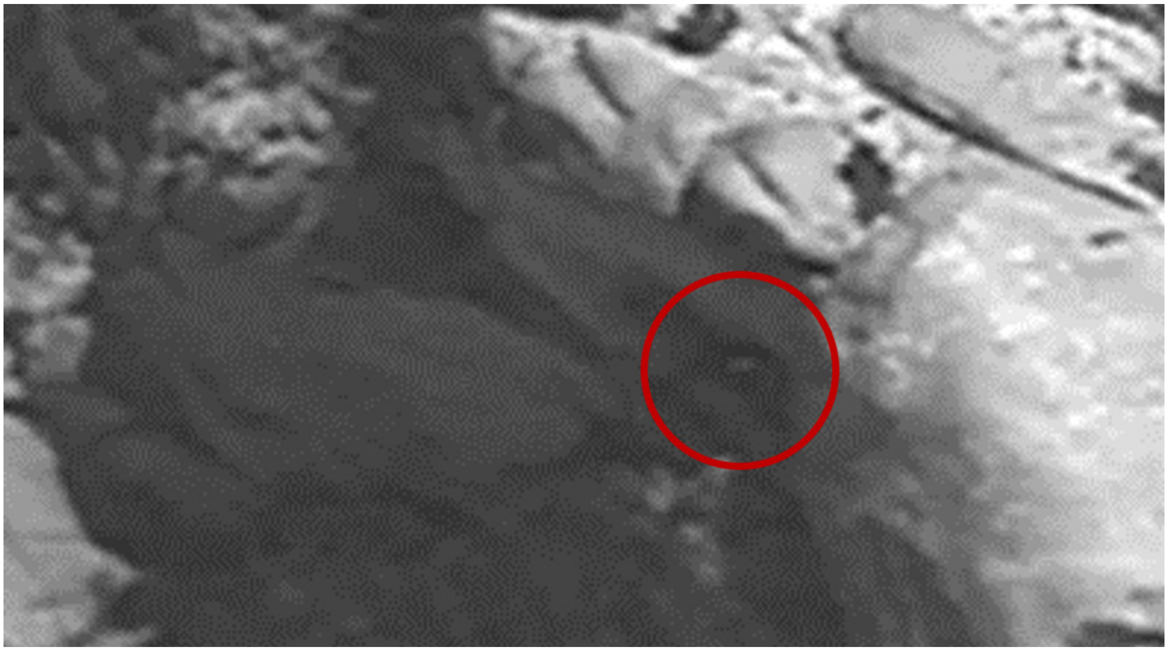


Figure 17. A Video Still Taken from the Footage of the UAS Observer Using Thermal Imaging in 2019, Showing RN315 with a Nearly 9-week-old Chick.

The chick is shown as a pale (warm) shape in the middle of a cool cliff face. This image shows the challenges the UAS observer faced with low resolution imagery, and how thermal imaging was able to partially compensate in the late nesting season.

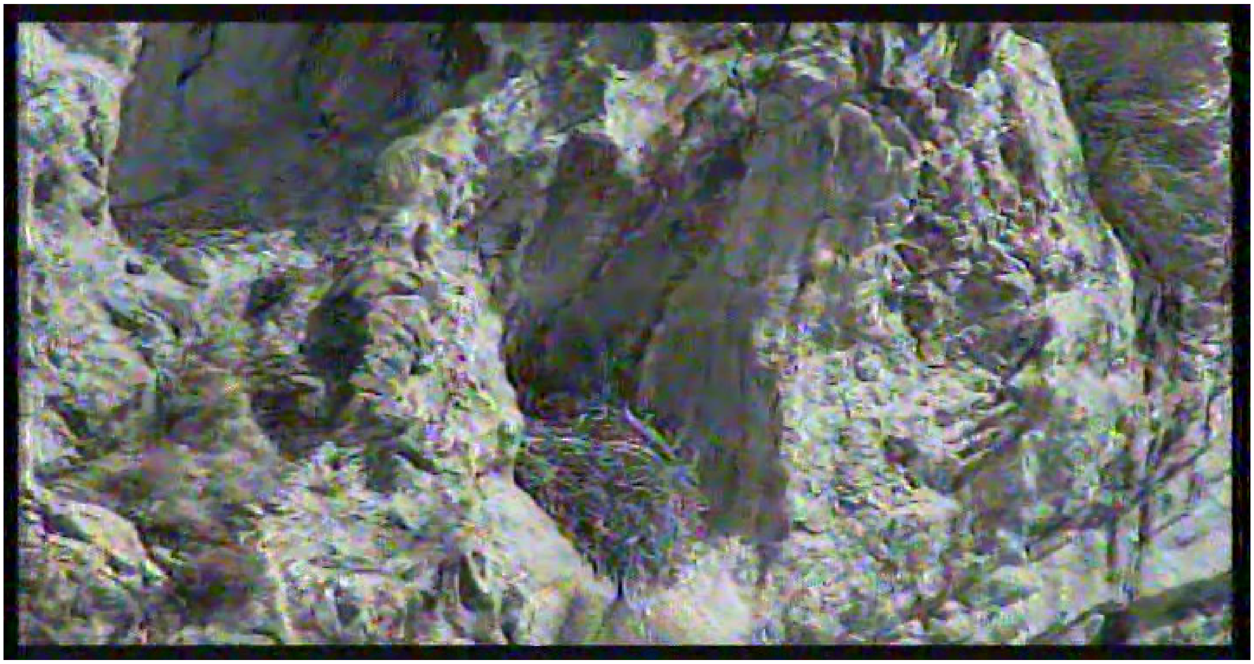


Figure 18. A Video Still Taken from the Footage of the sUAS Observer in 2020 (E900 with Sony FCB-EV7520A), Viewing Nest RN248.

The photo shows the low resolution and video artifacts that inhibited the sUAS's ability to make accurate nest activity identifications in 2020.

6.10 ADDITIONAL METRICS FOR SUCCESS

The results of the mixed-effect logistic regression models indicate that the ground observer and sUAS platform had essentially equally *(high)* accuracy in determining the status of any given nest in 2019. Both platforms were more than 85% likely to determine nest status accurately and confidently in the early season, growing to more than 95% accurate in the late season. This can be attributed to the experience and skill of the ground observer, as well as the ability of the sUAS platform to take high quality documentation photos and video for review. In 2020, the sUAS platform suffered greatly from the drop in payload resolution. It began strongly and was still confidently able to determine when nests were not in-use. However, it struggled to accurately identify when nests were in-use and to determine the difference between an incubating nest and a nest with chicks. The ground observer, on the other hand, displayed almost the same results as in 2019 *(Figures 19 & 20)*.

