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ARTICLE

Comparing occupied and unoccupied aircraft surveys of wildlife populations: assessing the gray seal (*Halichoerus grypus*) breeding colony on Muskeget Island, USA

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Abstract: Unoccupied aircraft systems (UAS) are now frequently used in wildlife research, including studies of marine species. Researchers are turning to UAS platforms for population assessment purposes because they may provide flexible, safe, and low-cost data collection. In these cases, it is important that the accuracy and precision of UAS-based approaches are evaluated to ensure data quality and comparability with legacy data. The present study compares image quality and survey performance of two small UAS with that of an occupied aircraft as applied to a population survey and molt-stage assessment of gray seals (*Halichoerus grypus*) in the northeastern United States. Population surveys using fixed-wing UAS and occupied aircraft provided similar quality imagery with only minor deviations in counts of both adult seals (<1% difference) and pups (3.7% difference). The multicopter UAS proved especially useful for molt-stage assessment when compared to both fixed-wing UAS and occupied aircraft surveys. The results of this study clearly illustrate that small UAS are reliable tools for conducting population assessments of pinnipeds and establishing life history stages of animals. These new tools provide flexibility in operations and may reduce costs and human risk in some cases.

Key words: gray seals, platform comparison, abundance, fixed-wing, multirotor.

Résumé : Les systèmes aériens inoccupés (UAS) sont maintenant fréquemment utilisés dans la recherche sur la faune, y compris les études sur les espèces marines. Les chercheurs font appel aux plateformes UAS aux fins d'évaluation des populations, car ces plateformes peuvent fournir la collecte de données flexible, sécuritaire, et à prix abordable. Dans ces cas, il est important que l'exactitude et la précision des approches utilisant des UAS soient évaluées afin d'assurer la qualité des données et leur comparabilité avec les données existantes. Cette étude compare la qualité d'images et la performance en matière de levé à partir de deux petits UAS avec celles d'un aéronef piloté dans le processus d'un relevé de population et de l'évaluation d'étape de mue de phoques gris (*Halichoerus grypus*) au nord-est des États-Unis. Les relevés de population utilisant les UAS à voilure fixe ainsi que l'aéronef piloté ont fourni des images de qualité semblable avec seulement des écarts mineurs dans les dénombrements des phoques adultes (différence de <1 %) et des nouveau-nés (différence de 3,7 %). L'UAS multirotor s'est avéré particulièrement utile pour l'évaluation d'étape de mue en comparaison aux relevés à partir d'UAS à voilure fixe et d'aéronef

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piloté. Les résultats de cette étude illustrent clairement que les petits UAS sont des outils fiables pour effectuer des évaluations de population de pinnipèdes et établir les stades biologiques d'animaux. Ces nouveaux outils offrent la polyvalence en matière d'exploitation et peuvent réduire les coûts et le risque humain dans certains cas. [Traduit par la Rédaction]

Mots-clés : phoques gris, comparaison des plateformes, abondance, voilure fixe, multirotor.

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Introduction

The use of small unoccupied aircraft systems (UAS, a.k.a. drones) is increasing, and is revolutionizing how scientists collect information on individual animals, their populations, and the ecosystems they inhabit. UAS applications in marine research are broad, including coastal geomorphological assessments (Mancini et al. 2013), oil spill response (Jacobs et al. 2015), and investigations of the biology and ecology of large marine vertebrates, such as dugongs (Hodgson et al. 2013) and whales (Durban et al. 2015). Small UAS can be used to efficiently survey populations of marine wildlife that aggregate on shore to rest, socialize or breed. This includes a variety of seabird species (Goebel et al. 2015; Ratcliffe et al. 2015) as well as some gregarious pinniped species (Goebel et al. 2015; Moreland et al. 2015; Pomeroy et al. 2015; Seymour et al. 2017).

Traditional approaches to surveying coastal wildlife species with occupied aircraft can be costly (Vermeulen et al. 2013), and represent significant human risk (Sasse 2003). The use of UAS can, in some situations, overcome these constraints (Linchant et al. 2015). Furthermore, depending on the accessibility and size of the survey site, UAS can often be employed more opportunistically than occupied aircraft (e.g., during emergent good weather windows), greatly increasing the efficiency of data collection. However, to be used in management programs aiming to estimate the density or abundance of animals, their accuracy and precision must be evaluated with respect to traditional methods used in wildlife assessment programs.

Gray seals are a large phocid seal ranging from Labrador, Canada, to as far south as Virginia, United States (US) (Lesage and Hammill 2001). Gray seals were once depleted throughout the Northwest Atlantic in the 19th and 20th centuries by bounty hunting and harvests (Lelli et al. 2009), but are recovering across much of their initial range, fueled primarily through sustained growth at a large breeding colony on Sable Island, Nova Scotia, Canada (Bowen et al. 2003, 2007). Over the past three decades, gray seals have been re-colonizing the southern portion of their range. Pupping was first observed on several isolated islands in Maine and Massachusetts in the mid 1980s (Wood et al. 2011), and is now well established at several colonies. Muskeget Island, Massachusetts, is currently the largest gray seal pupping colony in the US (Waring et al. 2016). Regional aerial beach counts and other population metrics indicate rapid growth in the US gray seal population (Johnston et al. 2015), although little is known about its true abundance and conflicts with human activities appear to be growing (Roman et al. 2015). Efforts to estimate regional abundance through freely available Google Earth imagery assessments and wildlife telemetry have been conducted with some success (Moxley et al. 2017).

