Canadian Science Publishing

ARTICLE

Nesting Common Eiders (*Somateria mollissima*) show little behavioral response to fixed-wing drone surveys[1]

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Abstract: Drones may be valuable in polar research because they can minimize researcher activity and overcome logistical, financial, and safety obstacles associated with wildlife research in polar regions. Because polar species may be particularly sensitive to disturbance and some research suggests behavioral responses to drones are species-specific, there is a need for focal species-specific disturbance assessments. We evaluated behavioral responses of nesting Common Eiders (*Somateria mollissima* (Linnaeus, 1758), $n = 19$ incubating females) to first, second, or in a few cases third exposure of fixed-wing drone surveys using nest cameras. We found no effect of drone flights ($F_{[1,23]} = 0$, $P = 1.0$) or previous exposures ($F_{[1,23]} = 0.75$, $P = 0.397$) on the probability of a daily recess event (bird leaves nests). Drone flights did not impact recess length ($F_{[1,25]} = 1.34$, $P = 0.26$); however, Common Eiders with prior drone exposure took longer recess events ($F_{[1,25]} = 5.27$, $P = 0.03$). We did not observe any overhead vigilance behaviors common in other species while the drone was in the air, which may reflect Common Eiders' anti-predator strategies of reducing activity at nests in response to aerial predators. Surveying nesting Common Eider colonies with a fixed-wing drone did not result in biologically meaningful behavioral changes, providing a potential tool for research and monitoring this polar nesting species.

Key words: Arctic, animal behavior, Common Eider, disturbance, drone, nest camera, unmanned aerial systems, unmanned aircraft vehicles, *Somateria mollissima*.

Résumé : Les drones peuvent être utiles dans la recherche polaire parce qu'ils peuvent réduire au minimum l'activité des chercheurs et surmonter les obstacles logistiques, financiers et de sécurité associés à la recherche sur la faune dans les régions polaires. Étant donné que les espèces polaires peuvent être particulièrement sensibles aux perturbations et que certaines recherches suggèrent que les réactions comportementales aux drones sont spécifiques à l'espèce, il est nécessaire d'effectuer des évaluations des perturbations propres à l'espèce. Les auteurs ont évalué les réactions comportementales des eiders à duvet (*Somateria mollissima*, $n = 19$ femelles en incubation) nicheurs à la première, à la deuxième ou, dans quelques cas, à la troisième exposition à des levés de drones à voilure fixe, et ce, au moyen de caméras de nidification. Ils n'ont trouvé aucun effet des vols de drones ($F_{[1,23]} = 0$, $P = 1{,}0$) ou des expositions antérieures ($F_{[1,23]} = 0{,}75$, $P = 0{,}397$) sur la probabilité d'un

Received 25 May 2021. Accepted 1 September 2021.

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[1]This article is part of a collection on Unoccupied Vehicle Systems in Arctic Research and Monitoring jointly published by Arctic Science and Drone Systems and Applications.

événement d'éloignement quotidien (l'oiseau quitte son nid). Les vols de drones n'ont pas eu d'impact sur la longueur des périodes d'éloignement ($F_{[1,25]}$ = 1,34, P = 0,26); cependant, les eiders ayant déjà été exposés à des drones ont pris des périodes d'éloignement plus longues ($F_{[1,25]}$ = 5,27, P = 0,03). Les auteurs n'ont observé aucun comportement de vigilance aérienne commun chez d'autres espèces pendant que le drone était dans les airs, ce qui peut refléter les stratégies anti-prédateur de l'eider visant à réduire l'activité aux nids en réponse aux prédateurs aériens. Les levés des colonies d'eiders à duvet nicheurs au moyen d'un drone à voilure fixe n'a pas entraîné de changements de comportement biologiquement significatifs, ce qui constitue un outil potentiel pour la recherche et la surveillance de cette espèce de nidification polaire. [Traduit par la Rédaction]

Mots-clés : Arctique, comportement animal, eider à duvet, perturbation, drone, caméra de nidification, systèmes aériens sans pilote, véhicules aériens sans pilote, *Somateria mollissima*.