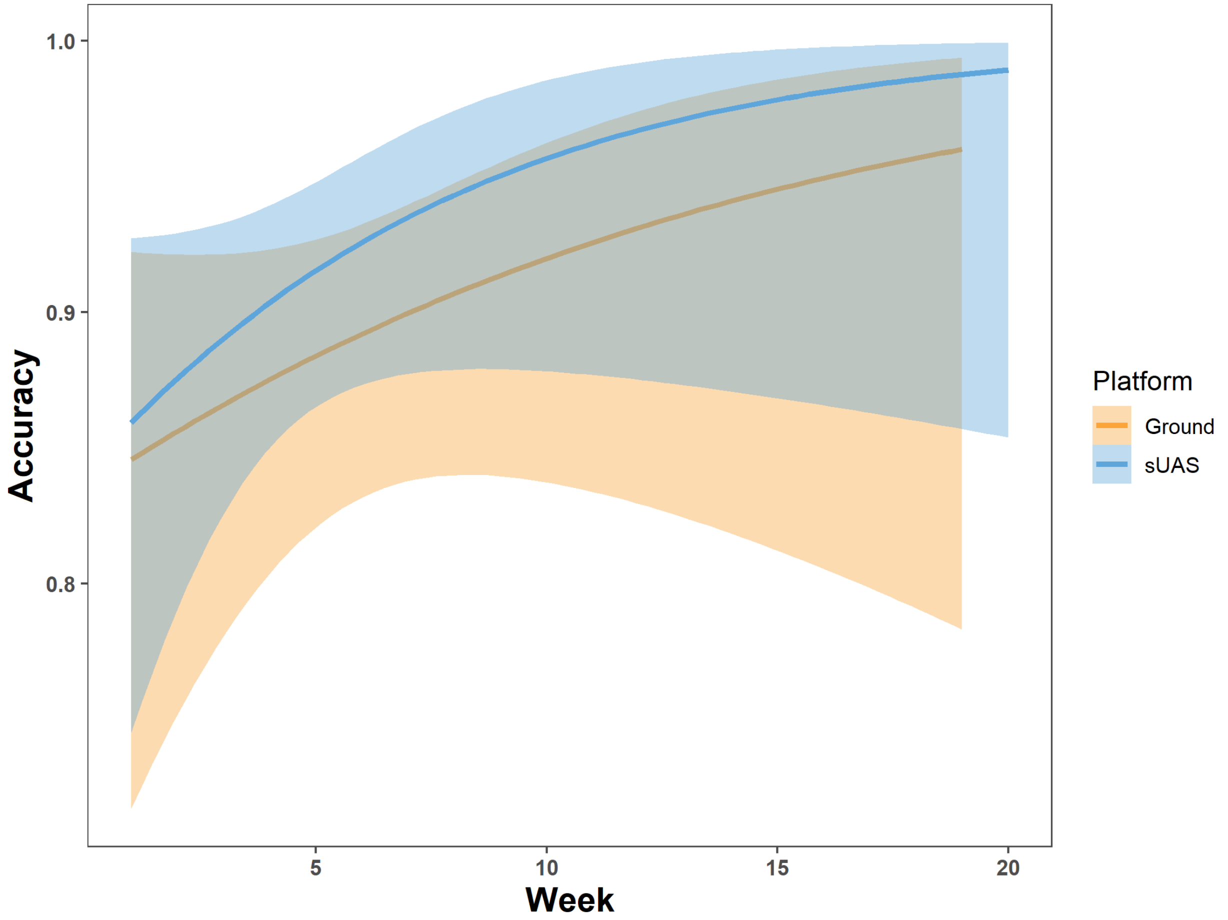


Figure 19. Comparison of the Accuracy of a Ground Observer (± 95% Confidence Intervals) vs an sUAS at Determining Any Given Nest's Status During 2019

Both platforms gained accuracy as the season went on, roughly equal in accuracy.

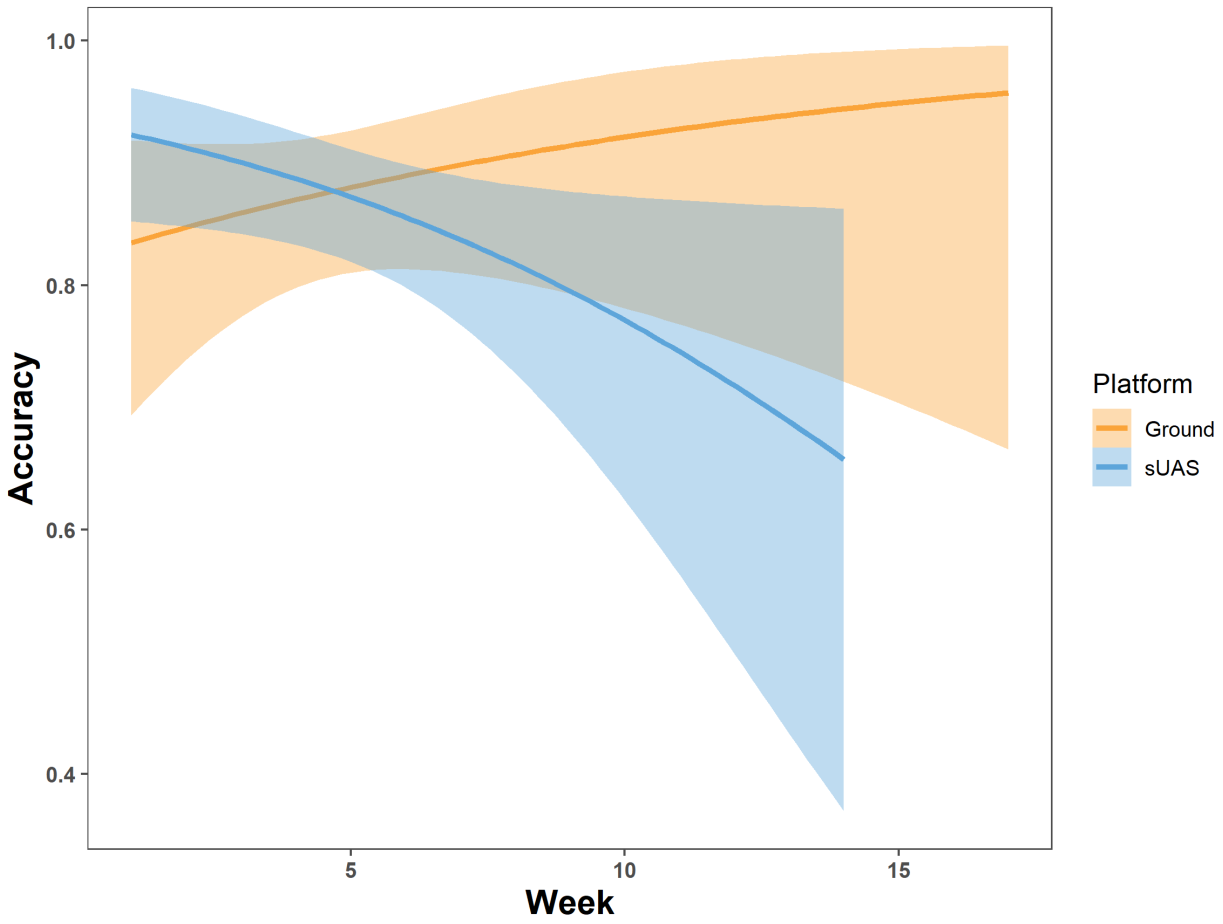


Figure 20. Comparison of the Accuracy of a Ground Observer (± 95% Confidence Intervals) vs an sUAS at Determining Any Given Nest's Status During 2020.

The ground observer gained accuracy during the season, mirroring 2019, while the sUAS lost accuracy. This represents the challenges of identifying an in-use nest's status with a low-resolution payload.

When determining which platform is most efficient and cost-effective, it is important to take total territory coverage into account, especially in the early nesting season when looking to identify in-use nests. The sUAS platform was able to survey approximately twice as many nests each week than the ground observer in both 2019 and 2020. This grants the sUAS more confidence in accurately calling the occupancy status of early season territories, as well as giving it an advantage in locating in-use nests promptly. This played out in 2019 as the sUAS located one in-use nest a full week before the ground observer. The ground observer had to rotate which nests to observe each week due to time pressure and the lengthy hikes needed to cover some territories. By being unable to cover all known nests each week, the ground observer was slower to identify an in-use nest, leaving it potentially vulnerable to disturbance *(Figure 21)*.

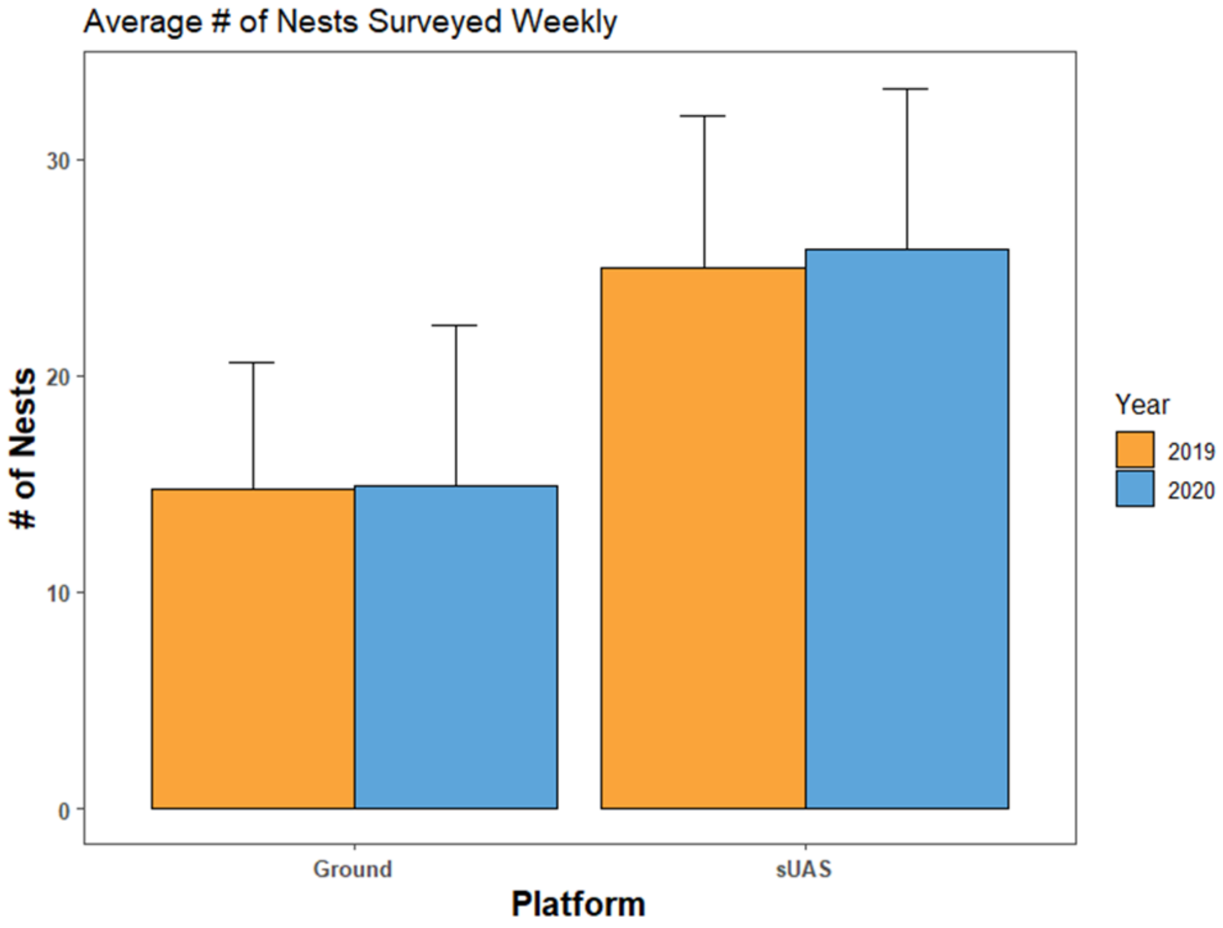


Figure 21. Chart Showing the Mean Number of Nests (+SD) Surveyed Each Week During the Early Season.

