EVALUATION OF SMALL UNMANNED AERIAL SYSTEMS AS A CENSUS TOOL FOR ALEUTIAN TERN *ONYCHOPRION ALEUTICUS* COLONIES

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ABSTRACT

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Aleutian Tern *Onychoprion aleuticus* numbers in Alaska appear to be in decline; however, colonies are difficult to count for the purposes of monitoring due to their co-occurrence with Arctic Terns *Sterna paradisaea*, low nesting densities, high variability in attendance, sensitivity to human disturbance, and remote terrain. We paired visual observations with unmanned aerial systems (UASs) to test the feasibility of using this technology to survey a small colony of nesting Arctic and Aleutian terns in southcentral Alaska. We used counts of terns in the air and nest attendance to test for disturbance from UAS flights. We conducted 11 UAS flights over seven days at altitudes ranging from 15–30 m and located 23 nests in the 4.1 ha (0.041 km^2) colony site (5.6 nests ha^{-1}) by systematically searching the orthomosaics. We were most likely to distinguish tern species in the 18-m and 15-m altitude photos; the white forehead was most visible in side angle rather than top-down. Nest attendance and the number of aerial birds were not influenced by the UAS in this colony, which experiences high *Larus* gull activity. Aleutian Terns arrived on 19 May and were attending nests by 02 June; nest attendance declined throughout June. We believe the best approximation of total nesting pairs will be achieved by counting nests 7–10 d after first initiation. In mixed species colonies, we recommend that UASs fly in a 'lawn mower' pattern with overlap to maximize side angle images and aim for an image resolution of < 4 mm (which was achieved by 15-m altitude flights with our camera setup). In single species colonies, 30 m is sufficient and can be achieved more efficiently.

Key words: unmanned aerial system (UAS), tern nesting surveys, Aleutian Tern, *Onychoprion aleuticus*, disturbance

INTRODUCTION

The Aleutian Tern *Onychoprion aleuticus* is a seabird that nests colonially on the coasts of Alaska and eastern Russia (North 2013). It may be Alaska's most imperiled seabird; known Aleutian Tern colonies in Alaska have declined by over 90 % since the 1950s to a current population size estimated to be ~ 5 500 individuals (Renner *et al*. 2015). There is great uncertainty around current numbers, highlighting a need for increased precision on counts. Monitoring Aleutian Terns is difficult because they have a large breeding range, colonies occur in a variety of potential habitat types, and terns may alternate or move locations within and between seasons (Oehlers 2012). At known colony locations, counting nests or individuals is confounded by relatively low nesting densities, highly variable attendance (Pyare *et al*. 2013), frequent nest failure and abandonment (Oehlers 2012), and co-occurrence with Arctic Terns *Sterna paradisaea*. Additionally, Aleutian Terns are thought to be highly sensitive to human disturbance and have the potential to abandon colonies upon use of invasive survey methods (North 2013).

Unmanned aerial systems (UASs) offer an alternative approach for surveying species that are prone to disturbance and/or occur in habitats that are hard to access (Anderson & Gaston 2013). UASs have been used to survey nesting colonies of numerous species, including Black-headed Gulls *Chroicocephalus ridibundus* (Sarda-Palomera *et al*. 2012) and Common Terns *Sterna hirundo* (Chabot *et al*. 2015). UASs could facilitate surveys of Aleutian Tern colonies, but we need information to confirm whether tern species can be distinguished from other species and that the UAS will not cause nest abandonment.

Using both visual observations and a UAS to survey a mixed-species tern colony, our objectives were to: 1) document nesting phenology to determine the best timing for census, 2) define UAS settings and flight altitude sufficient to distinguish Aleutian Terns from Arctic Terns, 3) document if UAS flight disturbs nesting terns, and 4) estimate the number of nests in the colony.