Introduction

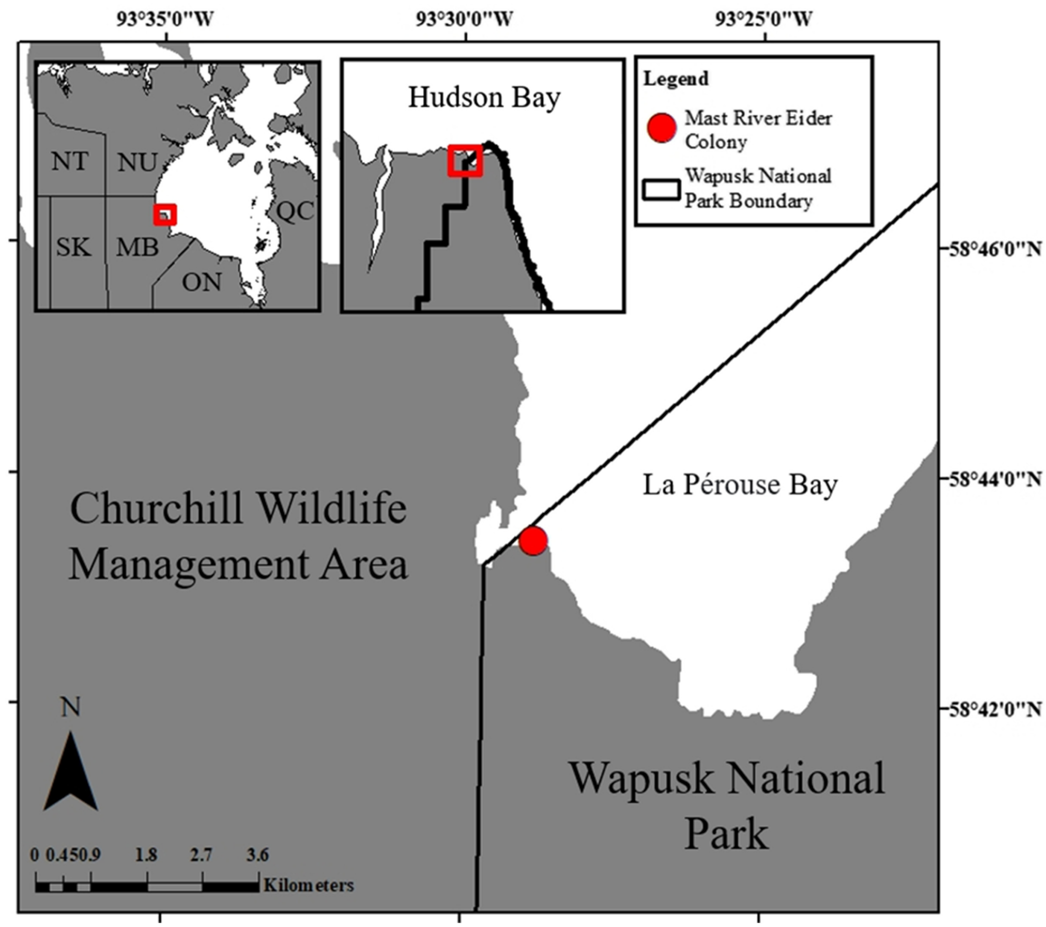
Polar regions are the most rapidly changing areas across the globe due to climate change (Stroeve et al. 2007; Higdon and Ferguson 2009; Kovacs et al. 2011). As a result, there is a need for high-quality data to address changes to the habitat and wildlife populations inhabiting those areas. However, such data can be logistically and financially difficult to obtain due to limited infrastructure across this remote landscape (Mallory et al. 2018). Drones have become a popular tool in wildlife ecology (Christie et al. 2016; Chabot 2018; Johnston 2019) and provide a potential technology that could advance data collection in polar regions. In particular, drones enable rapid data acquisition in the field (Barnas et al. 2019), provide opportunities to obtain high-resolution data that is often not available from satellite imagery or inadequate due to cloud cover and other atmospheric conditions that reduce image quality (Loarie et al. 2007), and allow access to areas that can be logistically difficult to reach or even unsafe to access by researchers (Sasse 2003; Brisson-Curadeau et al. 2017). While drones have been used to study a variety of taxa (Durban et al. 2015; Wich et al. 2015; Schofield et al. 2017; Kim et al. 2018), these tools have received particular attention for the study of birds (Chabot et al. 2015; Weissensteiner et al. 2015; McEvoy et al. 2016; Barnas et al. 2018*b*; Scholten et al. 2019). Specifically, drone research has focused on detection of colonial nesting birds (Chabot and Bird 2012; Sardà-Palomera et al. 2012; Hodgson et al. 2016). For polar regions, information about large colonies of breeding birds is important for conservation, but often is challenging to obtain for the reasons listed above. Further, counting large numbers of birds can lead to observer fatigue and possible bias in estimates. Imagery collected from drones provides the opportunity for data to be reviewed by multiple observers or through automated procedures to confirm counts. Finally, as species in polar regions may be particularly susceptible to human disturbance (Mallory 2016), the development of less invasive drone-based methods should be prioritized.