There is high variation from week to week depending on which territories were assigned for survey, but the sUAS consistently outperformed the ground observer over the same territory assignments.

7.0 COST ASSESSMENT

The cost assessment included actual costs of both the sUAS and the on-the-ground observer. However, the actual costs are skewed based on a few circumstances that were out of the ordinary for this project. Just as this demonstration was beginning, the DoD memo was released banning COTS sUAS. The cost of the modified COTS sUAS included non-recurring engineering costs that would not have been included in a COTS sUAS. The changes in policy also required assistance from a Government organization to prepare and obtain a waiver for the project and provide direct oversight of the flights.

7.1 COST MODEL

The tables below break out the costs for each of the monitoring methods for comparison. Due to the significant differences between the two sUAS these were also broken out for comparison. Table 5 provides the costs for year one using the DJI Matrice and Table 6 provides that costs for year two using the E900. Both tables show the cost of Government support for waiver preparation and sponsor/oversight of flights. This cost should not necessarily be considered for future projects.

Table 5. One Year Cost Model for an sUAS.

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Platform	Purchase of sUAS *Modified commercial sUAS *(DJI Matrice)*	$18,139
Payload	Purchase of camera	NA- Integrated into platform
Batteries/Chargers	Purchase of extra batteries/chargers	$1,528
Binoculars/Scope	Not Applicable for sUAS	NA
Transportation	Mileage to-from observation locations	$3,000
Maintenance/Repair	Purchase of repair kit and replacement parts	$256
Monitoring Labor	Team of three	$55,346
Waiver Development *(Contractor)*	Development of waiver request memo and supporting documentation	$7,000
Govt. waiver prep and sponsor/training/oversight of flights	Cost of Govt. support for waiver	$79,557
Total		$164,826

Table 6. One Year Cost Model for an sUAS

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Platform	Purchase of sUAS *Modified commercial sUAS *(E900)*	$5,500
Payload	Purchase of camera	$5,895
Batteries/Chargers	Purchase of extra batteries/chargers	$1,651
Binoculars/Scope	Not Applicable for sUAS	NA
Transportation	Mileage to-from launch locations	$3,000
Maintenance/Repair	Purchase of repair kit and replacement parts	$893
Monitoring Labor	Team of three	$48,840
Waiver Development *(Contractor)*	Development of waiver request memo and supporting documentation	$7,000
Govt. waiver prep and sponsor/ training/oversight of flights	Cost of Govt. support for waiver	$61,249
Total		$134,028

Table 7 below shows the costs for the military UAS. Because the military UAS was used on an as available basis the costs of the platform/payload were not applicable. Only the cost associated with the biologist that sat with the UAS pilots was calculated. The cost of a military UAS not be cost-effective for natural resource monitoring alone. However, if an installation has a UAS program and the platform can be made available as part of the pilot training program, it is a useful tool to have.

Table 7. One Year Cost Model for an UAS

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Platform	Not Available	NA
Payload	Not Available	NA
Batteries/Chargers	Not Applicable	NA
Binoculars/Scope	Not Applicable	NA
Transportation	Not Applicable	NA
Maintenance/Repair	Not Available	NA
Monitoring Labor	One Biologist	$10,910
Waiver Development *(Contractor)*	Not Applicable	NA
Govt. waiver prep and sponsor/ training/oversight of flights	Not Applicable	NA
Total		$10,910

Table 8 below provides a detail on the costs for on the ground monitoring. This was performed by one biologist for the two-year study.

Table 8. One Year? Cost Model for On-the-Ground Monitor

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Platform	Not Tracked	NA
Payload	Not Tracked	NA
Batteries/Chargers	Not Tracked	NA
Binoculars/Scope	Approximate Cost	$2,000
Transportation	To and from observation locations	$3,130
Maintenance/Repair	Not Tracked	NA
Monitoring Labor	One Biologist	$14,715
Waiver Development ***(Contractor)***	Not Tracked	NA
Govt. waiver prep and sponsor/ training/oversight of flights	Not Tracked	NA
Total		$19,845

Table 9 below shows the cost of using helicopters for monitoring. These costs are based on historical costs since helicopters were not used during the two-year study.

Table 9. One Year? Cost Model for a Helicopter

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Platform	Per hour cost of $1,500 for 36 days (4 hours/ day)	$216,000
Payload	Not Tracked	NA
Batteries/Chargers	Not Tracked	NA
Binoculars/Scope	Approximate Cost	$2,000
Transportation	Not Tracked	NA
Maintenance/Repair	Not Tracked	NA
Monitoring Labor	One Biologist	$8,640
Waiver Development ***(Contractor)***	Not Tracked	NA
Govt. waiver prep and sponsor/ training/oversight of flights	Not Tracked	NA
Total		$226,640

The two tables below provide a side-by-side comparison of the two sUAS, UAS, on-the-ground monitor and helicopter. Table 10 includes the cost of Government support to prepare, obtain a waiver for the sUAS and monitor flights, while Table 11 removes those costs. Due to the unique circumstances faced during this demonstration, it is assumed that the additional cost for Government support for waiver and oversight would not be necessary for future projects.

Table 10. Cost Comparison of Methods with Government Support for Waiver

Cost Elements	sUAS-DJI Matrice	sUAS- E900	UAS	On-The-Ground	Helicopter
Platform	$ 18,139	$ 5,500	NA	NA	$ 216,000
Payload	NA	$ 5,895	NA	NA	NA
Batteries/Chargers	$ 1,528	$ 1,651	NA	NA	NA
Binoculars, scope	$ -	$ -	NA	$ 2,000	$ 2,000
Transportation *(to-from observation locations)*	$ 3,000	$ 3,000	NA	$ 3,130	
Maintenance/Repair	$ 256	$ 893	NA		
Monitoring Labor	$ 55,346	$ 48,840	$ 10,910	$ 14,715	$ 8,640
Waiver Development (*contractor*)	$ 7,000	$ 7,000	NA	NA	
*Govt. waiver prep and sponsor/training/oversight of flights	$ 79,557	$ 61,249	NA	NA	NA
Total	**$ 164,826**	**$ 134,028**	**$ 10,910**	**$ 19,845**	**$ 226,640**

** Cost specific to this project as a result of DoD Memo banning COTS sUAS and FY19 NDAA prohibiting the procurement or operation of Chinese made sUAS.*

Table 11. Cost Comparison of Methods without Government Support for Waiver

Cost Elements	sUAS-DJI Matrice	sUAS- E900	UAS	On-The-Ground	Helicopter
Platform	$ 18,139	$ 5,500	NA	NA	$ 216,000
Payload	NA	$ 5,895	NA	NA	NA
Batteries/Chargers	$ 1,528	$ 1,651	NA	NA	NA
Binoculars, scope	$ -	$ -	NA	$ 2,000	$ 2,000
Transportation *(to-from observation locations)*	$ 3,000	$ 3,000	NA	$ 3,130	
Maintenance/Repair	$ 256	$ 893	NA		
Monitoring Labor	$ 55,346	$ 48,840	$ 10,910	$ 14,715	$ 8,640
Waiver Development (*contractor*)	$ 7,000	$ 7,000	NA	NA	
*Govt. waiver prep and sponsor/training/oversight of flights	$ -	$ -	NA	NA	NA
Total	**$ 85,269**	**$ 72,779**	**$ 10,910**	**$ 19,845**	**$ 226,640**

** Cost specific to this project as a result of DoD Memo banning COTS sUAS and FY19 NDAA prohibiting the procurement or operation of Chinese made sUAS.*

Cost Elements:

sUAS Platform: The sUAS platform is a primary cost. The platform must be able to meet, in this case, DoD Army cybersecurity and procurement requirements while also being able to accommodate the necessary payload. Performance, durability, and flight time are all important factors when selecting a platform.

Costs for the sUAS DJI Matrice 600: This is based on actual costs of the two DJI Matrice acquired from the Government. The DJI Matrice 600 were COTs that had been modified to use a U.S. developed software for control. This modification increased the cost of the sUAS.