METHODS

Study area

We focused on a small colony of Aleutian and Arctic Terns in southcentral Alaska (Fig. 1). The location of this colony has been consistent since its discovery, and its proximity to the road network allowed a much more detailed level of study than most remote colonies. The colony is sparsely distributed in a very wet muskeg near the southwestern outlet of Headquarters Lake, located in the Kenai National Wildlife Refuge (60°27′32.4″N, -151°4′19.2″W; WGS84). Aleutian Terns were first observed and confirmed nesting here in 2003 when three recently fledged chicks were found. In 2004, Aleutian Tern adults were observed returning to six or eight locations presumed to have nests, but nesting status was not confirmed due to difficult terrain and concerns about causing disturbance. In 2013, at least 25 likely Aleutian Tern nesting locations were observed. Arctic Terns, also nesting in the colony, can be distinguished from Aleutian Terns using bill color and forehead color.

Colony observations

To determine the timing of colony arrival and nest initiation (prior to beginning flights), we observed the colony from a 4-m tall viewing station concealed in black spruce forest. The viewing station was on the edge of the colony and provided a full view of the colony. We observed the area throughout May to document when Aleutian Terns returned, formed pairs, and initiated nests. Once nesting was initiated (defined as nest attendance), we mapped nesting locations using an azimuth from the viewing station and measured distance using a rangefinder (Leica Rangemaster 1600-B).

UAS flights

We used a 3DR Solo quadcopter, a small commercial UAS that weighs 1.5 kg and can handle a payload of up to 700 g. We equipped the 3DR Solo with a u-blox NEO-MGN GNSS receiver for navigation. An FAA-licensed UAS pilot remotely flew the aircraft with assistance from a visual observer. The UAS launch site was always > 100 m from the colony edge (following Vas *et al*. 2015). The UAS ground crew (pilot and observer) maintained a visual line of sight with the aircraft at all times and observed tern behavior from the forest edge located about 400 m west of the colony. An additional observer at the viewing platform recorded the behavioral response of the terns while the UAS was flying overhead (see "Visual tern counts").

We used a Pentax Ricoh GRII digital camera to acquire the images. The camera was attached to the UAS in a fixed nadir position. The camera had a 16.2 megapixel CMOS sensor and a 18.2 mm fixed focal length lens. We set the camera focus to infinity, ISO to 400, shutter speed to 1/1600, and intervalometer to 2 s. We created automated flight plans to photograph the colony using the Droidplanner Tower application. We configured the flight plans for an image end-lap of 80 % and side-lap of 60 %, as recommended by the photogrammetry software Agisoft Photoscan. Battery life limited the flights to approximately 13 min. Adjustments in aircraft velocity were used to limit image distortion caused by pixel blur. Pixel blur is the distance (in pixels) the camera travels while the shutter is open and can be calculated using the following formula:

Pixel blur = (velocity × shutter speed)/Ground Sample Distance

and

Ground Sample Distance (GSD) = (sensor height in pixels/distance between image centers on ground)

A pixel blur of < 0.4 was found to produce sharp images and was used to determine aircraft speed:

Maximum aircraft speed = (pixel blur × Ground Sample Distance)/shutter speed

For example: if pixel blur = 0.4, shutter speed = 0.000625 s, and GSD = 0.005 m, then maximum aircraft speed = (0.4 × 0.005 m)/0.000625 s = 3.2 m/s.

We conducted photographic surveys on 09, 12, 13, 16, 19, 21 and 23 June 2017. The first survey occurred one week after an Aleutian Tern was observed incubating. Each survey was flown at a fixed altitude and no more than two surveys were flown per day. We flew the first flight at an altitude of 61 m above ground level (AGL). We conducted additional flights at 30, 23, 18, and 15 m AGL after terns showed no signs of disturbance. We geotagged the recorded images using the program MissionPlanner, which used the aircraft telemetry logs and image timestamps. The geotagging process embeds the latitude, longitude, and altitude of the camera position in the image file header or EXIF.

Image processing

RAW images from the Ricoh camera were converted to JPEG's using Adobe Lightroom. The geotagged images were imported into the photogrammetry software Agisoft Photoscan Professional. The software used a technique called Structure From Motion (SFM) to produce an accurate three-dimensional model from the two-dimensional images. Images were aligned using object recognition and computer vision to find common pixel points (called tie points) among overlapping images. Using the camera positions from the image geotags, the SFM software used traditional photogrammetric ranging algorithms to calculate the three-dimensional position (latitude, longitude, and elevation) of the tie points. The set of tie points was then used to create a digital elevation model of the project area surface. By overlaying the aligned images on the elevation surface, an orthorectified mosaic was created.