The primary assumption is that drones are less invasive than traditional methods, thereby they do not impact behaviors that would introduce bias into the counts (e.g., flushing and never being counted or moving in ways that they would be double-counted) or alter fitness of the birds monitored (e.g., reduce survival of monitored individuals or number of offspring they produce). However, this is an area of growing research. Several studies have anecdotally evaluated behavior, but controlled studies focused on behavior have been conducted only in recent years (Barnas et al. 2018*b*; Barr et al. 2020; Egan et al. 2020). A review of behavioral studies by Mulero-Pázmány et al. (2017) concluded that there are many factors that impact behavioral responses of wildlife, which include species, life history characteristics, drone platform characteristics, altitude, and flight approaches (at angles vs. directly at animals). In particular, Mulero-Pázmány et al. (2017) noted that birds were more sensitive than other types of animals to drones. Further, fixed-wing drones appeared to cause more disturbance than rotary-wing drones when surveying breeding ducks, especially at lower altitudes (<80 m above ground level (AGL); McEvoy et al. 2016). Shorebirds and wading birds also responded more to fixed-wing drones (Vallery 2018). This is likely due to the resemblance of these drone platforms to raptors. Since fixed-wing drones have longer endurance and better stability in stronger wind, they may be more appropriate in polar regions, but this begs the question of their impact on the birds we aim to benefit by using the tool. As a result, there is substantial need to evaluate species-specific wildlife responses to drones in the capacity to which they would be used to collect survey data necessary for population estimates and habitat assessments. Evaluations should include protocols that have been planned relative to drone platforms, sensor resolution requirements affecting altitude, flight approaches, and the potential species impacted by such surveys.

Common Eiders (*Somateria mollissima* (Linnaeus, 1758), hereinafter "eiders") are an Arctic breeding waterfowl species that are a suitable candidate for monitoring with drone technology. Eiders are an ecologically significant species for Arctic ecosystems due to their role in food webs and the transportation of marine subsidies (e.g., marine mollusks) into terrestrial environments where they nest (Clyde et al. 2021). These birds are culturally important to northern communities as they have long been hunted as a source of subsistence and raw materials (Pars 2001; Henri et al. 2010; Waltho and Coulson 2015; Henri et al. 2018) resulting in interest in monitoring population dynamics. Recent research has indicated that climate-induced earlier sea-ice breakup may actually benefit eiders in some regions (Jónsson et al. 2009; Chaulk and Mahoney 2012; Jónsson et al. 2017), but in some areas eider populations appear to have decreased (Jean-Gagnon et al. 2018). Fully understanding the impacts of climate change and predicting population responses of eiders is contingent on accurate estimates of nesting bird numbers. Unfortunately, eiders typically nest in relatively dense congregations on off-shore islands, which makes nesting surveys logistically and financially challenging. Further, eiders are thought to have evolved extremely high nest attendance in response to aerial predators (*Laridae* spp.) (Laurila 1989; Bolduc and Guillemette 2003*b*), so any researcher-induced disturbance that results in flush responses by eiders may have a disproportionately negative impact due to increased predation risk or thermal stress (Bolduc and Guillemette 2003*a*). In fact, each additional daily disturbance increased the predation risk by a factor greater than six at eider nests in northern Norway (Stien and Ims 2016). Therefore, monitoring approaches that increase disturbance will likely increase predation so selecting appropriate techniques is of critical importance.

As drones are thought to cause less disturbance than ground-based survey methods, these tools may become important for monitoring eiders in the future since current practices involve foot searches where eiders are flushed from the nest (e.g., Iles et al. 2013). However, before drones can be fully implemented into eider monitoring strategies, possible disturbance effects of drones on nesting eider behavior need to be investigated. The objective of this study was to evaluate behavioral responses of nesting eiders to fixed-wing drone surveys. Specifically, we examined whether daily nest attendance patterns changed on days with drone surveys versus days without. On a subset of nests, we further examined individual behaviors prior to a flight, during flights, and after the conclusion of the flights to examine specific behaviors that may suggest increased stress in response to drones. We then used this information to suggest best practices that can inform survey design using drones that either focus on eiders or are in areas where eiders are nesting.

Fig. 1. Location of the Mast River Common Eider (*Somateria mollissima* (Linnaeus, 1758)) colony along the border of Wapusk National Park, Manitoba, Canada. Mapping files provided by Wapusk National Park; Canadian provinces and territories layer taken from ESRI online.