Costs for the sUAS E900: This was an estimated cost provided from the Government. The E900 used in the second year were loaned to the program. The E900s used in this project could be considered developmental. The payload was integrated into the system and was not part of the original system.

sUAS Payload: The sUAS payload includes the camera and/or sensors. The payload can be a significant cost depending upon the requirement and whether or not it has been integrated into the platform. The payload weight will also need to be considered when selecting an sUAS platform.

Batteries/Chargers: Batteries are critical for the operation of the sUAS and are a significant cost. Back up batteries are necessary to ensure flights can continue without downtime. Charging infrastructure for the batteries was also a consideration. Because the sUAS are used in remote locations, it is necessary to have portable charging for the batteries.

Binoculars/Scopes: High quality binoculars and scopes are necessary for on-the-ground and helicopter monitors.

Transportation: Both sUAS and on-the ground monitoring requires transportation from a starting location to the monitoring or launch location.

Maintenance/Repair: Although little maintenance or repair was performed during this demonstration, it is important to consider when implementing a program. Common maintenance/repairs include battery charging, loose bolts/fittings, broken rotors, landing gear, etc. Each platform was only operated for a few months in each year. Industry data suggests the life cycle of the typical sUAS to be approximately 200 flights.

Monitoring Personnel: Personnel for the sUAS consisting of a pilot, an operator, a biologist, and observer. The observer was a person associated with the waiver who ensured that all requirements were being met. However, based on experience, the four people could be reduced to two *(pilot/biologist)*.

Waiver Development *(Contractor):* The Exemption to Policy (ETP) waiver process includes the technical documentation of the sUAS to obtain an Airworthiness Release (AWR). Once the AWR is in place, the development and approval of standard operating procedures, System Safety Management Plan, risk acceptance memos, and the formal ETP memo signed by a senior official may be prepared.

The preparation of this material, the submission through a SIPR account, discussions/clarifications from the Army CIO, staffing of memos for signature, all take time and have an associated cost. The process to obtain an ETP changed three times from 2018 to 2020.

Access to Installation and Logistics: This cost is associated with obtaining base access and coordination with range control and flight control.

Government Waiver Preparation and Sponsorship/Training/Oversight of Flights: This cost may be eliminated or significantly reduced in the future. During this demonstration, it became necessary to engage with another Government organization to sponsor the waiver and to support its development. In addition, this organization was able to provide a modified sUAS that was capable of meeting DoD cyber requirements. Because they were the sponsor of the waiver, they were on-site to provide training on the sUAS and weekly flights.

7.2 COST DRIVERS

The most significant cost driver is DoD Army sUAS policy. The platform/payload must meet Department of Army cyber security requirements. Each platform must undergo an evaluation and provide an Exemption to Policy (Waiver) to operate in restricted airspace. The cost associated with obtaining an ETP includes labor to develop the ETP application package *(Standard Operating Procedures, System Safety Management Plan, and Memos),* upload through SIPR, and track through the system. The waivers are only for six months. In addition, each sUAS must have an Airworthiness Release.

The prohibition on foreign made sUAS impacts costs because the U.S. market is still developing and has not yet produced a cost competitive commercial sUAS to compete with foreign made sUAS. As the U.S. market matures and purchases increase, this will begin to bring the costs down.

7.3 COST ANALYSIS AND COMPARISON

Costs are based on golden eagle monitoring on a MRTBF with vast distances between nests and rugged terrain. Breeding season begins in February and goes through June, allowing for a range of temperatures and weather conditions.

The cost comparison assumes that both the sUAS and on-the-ground monitoring start and return from the same location. The time to survey nests and return to the starting location was recorded.

Industry data on life expectancy of an sUAS is approximately 200 flights. When first envisioning this project, it was thought that the sUAS would be most cost-effective and could replace the current approach of on-the-ground monitoring. The results from the demonstration show that the use of an sUAS is a good tool to have available but may not be able to cost-effectively replace on-the-ground monitoring. For instances where the nests are too high or distances too long or rugged, sUAS are a good tool. As the cost of the sUAS system is reduced and the policy surrounding flying the sUAS in DoD airspace is streamlined or eliminated, it may become cost-effective compared to on-the-ground monitoring. The sUAS is more expensive than on-the-ground monitoring, however, the sUAS provides benefits over that of the on-the-ground monitor such as photos which can be used to study and accurately age the chicks. The sUAS can also cover more territory than an on-the-ground monitor and access nests that are too high or at a difficult angle to see from the ground.

In addition, some of the costs associated with this demonstration can be reduced or eliminated. For instance, a three-person team was used to monitor eagles *(the pilot in charge, operator, and observer).* In the future, this team could be reduced to a two-person team. In addition, the Government sponsor of the waiver observed weekly flights which required labor and travel. Due to COVID-19 in the 2020 season, the Government sponsor was able to designate a local Government Point of Contact (POC) to provide oversight which reduced costs. The use of sUAS compared to a helicopter is cost competitive.

8.0 IMPLEMENTATION ISSUES

8.1 SUAS IMPLEMENTATION

A major implementation issue with the use of sUAS in DoD airspace involves obtaining an Airworthiness Release (AWR) and Exemption to Policy (ETP). This policy seeks to prevent the use of foreign made sUAS based on cybersecurity vulnerabilities. Both approvals take time to develop, review, and obtain approval. Under the 2019 DoD Army policy, a modified DJI Matrice 600 was used to monitor golden eagles after obtaining an ETP. However, because of the FY 2020 NDAA, Section 848 Prohibition on Operation or Procurement of Foreign Made Unmanned Aircraft Systems, the procurement or use of Chinese made sUAS was prohibited. This led to the use of a different sUAS platform. Each change of platform requires a new AWR and ETP. The ETP can only be granted for six months at a time and the time to obtain an approval may take 45-60 days minimum.

To obtain an Airworthiness Release, a Standard Operating Procedure, System Safety Management Plan, Material Risk Acceptance Memo, and Operational Risk Acceptance Memo, must be developed and submitted to the Aviation Engineering Directorate. Once the AWR is provided, it is sent along with the other documents with a memo, signed by a Senior Level memo requesting an ETP. The AWR is valid for three years.

The sUAS platform used for observation and data collection has real potential for becoming a quick, cost-effective way to monitor the progress of nesting birds in hard to reach places. For this platform to work efficiently and in a manner that collects the best data, some points described below have been found over the past two years to help improve the use of this platform.

Good metadata and a member of the team that has experience with eagle behavior and good knowledge of the territory is key to obtaining useful data. A trained eye for these sUAS platforms was able to compensate for finding nests with sometimes less than ideal video streaming quality or lighting situations. A profile containing pictures from multiple angles and distances and GPS coordinates of known nest in the territory was critical to confirming nest locations and to reduce the time that the sUAS team spent locating nests during a flight.

For the legal operation of the sUAS to fly commercially, Federal Aviation Administration (FAA) regulations require one member of the team to be Part 107 rated as a commercial remote pilot. While the Part 107 remote pilot does not need to be on the controls during flight, he/she must be present and is responsible for lawful compliance of the operation; or in other terms, is serving as Pilot in Command (PIC). To comply with Part 107 while also maintaining the ability to collect high quality data, the sUAS must have some certain technological capabilities. For instance, per Part 107 the sUAS must remain in Visual Line-Of-Sight (VLOS) of the PIC, the person manipulating the controls, and a visual observer without the use of any vision aiding device other than corrective lenses. The sUAS must also remain an adequate distance from a nesting site to not "take" the eagles as per BGEPA requirements. Therefore, to comply with both regulations, a long-range transceiver for video transmission, as well as a high optical zoom HD camera, is necessary to record proper data.

Both platforms have stabilization systems utilizing software that controls a three-axis gimballed camera mount. An HD camera with a gimbal mount was key to obtaining a clear picture for data collection from long distances and in variable wind conditions. The camera for both sUAS platforms had a 30x zoom which allowed the sUAS to maintain legal distance from nesting sites to avoid disturbing nesting eagles. Long distance video transmission capabilities, in this case greater than one mile, also aided in keeping distance from nesting birds. Both cameras on the platforms had auto focus, though the DJI also provided an intuitive touchscreen focus selector to allow operators to quickly refocus on any part of the camera view angle. In addition, DJI had auto and manual exposure, which was very effective in compensating for harsh shadows and high contrast lighting on cliff faces. Both systems offered the ability to record both photo and video data. However, the DJI provided direct on-board data recording while the E900 only allowed for data to be recorded from the receiver, which led to corruption and degradation of the photos and video due to radio interference. Direct on-board data recording capabilities are vastly preferable as a means of retaining high-quality photos and video. On the other hand, because of the E900's modular components and features, it is able to offer the ability to slave two different controllers to the sUAS which proved beneficial. The ornithologist was able to control the camera gimbal and zoom to find nests with one controller, while the operator was able to fly the sUAS into viewing position using a separate controller.