Visual tern counts

We conducted counts, without distinguishing species, in the air during UAS flights and during a control period when the UAS was not in flight. These counts were used to test if terns flushed during UAS flights, and also served as an alternative estimator for the number of nesting birds to compare to other count methods. We counted aerial terns by scanning the colony north to south

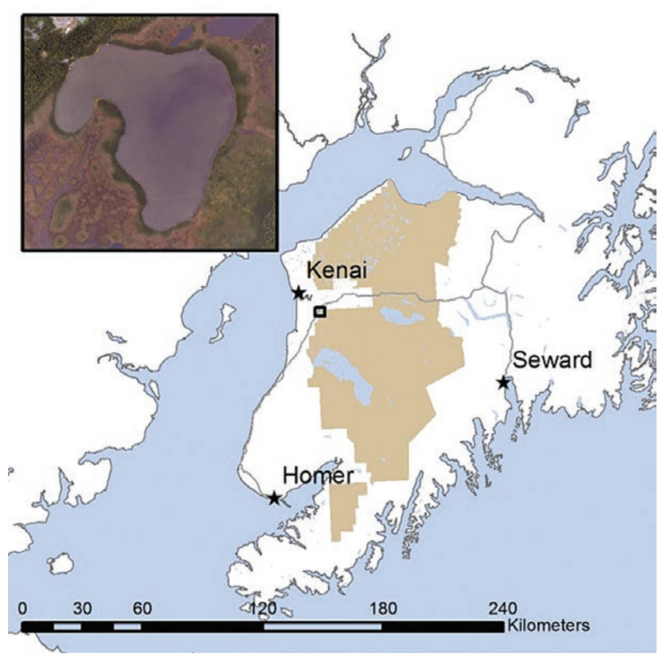

Fig. 1. Location of the Headquarters Lake Aleutian and Arctic Tern colony, Kenai Peninsula, southcentral Alaska. The lake is southwest of the city of Kenai (star) on the Kenai National Wildlife Refuge

from the viewing station and counting all terns flying over the entire colony. On average, we counted aerial terns every 3–5 min (minimum/maximum time between counts = 1 min/23 min); the count took < 15 s. We conducted 44 control counts: 16 on two days when the UAS was not flown and the remainder on days when the UAS was flown but was not in the air during the count. We conducted 41 counts when the UAS was aloft; altitudes were 60 m (n = 7), 30 m (n = 16) and 18 m (n = 18). We compared the control counts to the UAS counts using a Mann-Whitney-Wilcoxon Test (Hollander *et al*. 2013). We noted anecdotal observations of avian predators and any interactions of terns with the UAS. We did not note other signs of disturbance, such as watching the UAS or increased calling.

In order to determine whether UAS presence led to flushing from the nest, we observed six tern nests that were visible from the viewing station. We made observations every three to four min during UAS flights (n = 66 observations) and during control periods when the UAS was not in the air (n = 63 observations). We documented nest attendance when the UAS flew at 60 (n = 12), 30 (n = 13), 23 (n = 12), 18 (n = 17) and 15 m (n = 12) AGL.

Nest count and nesting success

We estimated the number of nesting pairs of each tern species by systematically searching the orthomosaics for nest locations using a 26 ha (0.26 km^2) rectangular grid (each cell 10 m × 40 m) in ArcMap 10.3. We identified nests as adult terns sitting on the ground. We gave each nest a unique identification number and georeferenced the point in ArcMap. We estimated the area of the colony by creating a convex hull of the nest locations using XTools Pro. We compared nests found on photographs to nest locations found using viewing platform observations by mapping the nest locations via an azimuth and distance from the viewing platform. We tracked each nest location across time to evaluate nesting success. We also recorded other bird species found in the photos. To compare the counts of nests to alternative colony census methods, we compared results from the nest count to counts of terns in the air (see “Visual tern counts”).