Methods

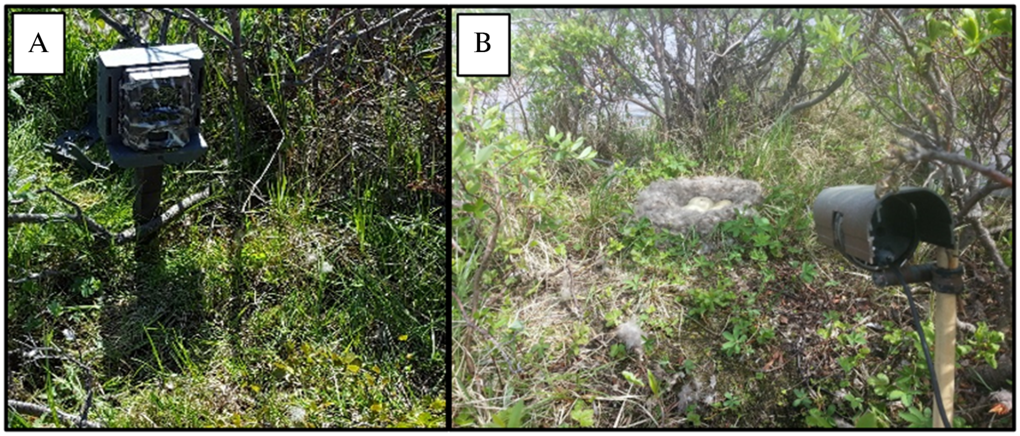
Study area

We conducted this study 11–16 June 2016, on a nesting eider colony located along the northwest border of Wapusk National Park, Manitoba, Canada. Eiders in this colony nest on small islands (size range: 1–300 m^2) within the braided delta of the Mast River, which borders Wapusk National Park and the Churchill Wildlife Management Area (Fig. 1). Vegetation surrounding eider nests are predominately dwarf shrub species in the genera *Betchula* and *Salix*. For further details on the geography of the region, see Brook and Kenkel (2002) and Shilts et al. (1987).

Nest camera setup

Eider nest monitoring for this study was done as a part of a larger annual eider behavior monitoring project. The density of eiders in the area was approximately 38 nests/km^2, with eiders nesting on average 63 m apart from one another (Stechmann 2019). We only describe methods relevant to the deployment of cameras at nests used for evaluating behavioral responses to drone surveys. Nest searches were done by teams of researchers on the ground

Fig. 2. We monitored Common Eider nesting behaviors in response to drone flights using time-lapse photography from trail cameras (A) and continuous video from miniature security cameras (B).



during the first week of eider nest incubation (early June). At a subset of located nests, we deployed camera equipment intended for monitoring predation events and nest attendance behaviors of female eiders since only females engage in incubation. Nests were selected for camera deployment based on distances to other monitored nests within the colony to ensure wide geographic coverage. For further details on eider nest searching and monitoring protocols, see Stechmann (2019).

We deployed two different types of camera systems for this study. We used Reconyx PC-800 Hyperfire trail cameras (Holmen, Wis.) programmed to capture a single image every 2 min (time-lapse settings), as well as a burst of 30 images if motion was detected by the infrared sensor (Fig. 2A). We used a high sensitivity for the infrared sensor, with no time-delays or quiet period following triggers. The second camera type used were custom-made miniature surveillance cameras (Fig. 2B) following the methods of Burr et al. (2017). These cameras recorded video rather than still images and were connected by a cable to a DVR recorder, which saved data to a 32 GB SD card. Cameras were powered by a 12 V, 36 A battery, which enabled continuous behavioral monitoring for 5–9 days. The bulk of video camera equipment (DVR box, batteries, cables, etc.) were stored approximately 25 m away from the nest, allowing changes of batteries and SD cards without disturbing the nesting eider. Both camera systems described were mounted on wooden or steel posts, approximately 0.5–1.5 m off the ground.

Drone surveys

We used a Trimble UX5 fixed-wing drone (color, black; wingspan, 100 cm; weight, 2.5 kg; and cruise speed, 80 km/h) to survey the eider colony. The UX5 is a delta-wing-shaped rear-propelled aircraft powered by a lithium polymer battery allowing flight times up to 50 min. The aircraft was launched using an elastic catapult, and then followed a pre-programmed flight path to survey the target area in a "lawnmower" transect pattern. Following completion of the survey, the drone moved towards the designated landing area and executed a "belly landing".

Drone surveys of the eider colony were done on 11, 14, and 16 June 2016, for a total of 11 individual flights. A nest was considered exposed to a flight if it was within the boundaries of the flight lines generated from the keyhole markup language file (.kml). Given that the park requires a permit for conducting research and especially using drones, we were confident that the only exposure to drones was from our research team because no one else had the appropriate permits to conduct drone operations that year on that species. We flew several surveys each day at altitudes of 75, 100, and 120 m AGL. Most flights were at 120 m AGL (9 of 11) and only a single flight took place at each of 75 and 100 m AGL. As the original intent of these surveys were to evaluate mapping efficacy from different survey altitudes, these flights were not ordered in a fashion that allows us to properly estimate the impact of different survey altitudes on eider behaviors (i.e., some eiders were only flown at 120 m, others at 75 m followed by 100 m, and vice-versa). We have previously found no effect of differences in these survey altitudes on nesting behavior of Lesser Snow Geese (*Anser caerulescens caerulescens* (Linnaeus, 1758)) (Barnas et al. 2018*b*), and others have observed less variation in responses to altitudes above 50 m AGL (McEvoy et al. 2016; Collins et al. 2019). Note that all of our survey altitudes are generally much higher than those presented in the literature (Rümmler et al. 2015; Vas et al. 2015). For additional details on flight schematics and technical specifications of the drone used in this study, see the Drone Reporting Protocol provided in Supplementary Data file a[2] following Barnas et al. (2020*a*).