As mentioned in section 4.2, Dugway has a wide range of temperatures and weather conditions during the observation period. It was found during use of the sUAS that cold temperatures adversely affect battery performance and consequentially the amount of time the drone could spend per flight investigating a territory. This led to increased time in a territory as time would be needed for a battery swap and a second flight to obtain the necessary data. Other weather considerations included windy conditions at the surface as well as at observation altitude. These conditions required more finesse from the pilot, as well as requiring the sUAS to expend more battery power as the gimbal and stabilization systems on the platform worked harder to compensate for the windy conditions and maintain a fixed three-dimensional GPS location. The extra battery power required to hold location ended up limiting the loiter time and range of the sUAS. Comparing the two platforms that were used, it was found that the E900 had better battery power duration and a more compact battery system. The downside of this more compact system was a top-heavy design, which made the E900 more unstable and prone to tipping while landing in a crosswind.

8.2 UAS IMPLEMENTATION

The UAS observation method was the most uncertain upon the start of the 2019 nesting season and it proved to be unreliable as a method of weekly nest observations due to scheduling and payload restrictions. The realities of flight scheduling with RIAC students resulted in flight days that were sporadic. RIAC allowed the use of their students and platforms on an as-available basis, and other missions, weather concerns, or maintenance frequently bumped nest observations off the schedule. In addition, the sections of airspace the students were scheduled for were often not over the desired areas of range containing eagle nests to be surveyed. It became clear to the DPG Team that rather than using the UAS as a stand-alone observation method, it would be more useful as a precision tool for obtaining rapid nest observations in areas with no ground access or with critical range use planned within the next two weeks.

The UAS platform was unique in that it was able to view nests with no ground access within 2 miles. It also possessed a highly useful thermal camera capability, which could identify a chick within a nest in seconds *(given an appropriate time of day, before the cliff face has heated in the sun).* However, the payloads carried by the UAS fleet in 2019 proved to be inadequate to observe most eagle nests due to low resolution imagery. The HD payload upgrade in 2020 improved the nest-monitoring potential of the platform immensely. The DPG Team does not recommend the use of UAS platforms for nest surveys unless equipped with HD payload capabilities.

If the nest location was well known, the UAS was by far the fastest and most efficient observation method due to lack of drive and hiking time between observation points. However, the nature of the platform's flight and approach patterns made detailed nest metadata critical to the success of the survey. UAS platforms must determine an approach angle and loiter point for a territory observation from several kilometers away, requiring the observation team to have precise knowledge of the nest's location reference data, elevation, aspect, bearing from the ideal viewpoint, and topographical inclusion before the nest can be found. The UAS observation team found that landscape level photos combined with detailed descriptions of a nest's location were sufficient to allow for a successful survey. Without this metadata, the UAS platform was nearly incapable of locating a nest in the time allowed.

The DPG Team found that the most important factor influencing the success of the UAS team was the integration of the biological observer into the military framework of the RIAC students. The civilian observer had to learn the correct protocols and language, as well as establish trust and communication pathways with both the students and the instructors. Once the observer was able to work within the RIAC team, the frequency and success of survey flights increased dramatically. The RIAC students and instructors also found the nest surveys to be useful training experiences. Eagle nests are small, cryptic targets for a UAS operator, which presented the students with invaluable practical experience. The nest metadata was also presented in the style of a mission packet, allowing the students to practice working with external intelligence to locate a target. The DPG Team highly recommends nest monitoring as a dual-purpose use of UAS platforms, for both natural resource monitoring and student pilot training exercises.

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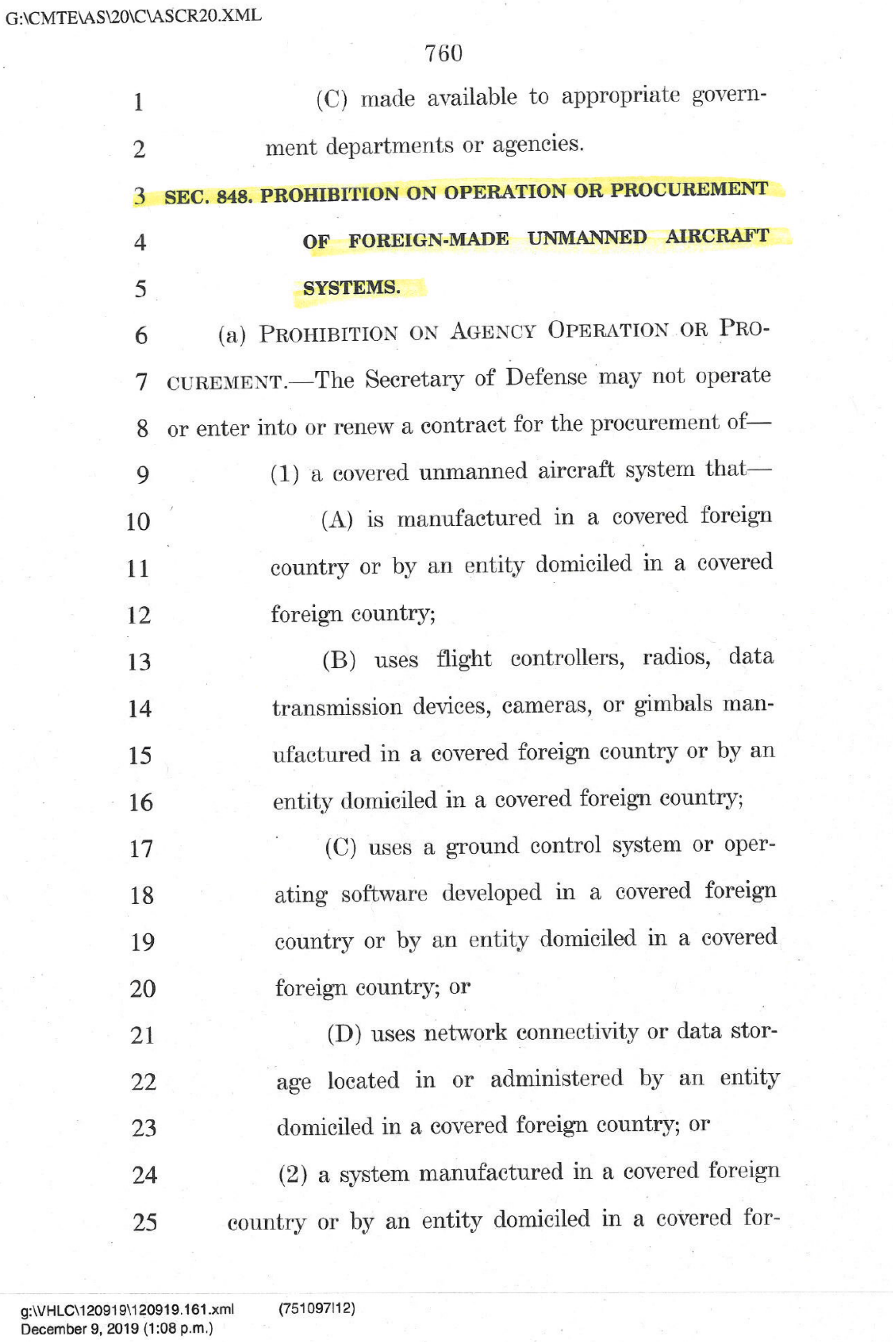
APPENDIX A POINTS OF CONTACT

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone Fax E-mail	Role in Project
Samantha Phillips	Select Engineering Services 5330 Valdez Circle, rm 2112 Dugway, UT 84022	Phone: (385) 243-5503 Sam.phillips@sesincusa.com	Principle Investigator
Rene Parker	Select Engineering Services 1544 N. Woodland Park Dr., #310 Layton, UT 84041	Phone: (801) 528-5181 Fax: 801-399-1863 Rene.parker@sesut.com	Project Manager
Robert Knight	DPG Natural Resources Office 5330 Valdez Circle, rm 2118 Dugway, UT 84022	Phone: (435) 849-0586 Robert.n.knight.civ@mail.mil	Technical POC Dugway Proving Ground Host Demonstration Location
Steve Slater	HawkWatch International 2240 South 900 East, Salt Lake City, UT 84106	Phone: (801) 484-6808x108 sslater@hawkwatch.org	Subcontractor-Support for Eagle Monitoring
Ron Delgado	Sigmatech RIAC Bldg. T-4039 Stark St., Dugway, UT 84022	Phone: (435) 831-3684 Fax: (435) 831-3678 Ronald.l.delgado6.ctr@mail.mil	Technical POC RIAC sUAS/UAS Scheduling UAS-Missions

APPENDIX B FY 2019 NATIONAL DEFENSE AUTHORIZATION ACT (NDAA)



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(C) made available to appropriate government departments or agencies.

SEC. 848. PROHIBITION ON OPERATION OR PROCUREMENT OF FOREIGN-MADE UNMANNED AIRCRAFT SYSTEMS.