Gray seal population assessments often use mark-recapture methods or aerial surveys of pups at breeding sites (Bowen et al. 2003) to estimate total population size. In these cases, pup counts are incorporated into a population model that integrates demographic parameters to estimate total abundance. To obtain accurate estimates of total pup production from pup counts, multiple flights may be conducted in a season to identify the proportion of pups in different developmental stages. After being born, gray seal pups undergo a series of molt stages until they are weaned 2–3 weeks later (Kovacs and Lavigne 1986; Lesage and Hammill 2001). These molt stages can then be used to model the temporal distribution of

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births, to correct for pups that were not yet born at the time of the pupping survey (Stenson et al. 2003). While this approach has not yet been applied to the breeding population of gray seals in US waters, a time series of molt-stage data was collected in 2016 with an APH-22 multicopter to inform total pup production.

Gray seals in the northeastern United States (NEUS) present an excellent opportunity to evaluate the utility of UAS for population assessment purposes. Their breeding populations are largely restricted to small islands that can be efficiently surveyed using small fixed-wing UAS without disturbance (Hammill et al. 2017). Furthermore, because there is a time series of pup counts from aerial imagery for this population, there is an opportunity to determine how UAS methods compare to traditional occupied aircraft surveys to guide future assessments.

In this study, we evaluate the performance of a small fixed-wing UAS in surveying the density of gray seals during the breeding season at Muskeget Island, Massachusetts, as compared to traditional manned aircraft. In addition, we test the hypothesis that a multicopter UAS is superior to a fixed-wing UAS and to a manned aircraft for obtaining pup molt-stage information. These performance evaluations will help guide future projects aiming to assess gray seal populations in the NEUS, and provide useful information for others seeking to use small UAS to study pinniped populations at terrestrial breeding grounds.

Methods

Study location

Aerial surveys with two small UAS platforms and a Twin Otter occupied aircraft were conducted on Muskeget Island (41°20′7″N; 70°18′15″W), approximately 9.5 km to the west of Nantucket Island, Massachusetts (Fig. 1). Muskeget Island is approximately 1.6 km long by 0.8 km wide. Gray seals pup on Muskeget from mid-December to early February (Wood et al. 2011). All surveys were conducted on 15 January 2016, during the presumed peak of the pupping season. On the day of the survey, winds were 10–15 kn, ambient temperature reached 8.8 °C, and skies were clear or partially cloudy.

Platforms, sensors, and flight execution

Occupied aircraft and sensor

Two pilots and three observers on board a de Havilland Twin Otter surveyed the island. The Twin Otter was equipped with a belly-mounted camera system, using three Canon Mark III 5D cameras with Zeiss 85 mm prime lenses configured in a port-center-starboard configuration. Aperture priority was set to 5.6 and ISO set to 800.

The NOAA Twin Otter conducted the first survey at approximately 1300, flying five west to east passes at 229 m in altitude and 100 kn. Images were obtained at 2 s intervals and had roughly 60% horizontal overlap (between swaths) and 10% side overlap (between each image in the swath of three, with cameras set at a 21° angle). With cameras at this altitude, images had approximate on-ground sampling distance of 1 cm/pixel. The survey time over the island, including circling, was approximately 17 min.

Unoccupied aircraft systems

senseFly eBee fixed wing and sensor

The island was surveyed using a senseFly eBee UAS (http://www.sensefly.com), a commercially available fixed-wing system that is increasingly used in coastal marine science missions. These modular devices are light-weight foam airframes powered by a single brushless electric motor and a 11.1 V, 2200 mAh lithium polymer battery. They have a wing-span of 96 cm, weigh 0.7 kg, and are highly portable. The UAS followed a pre-programmed three-dimensional flight path guided by a precision GPS sensor, a high-resolution barometer,