RESULTS

Colony observations

We spent 15.25 h observing the tern colony from the viewing platform between 19 May and 21 June. Arctic Terns arrived first and initiated nests two days before we observed the arrival of a lone Aleutian Tern on 19 May. On 25 May, we observed Aleutian Terns forming pairs and copulating. On 30 May, we documented at least 16 Aleutian Terns in loose pairs landing at various locations on the ground together, but not landing in the same location. On 2 June, we observed an Aleutian Tern sitting on a nest, and two males were observed feeding females on the ground. We saw an Arctic Tern feeding a fledgling on the ground on 19 June, but no Aleutian Tern fledglings were observed during the duration of the study.

We observed high levels of *Larus* gull (predominately *L. glaucescens*, *L. argentatus*, and *L. canus*) activity. This was not surprising because Headquarters Lake is approximately 2.25 km from the Kenai Peninsula Borough’s Central Peninsula Landfill. We observed large groups of gulls (> 100 individuals) on the lake throughout June. On most days, we observed loosely formed groups of approximately 350 gulls flying 1–30 m above ground level over tern nests as they returned to Headquarters Lake from the landfill. We often observed terns mobbing gulls.

UAS flights

Eight of 11 UAS flights (Table 1) had enough images with overlap to produce an image mosaic of a portion of the colony. We experienced some technical failures (i.e., the camera did not consistently record images during a UAS flight, resulting in an image set that was too sparse to form a mosaic). For these flights, we examined the available photos individually. Because individual flight time was limited to 13 min, some image mosaics required two flights to cover the area. The image mosaics covered areas that ranged in size from 4.2–6.3 ha (0.042–0.063 km^2). Some image mosaics and image sets did not cover the entire 4.1 ha (0.041 km^2) colony area.

TABLE 1
The date, altitude, flight time, and products created from 11 UAS flights to survey Aleutian Tern nests at a colony in southcentral Alaska in 2017

Date	Altitude	Total time in flight	Product
09 June	61 m	15 min (11h16 – 11h30)	Observed reaction of terns to UAS (no photos)
09 June	30 m	6 min (11h37 – 11h43)	4.2 ha (10 acre) mosaic
12 June	23 m	13 min (11h30 – 11h43)	4.3 ha (10.5 acre) mosaic
13 June	23 m	11 min (12h01 – 12h12)	2.7 ha (6.6 acre) mosaic
13 June	15 m	14 min (12h27 – 12h41)	208 georeferenced images
16 June	23 m	13 min (12h03 – 12h15)	3.5 ha (8.6 acre) mosaic
19 June	30 m	12 min (10h58 – 11h10)	6.3 ha (15.5 acre) mosaic
19 June	18 m	26 min (11h16 – 11h30) and (11h38 – 11h50)	4.3 ha (10.7 acre) mosaic; 856 georeferenced images
21 June	30 m	13 min (11h46 – 11h59)	None – camera failure
21 June	18 m	~ 28 min (12h10 – 12h24) and (12h35 – 12h49)	4.8 ha (11.8 acre) mosaic; 851 georeferenced images
23 June	18 m	unknown	4.9 ha (12.2 acre) mosaic; 1167 georeferenced images

The spatial resolution of the photographs increased as altitude decreased (30 m AGL = 0.8 cm^2 pixels or ~ 230 pixels/tern, 23 m = 0.6 cm^2 pixels or ~ 400 pixels/tern, 18 m = 0.5 cm^2 pixels or ~ 600 pixels/tern, and 15 m = 0.4 cm^2 pixels or ~ 950 pixels/tern). At 30 m AGL, we could detect terns on nests but could not distinguish species. We could distinguish Aleutian from Arctic Terns in some of the 23 m images, but when the body positioning or lighting was poor, we could not see bill color or the forehead. Our ability to distinguish tern species was more likely in the 15 m and 18 m AGL flights (Fig. 2). We were more likely to see the white forehead of the Aleutian Tern in images from a side angle rather than a directly overhead camera angle. The 'lawn mower' flight pattern and image overlap allowed us to view several images of the same tern nest from different angles.