(a) PROHIBITION ON AGENCY OPERATION OR PROCUREMENT.—The Secretary of Defense may not operate or enter into or renew a contract for the procurement of—

(1) a covered unmanned aircraft system that—

(A) is manufactured in a covered foreign country or by an entity domiciled in a covered foreign country;

(B) uses flight controllers, radios, data transmission devices, cameras, or gimbals manufactured in a covered foreign country or by an entity domiciled in a covered foreign country;

(C) uses a ground control system or operating software developed in a covered foreign country or by an entity domiciled in a covered foreign country; or

(D) uses network connectivity or data storage located in or administered by an entity domiciled in a covered foreign country; or

(2) a system manufactured in a covered foreign country or by an entity domiciled in a covered for-

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December 9, 2019 (1:08 p.m.)

eign country for the detection or identification of covered unmanned aircraft systems.

(b) EXEMPTION.—The Secretary of Defense is exempt from the restriction under subsection (a) if the operation or procurement is for the purposes of—

(1) Counter-UAS surrogate testing and training; or

(2) intelligence, electronic warfare, and information warfare operations, testing, analysis, and training.

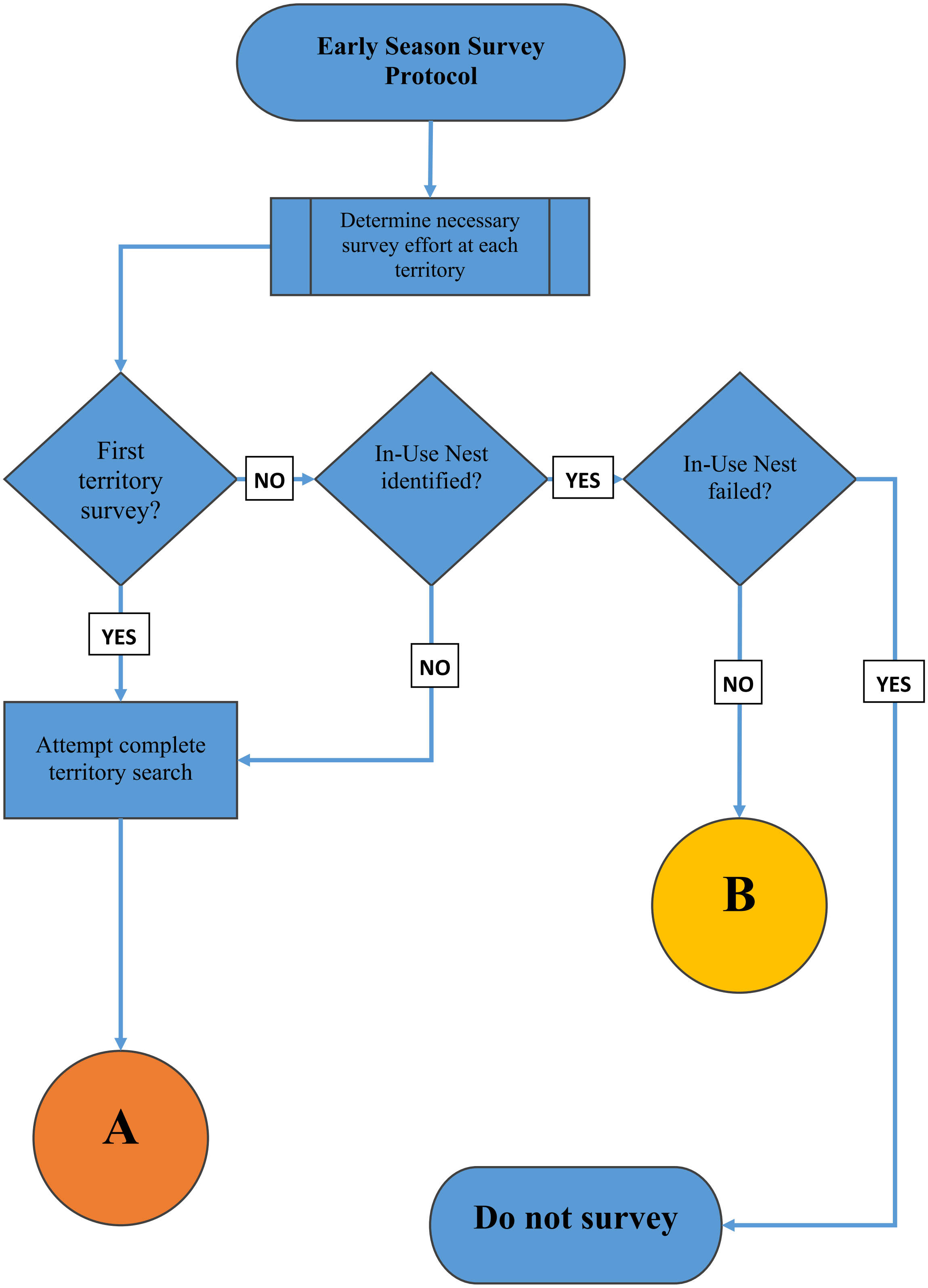
(c) WAIVER.—The Secretary of Defense may waive the restriction under subsection (a) on a case by case basis by certifying in writing to the congressional defense committees that the operation or procurement is required in the national interest of the United States.

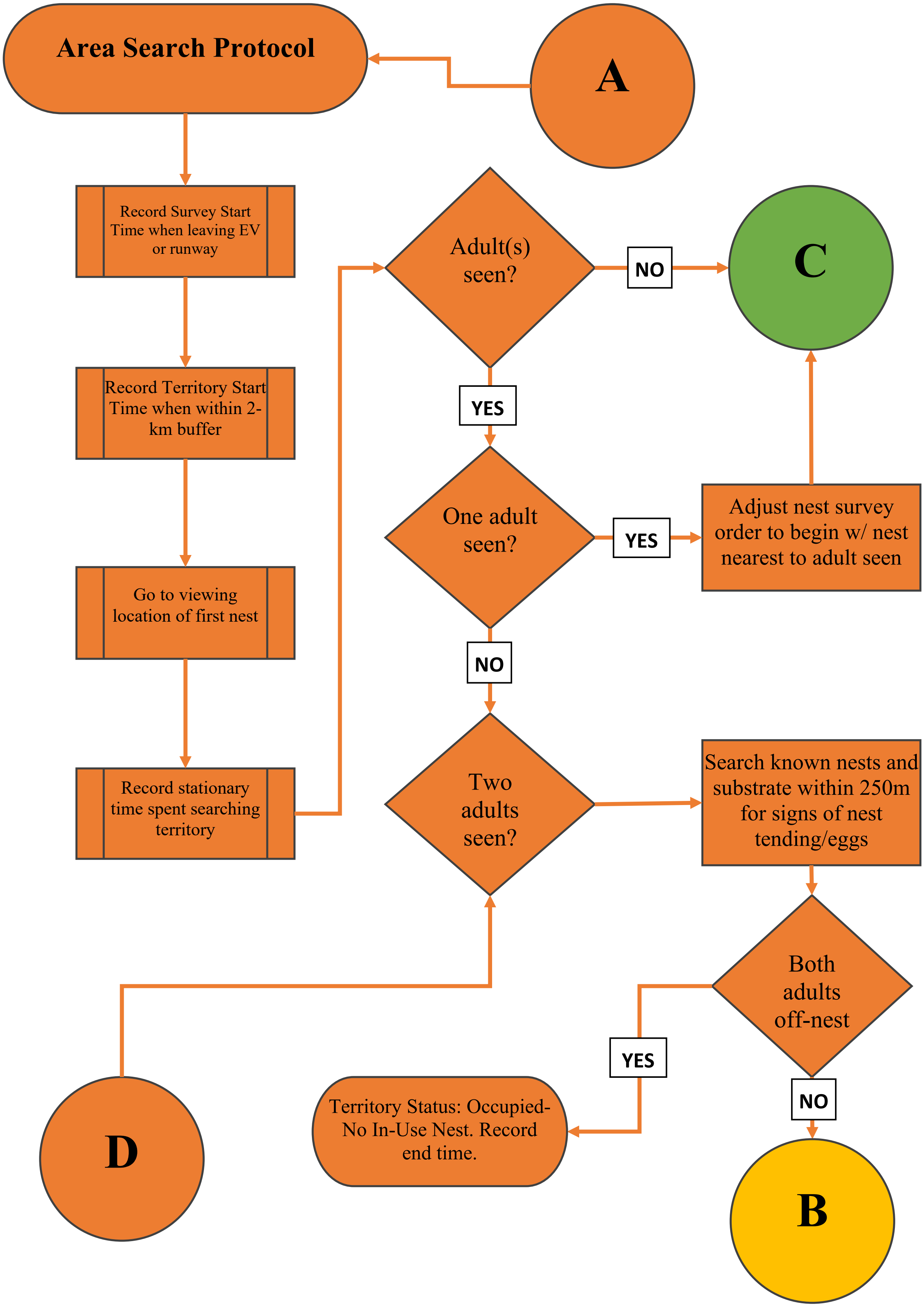
(d) DEFINITIONS.—In this section:

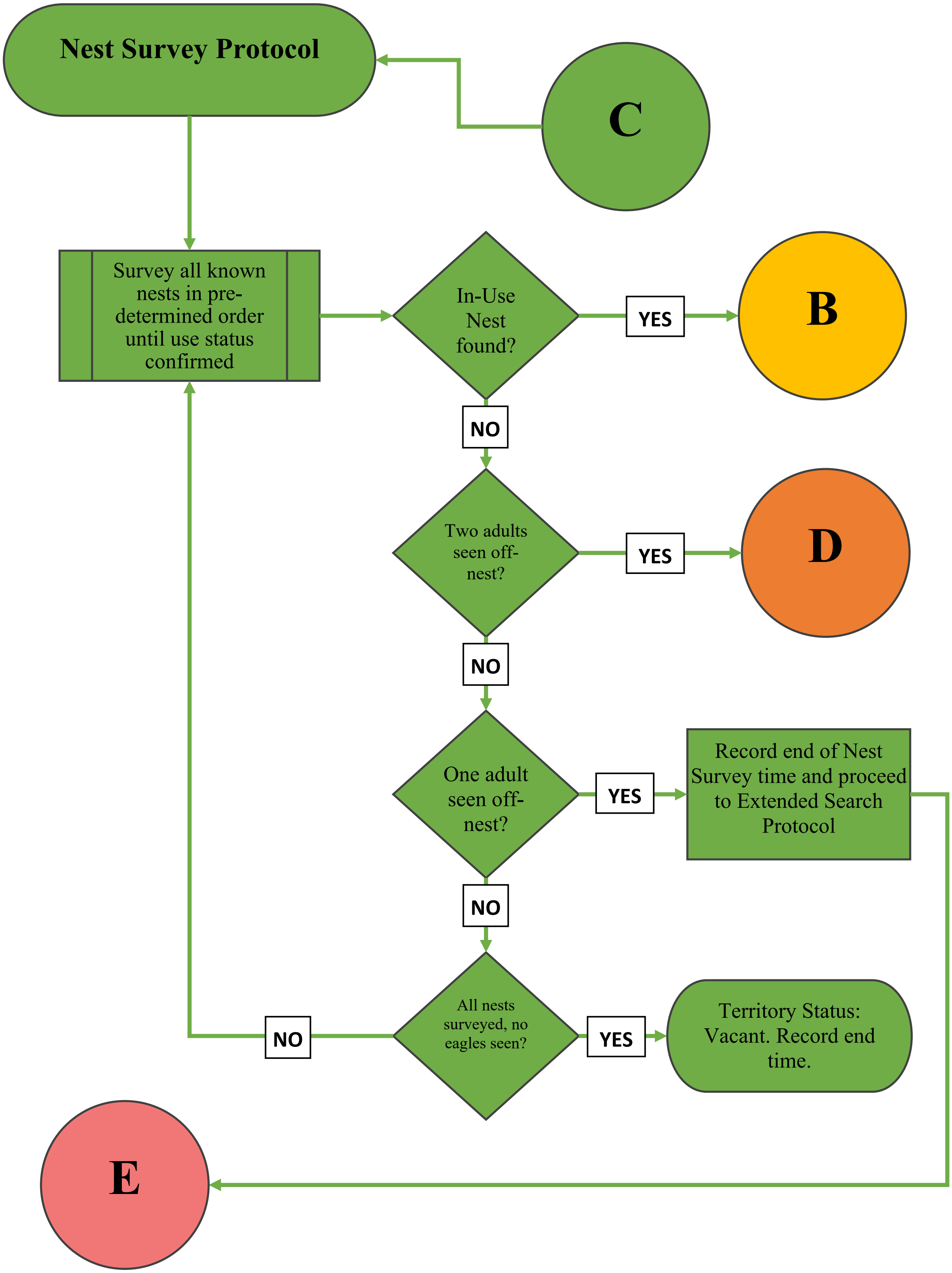
(1) COVERED FOREIGN COUNTRY.—The term "covered foreign country" means the People's Republic of China.

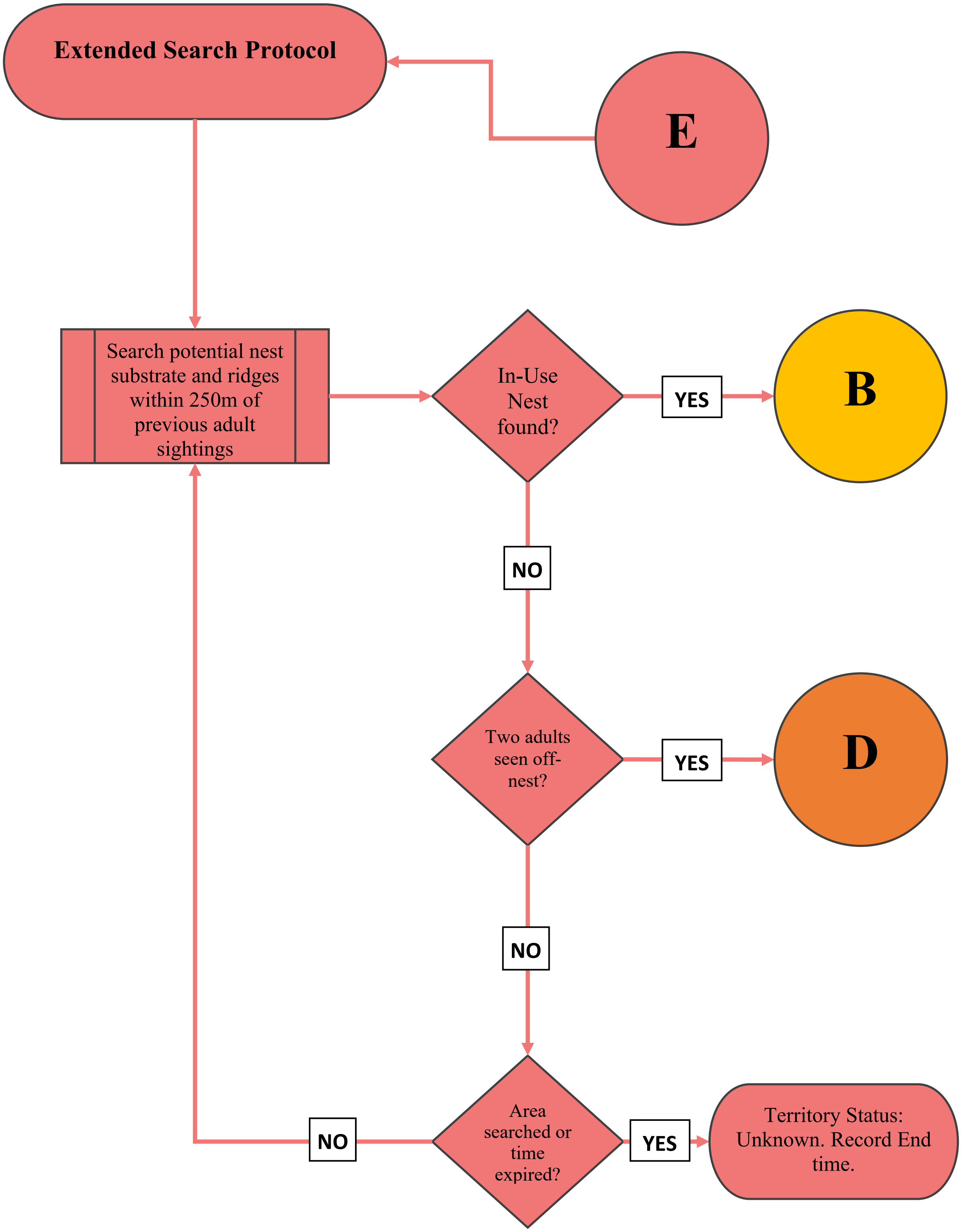
(2) COVERED UNMANNED AIRCRAFT SYSTEM.—The term "covered unmanned aircraft system" means an unmanned aircraft system and any related services and equipment.