Behavioral observations of day before and day of flights

To estimate the effects of drone surveys on eider nesting behaviors, we collected daily nest attendance behaviors of eiders on the day that they were surveyed by drone (Drone Day), and a paired control day before the surveys (Control Day). We first established if a camera-monitored eider was surveyed by drone flights on a flight day by inspecting each drone survey's keyhole markup language (.kml) file produced from Trimble's Aerial Imagery V2.0.0040 (Trimble, Sunnvale, Calif.) software. This allowed us to visualize whether individual nests were located within the survey area of flights on each day (11, 14, or 16 June), thus which days should be reviewed for behavioral observations. In some cases ($n = 6$), nests were flown over (nest location was within the flight area) on two or three separate days based on the mapping effort. Since previous exposures could result in lag effects or alter behaviors, we incorporated previous exposure into our analysis.

For eiders that were surveyed on a flight day, we reviewed camera data from that Drone Day and the previous Control Day using both trail and surveillance cameras. S. Ellis-Felege and A. Barnas reviewed images and video using Microsoft Photos App (Microsoft, Seattle, Wash.) and Windows Media Player (Microsoft, Seattle, Wash.), respectively. For each eider and each day, observers recorded the number and duration of recess events (minutes), where recess events are defined as events in which the attending female was physically off and away from her nest. For each recess event, we recorded the time the female left and returned to the nest, as well as whether the female was observed to cover her eggs with insulating down feathers.

We estimated the impact of drone surveys on whether or not eiders left their nest on a day using a generalized linear model. Note that we attempted a mixed model by including a random effect to account for repeated observations of the same eider nests, but this model did not converge. The resulting generalized linear model included a fixed effect for survey day (categorical with two levels: Control Day and Drone Day), and also a categorical fixed effect for whether or not an eider had previously been surveyed by a drone (prior exposure, categorical with two levels: yes or no). The generalized linear model was fit via Laplace approximation, assuming a Bernoulli distribution for recess event and a logit link function.

[2]Supplementary data are available with the article at https://doi.org/10.1139/juvs-2021-0012.

We constructed a separate linear model to estimate the impact of drone surveys on eider recess lengths (including a random effect for eider nest ID did not significantly improve fit based on a likelihood ratio test $\chi^2(1) = 0.59$, $P < 0.22$). This model contained the same fixed effects as above; however, we log transformed recess lengths and assumed a Gaussian distribution (based on improved model fit compared to an untransformed response variable and a gamma distribution). The model was fit with a restricted maximum likelihood approach and an identity link function.

In all cases, model fit was assessed based on estimates of dispersion and inspection of residual panel plots. All data manipulation and exploration was done in R Studio v3.4.3 (R Core Team 2017) using packages *dplyr* (Wickham et al. 2015), *lubridate* (Grolemund and Wickham 2011), and *ggplot2* (Wickham 2016). Models were fit using PROC GLIMMIX in SAS Studio v3.8. Statistical significance was assessed using $\alpha = 0.05$.

We qualitatively examined whether recess events on Drone Days occurred during drone survey times. Since some eiders were surveyed by multiple consecutive drone flights in a day, we defined the start of drone surveys as the start time for the first flight of the day, and the end of drone surveys as the end time for that eider's last survey flight of the day. For example, if an eider was surveyed by two flights ranging from 1000 to 1025 hours and 1030 to 1050 hours, we defined the range of flight times for that eider to be 1000–1050 hours. As turnaround times for individual flights were relatively fast (e.g. battery and SD swaps), we felt this was the simplest approach to this qualitative examination of recess events during drone surveys.

Behavioral responses to the flight process

The video data were also reviewed in more detail to examine specific behaviors of eiders at five nests that had not been previously flown over (three of which were used in the previously described analysis; all were from 16 June 2016 flights) during the flight period from 30 min before the flight (pre-flight), during the flight, and 1 h after the flight on the day of the flight (post-flight) following Barnas et al. (2018*b*). For this, we only examined behaviors of the first exposure of a single drone flight. Behaviors were classified as "resting" (sleeping, head tucked on back even if eyes were open), "nest maintenance" (adding vegetation to the nest bowl, turning eggs, self-preening), "low scan" (eiders passively observing environment), "high scan" (rapid head movement characterized by extended neck and clearly searching surrounding environment), "overhead vigilance" (birds tilted head to observe overhead, classified as head-cocking by Barnas et al. (2018*a*, 2018*b*)), and "off-nest" (bird stood up and left the nest; See Supplementary Data files b–e[2])). Because individual flight times varied, we calculated relative proportions of, rather than absolute, times to standardize and compare behaviors across flight periods. Due to the small sample size, we calculated summary statistics and graphically represent the data as the proportion of behaviors during each of the flight periods (pre-, during, and post-flight).