Visual tern counts

On average, 1.2 terns were in the air during June UAS flights ($n = 41$ counts, range = 0–5). These counts were significantly lower than control counts ($n = 44$, mean = 3.2, range = 0–14) when the UAS was not operating, which was counterintuitive. Birds in the air varied more between days than between the control and UAS flight (Table 2), with higher numbers of birds in the air on the two days when the UAS was not flown. Because of the low overall colony count and the decidedly non-normal distribution of small-valued counts, there was little power in these data to do statistical comparisons. The preponderance of these data, however, show no difference in counts between control and UAS flights. On 14 June, we observed more tern activity because of high gull activity and the presence of a Bald Eagle *Haliaeetus leucocephalus*. On 19 June, the average number of terns in the air was higher in the control because of an outlier of 14 terns in the air that were mobbing a low-flying eagle.

Fig. 2. Photos by the UAS of Aleutian and Arctic Terns at 30, 23, 18 and 15 m AGL. Examples of Arctic Tern images at the 18-m altitude were not available because this species was less likely to be on the nest late in the nesting season when we conducted the 18 m UAS flights. Photos were taken in June 2017 at the Headquarters Lake colony in southcentral Alaska.

We observed six terns incubating on nests from the viewing platform, three of each species. The proportion of nests that were attended decreased throughout June (Fig. 3). We detected no difference in this proportion when the UAS was in the air for either species (Table 3).

We did not observe terns attempting to mob the UAS. We observed the UAS fly directly over Aleutian Terns on their nests multiple times at 23, 18 and 15 m AGL without flushing the terns. We did observe an Aleutian Tern circle the UAS after flushing to mob a gull. We also observed two Arctic Terns dive on the UAS after first mobbing a Bald Eagle in the vicinity of the UAS path. They did not make contact with the UAS.

TABLE 2
The average number of Aleutian and Arctic Terns in air by day in 2017 at a nesting colony in southcentral Alaska

Date	No UAS	UAS in flight
07 June	2.0	
09 June	0.5	0.3
14 June	5.5	
19 June	3.4	1.8
21 June	1.9	1.6

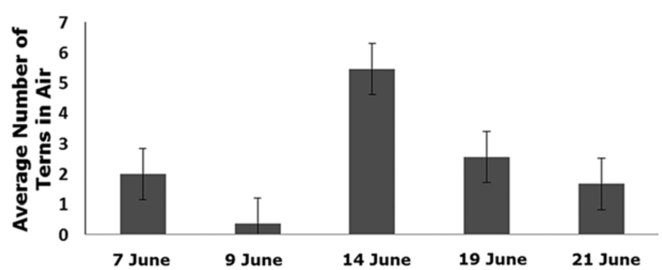

Fig. 3. Average number (and SE) of Aleutian and Arctic terns counted in the air at the Headquarters Lake colony, southcentral Alaska, June 2017.

TABLE 3
Average proportion of known, visible nests ($n = 6$) having terns in attendance for a colony in southcentral Alaska, June 2017

UAS in air	Number of times counted[a]	All nests	Arctic Tern nests	Aleutian Tern nests
No	63	0.68 (0.04)	0.62 (0.05)	0.74 (0.04)
Yes	66	0.64 (0.04)	0.55 (0.06)	0.71 (0.04)
Total	129	0.66 (0.03)	0.59 (0.04)	0.72 (0.03)

[a] The proportion of nests attended was counted 129 times and averaged (SE) across all counts.

Nest count and nesting success

We located 23 nests in the 4.1 ha (0.041 km^2) colony site by systematically searching the UAS orthomosaic (5.6 nests ha^{-1}). Nine of these nest locations were also observed from the viewing platform. The 23 nests were occupied by 12 Aleutian Terns, seven Arctic Terns, and four unidentified terns. In addition, we found two Great Horned Owl *Bubo virginianus* fledglings, a perched Bonaparte's Gull *Chroicocephalus philadelphia*, an unidentified tern fledgling, and a dead tern while systematically searching the orthomosaic. Seven to 10 d after the first Aleutian Tern was seen sitting on a nest, the majority (> 90 %) of terns were on the 23 nests in the UAS images (Table 3). Terns were less likely to be on their nests as the season progressed. We could not determine if activity away from nests was linked to a nest failure event or fledging.

We were unsuccessful in estimating nesting success via the UAS imagery because it was difficult to distinguish fledging from nest failure. When adults were not present at the nest during the UAS flight, it was unclear if the nest was still active; resolution was not sufficient to reliably detect eggs or chicks (Table 4).