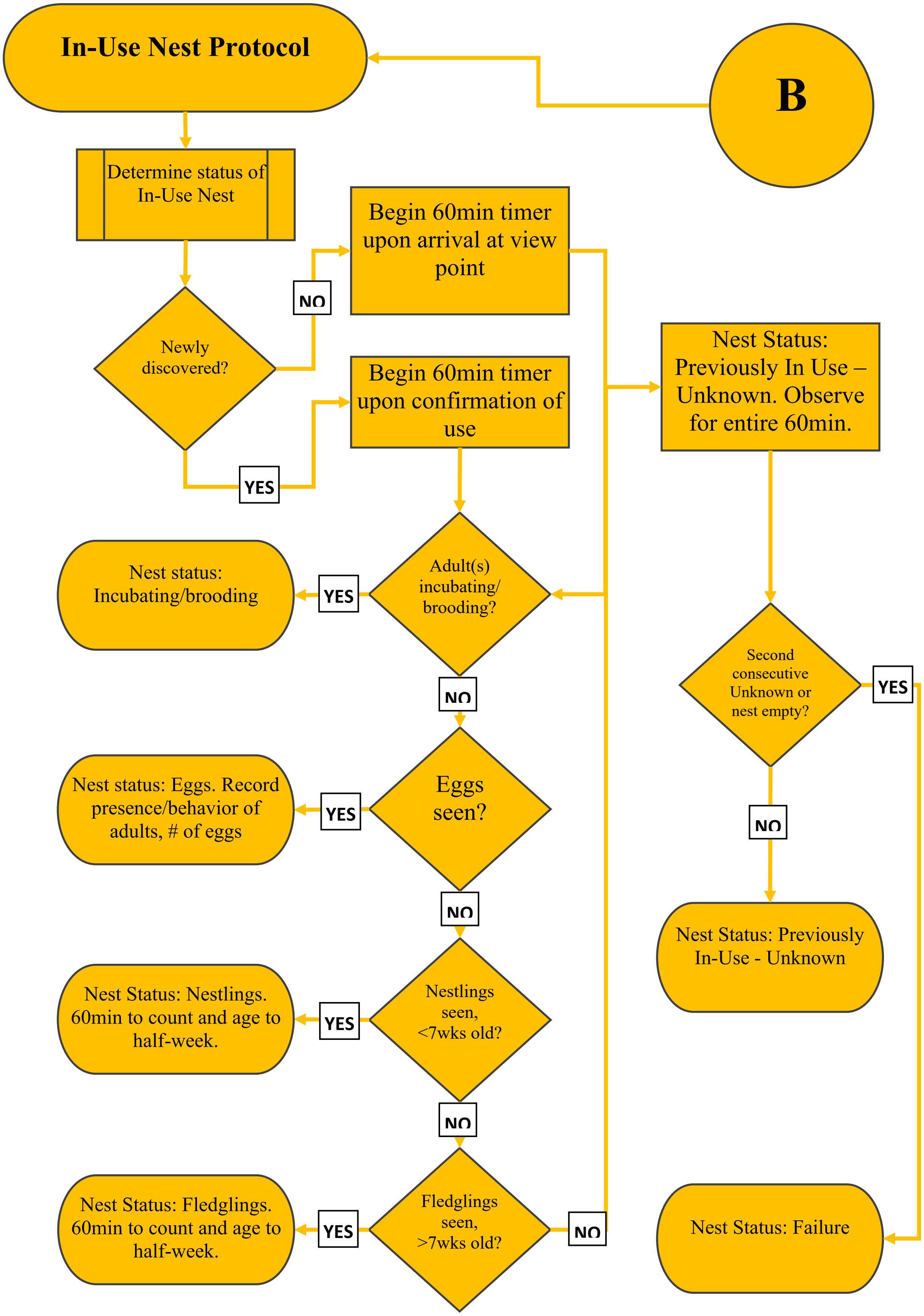
APPENDIX C SURVEY PROTOCOL FLOWCHARTS

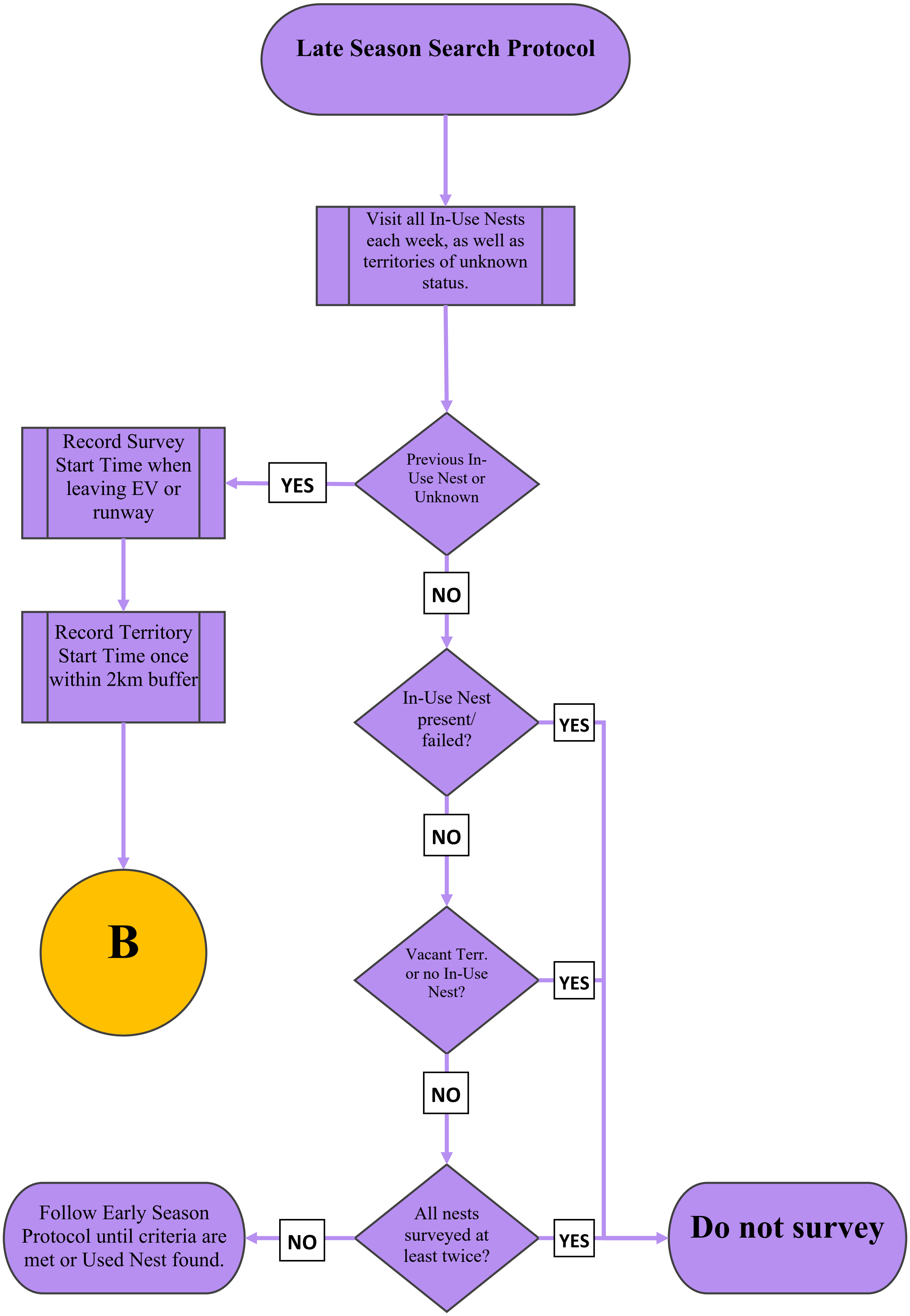



Area Search Protocol
A
Record Survey Start Time when leaving EV or runway
Record Territory Start Time when within 2-km buffer
Go to viewing location of first nest
Record stationary time spent searching territory
Adult(s) seen?
NO
C
YES
One adult seen?
YES
Adjust nest survey order to begin w/ nest nearest to adult seen
NO
Two adults seen?
Search known nests and substrate within 250m for signs of nest tending/eggs
Both adults off-nest
YES
NO
Territory Status: Occupied- No In-Use Nest. Record end time.
D
B


Nest Survey Protocol
C
Survey all known nests in pre-determined order until use status confirmed
In-Use Nest found?
YES
B
NO
Two adults seen off-nest?
YES
D
NO
One adult seen off-nest?
YES
Record end of Nest Survey time and proceed to Extended Search Protocol
NO
All nests surveyed, no eagles seen?
NO
YES
Territory Status: Vacant. Record end time.
E


Extended Search Protocol
E
Search potential nest substrate and ridges within 250m of previous adult sightings
In-Use Nest found?
YES
B
NO
Two adults seen off-nest?
YES
D
NO
Area searched or time expired?
NO
YES
Territory Status: Unknown. Record End time.


In-Use Nest Protocol
B
Determine status of In-Use Nest
Newly discovered?
NO
Begin 60min timer upon arrival at view point
YES
Begin 60min timer upon confirmation of use
Nest Status: Previously In Use – Unknown. Observe for entire 60min.
Nest status: Incubating/brooding
YES
Adult(s) incubating/ brooding?
NO
Nest status: Eggs. Record presence/behavior of adults, # of eggs
YES
Eggs seen?
NO
Nest Status: Nestlings. 60min to count and age to half-week.
YES
Nestlings seen, <7wks old?
NO
Nest Status: Fledglings. 60min to count and age to half-week.
YES
Fledglings seen, >7wks old?
NO
Second consecutive Unknown or nest empty?
YES
NO
Nest Status: Previously In-Use - Unknown
Nest Status: Failure


Late Season Search Protocol
Visit all In-Use Nests each week, as well as territories of unknown status.
Previous In-Use Nest or Unknown
YES
Record Survey Start Time when leaving EV or runway
Record Territory Start Time once within 2km buffer
B
NO
In-Use Nest present/ failed?
YES
NO
Vacant Terr. or no In-Use Nest?
YES
NO
All nests surveyed at least twice?
NO
Follow Early Season Protocol until criteria are met or Used Nest found.
YES
Do not survey