Results

For day-before and day-of analysis, we were able to collect behavioral observations from 19 individual eiders monitored by cameras (16 trail cameras and three video cameras). This represents 65.5% (19/29) of the nests we monitored throughout the breeding season with cameras and 15.1% (19/126) of the total nests located that season. While we were unable to review two additional cameras due to camera malfunctions that limited our ability to have complete days of observations, in total we reviewed 44 days of nesting behavior from 10 to 16 June 2016. We found an equal number of eiders took no recesses on Control Days as Drone Days and similarly an equal number took at least 1 recess/day on Control Days as Drone Days (Table 1). Concordantly, we failed to find a significant effect of Drone Days

Table 1. Summary of Common Eider (*Somateria mollissima* (Linnaeus, 1758)) off nest events on Drone Days and Control Days from 22 nest-survey days (19 nests with three nests sampled on an initial and a subsequent drone exposure).

	Control days before drone survey	Day of drone surveys
Birds with no recesses	11	11
Birds with at least one recess	11	11

Table 2. Linear model estimates for measures of Common Eider (*Somateria mollissima*) nest attendance behaviors in relation to drone surveys.

		Fixed effects estimates ± SE			
Model	Family	Intercept	Drone Day*	Prior exposure†	Dispersion
Recess event	Bernoulli	−0.105 ± 0.445	0.00 ± 0.601	0.799 ± 0.923	1
Log recess length	Gaussian	2.935 ± 0.269	−0.401 ± 0.346	0.915 ± 0.398	0.83

*Reference category, Control Day.
†Reference category, no prior exposure to drone surveys.

($F_{[1,23]} = 0$, $P = 1.0$) or prior exposure ($F_{[1,23]} = 0.75$, $P = 0.397$) on whether or not eiders took a recess event (Table 2).

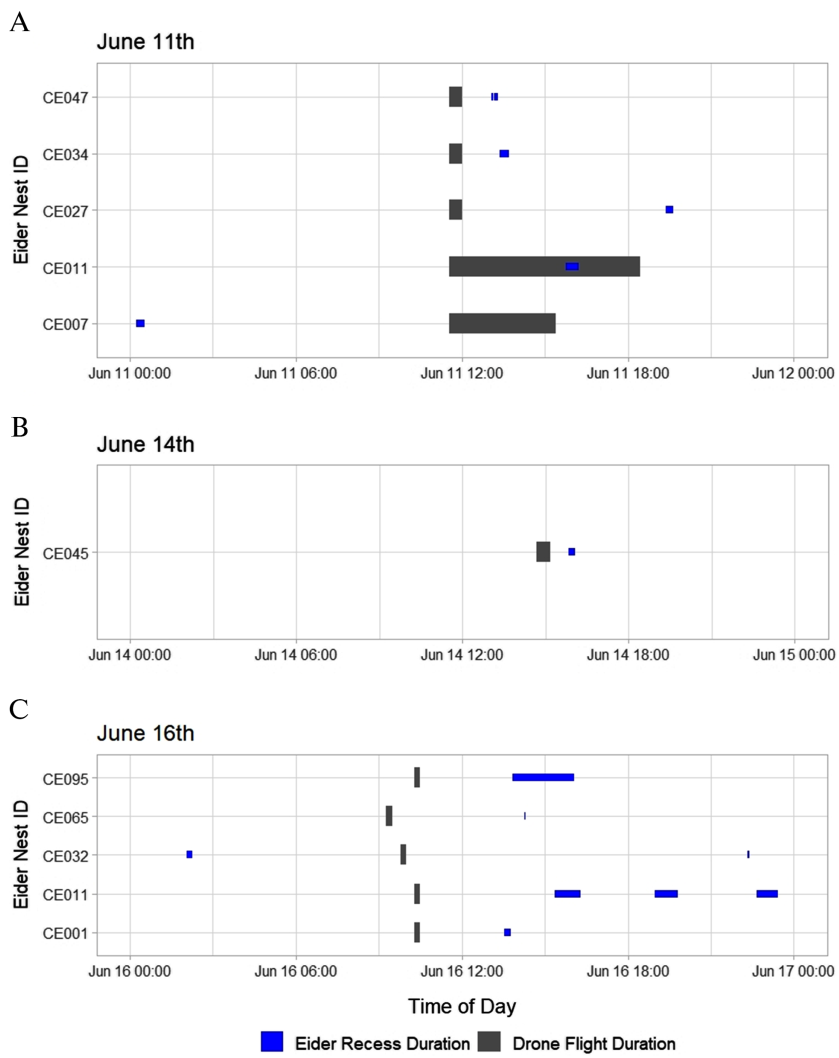
We observed 28 recesses total, 13 from birds on Control Days and 15 on Drone Days. We observed egg covering behaviors on 10 of 13 events on Control Days, and 13 of 15 events on Drone Days. Mean recess lengths (± SD) on Control Days were 31.8 ± 33.8 min (range: 6–138 min), and 28.2 ± 33.7 min (range: 2.5–133 min) for Drone Days. We failed to find a significant effect of Drone Days on recess lengths ($F_{[1,25]} = 1.34$, $P = 0.26$); however, we did find a significant, positive effect of prior drone exposure ($F_{[1,25]} = 5.27$, $P = 0.03$, Table 2). Of the recess events on Drone Days, only one actually took place during the period of drone surveys (Fig. 3A). We did not observe any predation events during recess events in this study.