In June, we counted an average of 2.2 terns in the air, which corresponds to approximately 10 % of the known nests. The average number of aerial terns on different days ranged from 0.37–5.46, with a peak in mid-June. The highest number of terns observed in the air was 22.

DISCUSSION

UASs are a promising option to census Aleutian Tern colonies with little disturbance. We successfully conducted a nest count of a sparsely-distributed, mixed-species colony, resulting in a count of 23 tern nests of which half were Aleutian Terns. To identify species, we needed to fly the UAS at 15–23 m AGL. Side angle images were more useful to separate the forehead patch in situations where a bird had lowered its head toward its chest. Bill color was often masked in the images by similar colors in the surrounding vegetation.

There was no evidence of Aleutian and Artic Terns flushing from their nests during UAS flights. Day to day variation in colony activity (as measured by birds in the air) was larger than the difference in nest attendance when the UAS was in flight. The colony in our study is subject to high levels of gull and eagle activity, thus eliciting flushing. Many other studies report that birds in nesting colonies do not exhibit more flushing behaviors during UAS flights and quickly habituate (Sarda-Palomera *et al*. 2012, Chabot *et al*. 2015,). Glaucous Gulls *L. hyperboreus* and Icelandic Gulls *L. glaucoides* flushed from their nest when a UAS approached but returned within minutes (Brisson-Curadeau *et al*. 2017). Breeders are less likely than non-breeders to exhibit behavioral responses to UAS (Mulero-Pázmány *et al*. 2017).

We assessed disturbance in terms of flushing from the nest, but UAS can have effects on animals other than nest flushing. Weimerskirch *et al*. (2017) found that only one of 11 seabird species had a behavioral response when a UAS approached at 50 m, but most species showed stress postures at 10 m. However, those showing no behavioral response did have an increased heart rate (Weimerskirch *et al*. 2017). Flying directly toward animals, larger UASs and louder engines are more likely to cause behavioral responses (Mulero-Pázmány *et al*. 2017). Birds may also be more disturbed when the UAS approaches from above, possibly because this movement pattern is similar to that of avian predators (Vas *et al*. 2015). However, the lawn mower flight patterns that are needed to create the orthomosaics in this paper are less disturbing than direct flight paths towards an animal (Mulero-Pázmány *et al*. 2017).

No standard method exists for visual census of Aleutian Tern colonies (Renner *et al*. 2015), with various researchers attempting to count birds in the air—either without flushing, when flushed after walking through the colony, or after flushing to mob a predator. In our study, counts of terns in the air were highly variable and in all cases much lower than nest counts from the UAS photos. Besides reducing disturbance, UAS surveys should provide more accurate and precise nest counts. Conducting multiple surveys close together in time, and having multiple observers visually search photographs for nests, would be helpful to quantify detection error. UAS surveys of tern colonies are limited by the location and size of the tern colony. The general area of the colony must be known, and an adequate launch site that allows the pilot to view the UAS during the flight is required.

Historical counts of Aleutian Terns have been conducted using a variety of methods that have the potential to greatly overestimate or underestimate actual numbers of nesting birds. Given recent increases in conservation concern for the species (e.g., Renner *et al*. 2015; IUCN status change to "Vulnerable"; BirdLife International 2017), accurate and unbiased counts of this little-known species will be of high importance. The benefits will likely apply broadly to any surface-nesting seabird.

Little information is known about Aleutian Tern nesting success (North 2013). There is the potential for the UAS imagery to document eggs or fledglings in the nest, but a high image resolution

TABLE 4
Number of tern nests found in orthomosaics taken on different days at an Aleutian and Arctic tern colony in southcentral Alaska, June 2017

Date	Days after nest initiation	Terns photographed on nest	Unattended nests[a]	No image coverage
07 June	7	4	1	18
12 June	10	21	1	1
13 June	11	16	1	6
16 June	14	4	6 (4 with eggs/ chicks)	13
19 June	17	8	15 (6 with eggs/chicks)	0
19 June	17	7	16 (7 with eggs/chicks)	0
21 June	19	5	14 (4 with eggs/chicks)	4
23 June	21	5	15 (3 with eggs/chicks)	3

[a] Unattended nests were located in photos but did not have an adult tern present.

or heat-sensing device is necessary. The vegetation surrounding the nest sites in this colony will likely require thermal detection because tern fledglings leave the nest site quickly after hatching and would be undetectable with standard photography. UAS flights repeated across the season have been used successfully to monitor nesting success in a Black-headed Gull colony (Sardà-Palomera *et al*. 2017).