We collected detailed behavior observations from five nests during the flight process, and we observed only the behaviors of resting, nest maintenance, low scan, and high scan. No off-nest or overhead vigilance behaviors were observed during any of the three observation periods of the flight process. While we had broad standard deviations indicating individual variation among eiders, we observed decreases in the mean proportion of time spent on nest maintenance and an increased mean for resting during the flight period (Fig. 4). We also observed slight increases in both low scan and high scan behaviors during the post-flight period (Fig. 4).

Discussion and conclusions

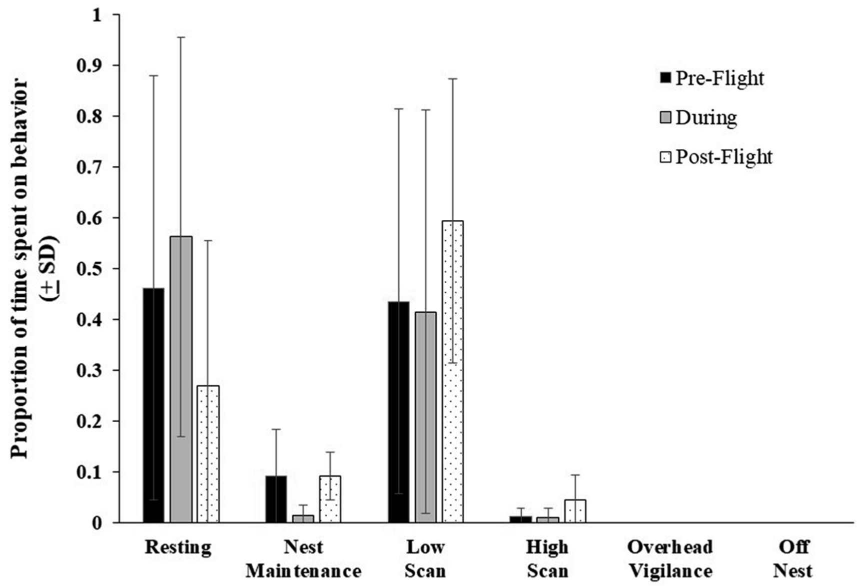
To the best of our knowledge, this is the first evaluation of nesting eider behavioral responses to a fixed-wing drone survey. This offered us an opportunity to evaluate drones for an ecologically and culturally important polar species with very high nest attendance where minor disturbances could have potentially negative fitness consequences. We did not find any changes in nest attendance patterns by eiders on days with drone flights compared to the day prior without a drone flight, which we suspect reflects the generally high nest attendance rates evolved to mitigate nest loss by avian predators (Bolduc and Guillemette 2003*b*). As a result, even if the drone was perceived as an aerial threat, eiders likely responded as they would to other aerial predators.

Fig. 3. Timing and lengths of observed Common Eider (*Somateria mollissima*) recess events on days with fixed-wing drone surveys in 2016: (A) 11 June, (B) 14 June, and (C) 16 June.



We did not find that the timing of recess events corresponded to drone flight times, as we only observed one recess event by a single eider during the drone operations, on 11 June. Qualitatively it appeared recess events were taken primarily during crepuscular hours or at night, a finding similar to previous studies of eider nest attendance (Stechmann 2019). Eiders generally take recess events outside of daylight hours to minimize nest loss from ubiquitous avian predators who are inactive at night (Swennen et al. 1993; Bolduc and Guillemette 2003*b*; Stechmann 2019). Our findings suggest the best time to survey when the female eider is on the nest is during the day, but if thermal sensors that use relative temperatures are used for detection, ideal survey times are typically at night or early mornings when the temperature contrast is greatest between the background and the nest (Bushaw et al. 2020; Helvey et al. 2020).

Fig. 4. Average and standard deviations of the proportion of time spent on individual behaviors of nesting Common Eiders relative to 30 min prior to a drone survey (pre-flight), during flight, and 1 h after (post-flight). Behavioral data is from 15 observations of five birds across three drone flights.



We did not find any effect of drone flights on recess duration; however, recess durations were longer with increased number of exposures to the drone. This may be partially explained by the fact that increasing exposure to drone survey days was conflated with increased investment in the nest. Typically increased investment by eiders results in shorter recess duration (Criscuolo et al. 2002; Garbus et al. 2018). However, longer recess durations may be indicative of nutritionally stressed birds, as individuals spend longer amounts of time away from their nest to feed or drink water (Bottitta et al. 2003), although most eiders are thought to only preen and drink during recess breaks (Öst and Kilpi 1999; Criscuolo et al. 2000). This increased time spent away from the nest puts nests at risk of predation, but notably we did not observe any predation events during the course of this current study. Therefore, eiders may have found the drone unthreatening during previous exposures since no predation events occurred. Common nest predators of the Mast River eider population include, but are not limited to, gulls (*Larus* spp.), bears (*Ursus* spp.), and Arctic foxes (*Vulpes lagopus* (Linnaeus, 1758)) (Iles et al. 2013; Stechmann 2019; Barnas et al. 2020*b*); therefore, the lack of drone-induced behavioral disturbance leading to nest failure is reassuring for the use of drones in this area regardless of the increased recess duration.

When we explored individual behaviors of eiders to the drone flight process, we found no evidence of eiders exhibiting overhead vigilance. While we acknowledge the small sample size for this portion of the work ($n = 5$), this is contradictory to other studies examining waterfowl responses to drones that have documented an overhead vigilance behavior (McEvoy et al. 2016; Barnas et al. 2018*b*; Ryckman, pers. comm.). This overhead vigilance in response to drones has also been documented in polar bears (*Ursus maritimus* Phipps, 1774) (Barnas et al. 2018*a*) and Antarctic birds (Rümmler et al. 2015; Weimerskirch et al. 2018), which suggests this qualitative measure of behavioral response may be informative across taxa.

We observed decreased nest maintenance activity and increased resting during flight periods compared to pre- and post-flight. Interestingly, the eiders increased vigilance (both low and high scan) in the post-flight periods, as well as resumed pre-flight nest maintenance behaviors. This may suggest that the eiders are detecting the drone, and altering behaviors to avoid detection as was seen in Blue-winged Teal (*Spatula discors* Linnaeus, 1766) on wetlands (Ryckman et al. pers. comm.). Such behaviors are possibly anti-predator responses that reduce movement to avoid being detected by a perceived aerial threat (Martin et al. 2000*a*), but some controversy exists on this topic (Martin et al. 2000*b*). A lack of the eiders flushing from the nest and instead engaging in a "hold-tight" strategy suggests eiders are not engaging in behaviors that may increase exposure of the nest to predators. However, shifts in behavior that are anti-predator responses may indicate a need for physiological measurements to be taken to determine if heart rate or other stress responses are actually occurring and if these have any negative consequences to fitness. Research suggests that lack of behavioral responses does not mean a lack of physiological response (Ditmer et al. 2015; Ditmer et al. 2019), and research on wildlife physiological responses to drones should be an area of future work.

Based on the general lack of behavioral responses in this study, we suggest drone-based surveys of eiders may be a useful technique in the future. We used a fixed-wing drone, but depending on the objective of the monitoring and sensors needed, a rotary-wing drone may be more appropriate. We found that the fixed-wing drone with an electrical optical camera was an appropriate tool for collecting imagery of the entire Mast River eider colony (approximately 7.6 km^2) in a relatively short timeframe, requiring less than 6 h of drone flights (Ellis-Felege, unpublished data). Fixed-wing drones provide longer duration, compared to rotary-wing aircraft, especially in high winds. However, rotary wing platforms provide flexibility for different kinds of sensors and applications. This may include thermal, multi-spectral, or hyperspectral sensors to enhance detections of cryptic-colored birds from the surrounding landscape (Scholten et al. 2019; Bushaw et al. 2020; Helvey 2020; Helvey et al. 2020). One major consideration with the use of these sensors is the altitude at which they were flown. For example, thermal sensors often require flights lower than 40 m AGL, and often much lower, in order to detect and confirm nests (Bushaw et al. 2020). Therefore, lower altitude surveys employing thermal sensors to detect eider nests may require additional investigations on potential disturbance responses. In short, our study provides valuable insights on the use of a fixed-wing drone on eider nesting behavior, but future work is required to determine implications of other drone platforms and flight approaches for conducting assessments of Arctic nesting birds such as eiders.

Acknowledgments

Funding was generously provided by University of North Dakota College of Arts and Sciences, UND Biology, National Science Foundation (#13197000 awarded to SNE), North Dakota EPSCoR Infrastructure Improvement Program-Doctoral Dissertation Assistantship #OIA-1355466, Wapusk National Park, Arctic Goose Joint Venture, the Central and Mississippi Flyway Councils, North Dakota View Scholarship, Anne Via, and in-kind assistance and guidance from Parks Canada, Wapusk National Park Management Board, and the community of Churchill, Manitoba, Canada. We are especially grateful for flight coordination and cooperation from Hudson Bay Helicopters. We thank Will Beaton for assistance in the field, and Mike Corcoran for assistance with drone flights. Wapusk National Park provided us with mapping files for the construction of Fig. 1, while the Canadian provinces and territories layer was accessed via ESRI online. Data collection and field procedures were authorized by Canadian Wildlife Service Research and Collection Permit 16-MB-SC001, Wapusk National Park WAP-2005-18760 and WAP-2015-18846,

University of North Dakota's Institutional Care and Use Committee #A3917-01 (protocols 1505-2 and 1601-2), and a Special Flight Operations Certificate 15-16-00058946 (RDIMS: 11717338) from Transport Canada.

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