Recommendations

To census Aleutian Tern nests, we recommend UAS flights occur 7–10 d after the first nest is initiated (highest nest attendance likelihood). In southcentral Alaska, this is early to mid-June. In mixed-species colonies, we recommend the UAS fly in a lawn mower pattern with overlap to maximize side angle images, which are the most useful for delineating species (end-lap of 80 % and side-lap of 60 %.). We recommend an image resolution of < 4 mm (achieved by 15 m AGL flight) to distinguish Aleutian and Arctic Terns. Single species colonies can be surveyed with an image resolution of 1 cm.

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REFERENCES

ANDERSON, K. & GASTON, K.J. 2013. Lightweight unmanned aerial vehicles will revolutionize spatial ecology. *Frontiers in Ecology and the Environment* 11: 138–46.

BIRDLIFE INTERNATIONAL. 2017. Species factsheet: *Onychoprion aleuticus*. [Available online at: http://dx.doi.org/10.2305/IUCN.UK.2017-3.RLTS.T22694716A119185243.en. Accessed 15 June 2018].

BRISSON-CURADEAU, É., BIRD, D., BURKE, C. ET AL 2017. Seabird species vary in behavioural response to drone census. *Scientific Reports* 7: 17884.

CHABOT, D., CRAIK, S.R. & BIRD, D.M. 2015. Population census of a large common tern colony with a small unmanned aircraft. *PloS One* 10: e0122588.

HOLLANDER, M. WOLFE, D.A & CHICKEN, E. 2013. *Nonparametric Statistical Methods*. Vol. 751. New York, NY: John Wiley & Sons.

MULERO-PÁZMÁNY, M., JENNI-EIERMANN, S., STREBEL, N., SATTLER, T., NEGRO J. J. & TABLADO, Z. 2017. Unmanned aircraft systems as a new source of disturbance for wildlife: a systematic review. *PloS One* 12: e0178448.

NORTH, M.R. 2013. Aleutian Tern (*Onychoprion Aleuticus*). In: RODEWALD, P.G. (Ed.) *The Birds of North America*. Ithaca, NY: Cornell Lab of Ornithology.

OEHLERS, S. 2012. *Observations of Aleutian Terns on the Yakutat Forelands, 2008–2012*. Yakutat, AK: US Department of Agriculture, US Forest Service.

PYARE, S., GOLDSTEIN, M. I., DUFFY, D., OEHLERS, S., CATTERSON, N. & FREDERICK, J. 2013. *Aleutian Tern (Onychoprion aleuticus) research in Alaska: Survey methodology, migration, and statewide coordination: final report to the Alaska Department of Fish and Game.* Juneau, AK: Alaska Department of Fish and Game.

RENNER, H. M., ROMANO, M. D., RENNEWE M., PYARE, S., GOLDSTEIN, M. I. & ARTUKHIN, Y. 2015. Assessing the breeding distribution and population trends of the Aleutian tern *Onychoprion aleuticus*. *Marine Ornithology* 43: 179–87.

SARDÀ-PALOMERA., F., BOTA, G., PADILLA, N., BROTONS, L. & SARDA, F. 2017. Unmanned aircraft systems to unravel spatial and temporal factors affecting dynamics of colony formation and nesting success in birds. *Journal of Avian Biology* 48: 1273–80.

SARDÀ-PALOMERA., F., BOTA, G., VINOLO, C. ET AL 2012. Fine-scale bird monitoring from light unmanned aircraft systems. *Ibis* 154: 177–83.

VAS, E., LESCROËL, A., DURIEZ, O., BOGUSZEWSKI G. & GRÉMILLET, D. 2015. Approaching birds with drones: first experiments and ethical guidelines. *Biology Letters* 11: 20140754.