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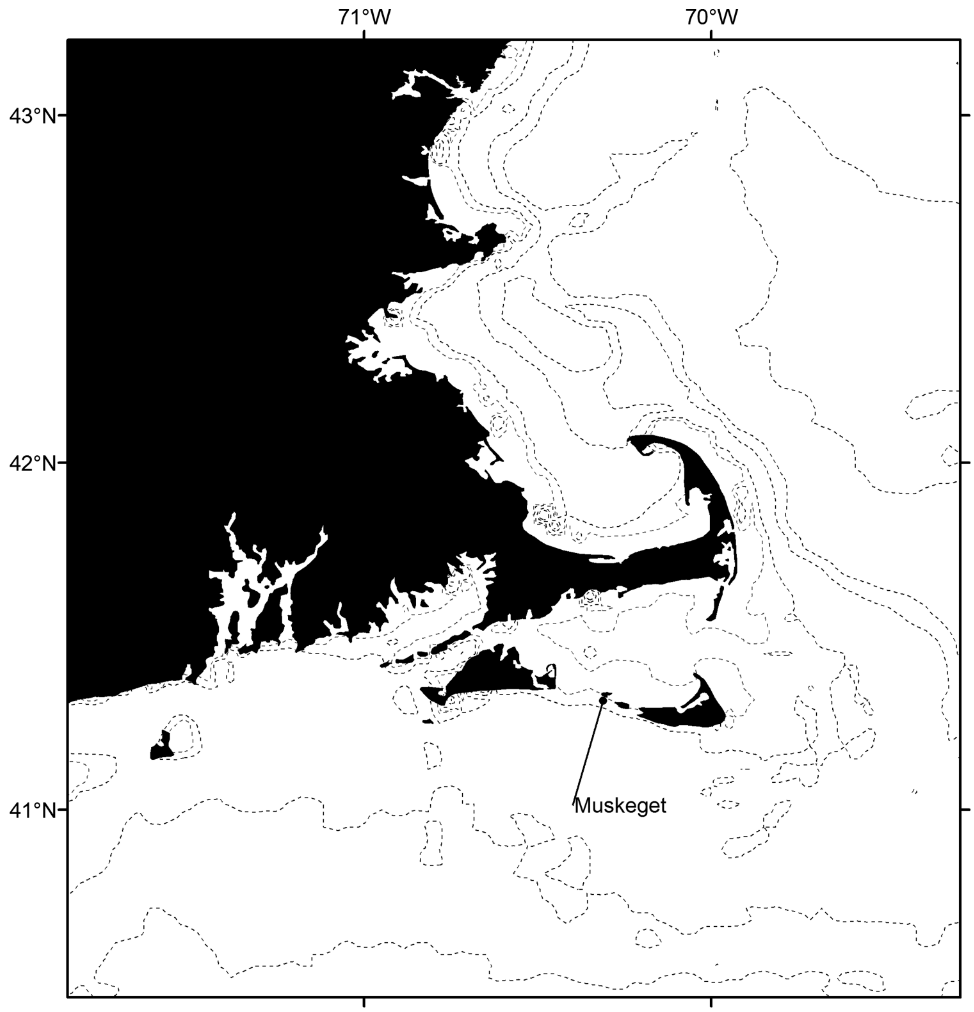
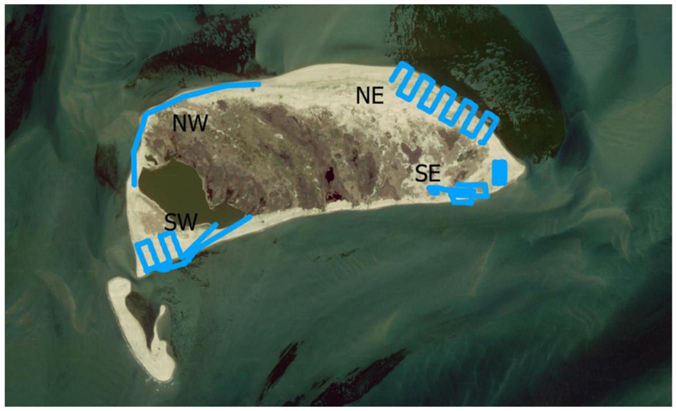
Fig. 1. Map of the northeastern United States coast illustrating the location of Muskeget Island.



ground-sensing camera, and wind-speed indicators. The instrument was launched by hand and recovered after a linear approach and landing within a selected 15 m radius region. Although the manufacturer suggests a 50 min flight time, flight times of 30–35 min were chosen given the low temperature (between 0 and 7 °C) and wind (<15 kn) conditions during the day, which can affect battery performance.

The eBee flew two surveys, one with each type of sensor package: a Canon s110 12MP red-green-blue (RGB) camera (set in shutter priority mode at 1/2000 of a second) and the senseFly Thermomap 1.2MP infrared camera. All mission planning was conducted in eMotion 2 (http://www.sensefly.com), an integrated mission planning, flight simulation, data management, and UAS control station software application. Flights were conducted along short parallel tracks to reduce bias with movement of animals in consecutive flight lines. Specifically, a series of five flights using the RGB sensor were conducted along parallel survey lines with 75% lateral and longitudinal overlap in photos. All RGB flights were conducted at 60 m altitude, resulting in an approximate on-ground sampling distance of 2.3 cm/pixel. Flights were between 23 and 32 min each for a total of 2 h and 24 min of flight

Fig. 2. Tracks of APH-22 flights performed for molt-stage image collection in Muskeget Island quadrants (NW, NE, SE, and SW).



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time. A series of three flights were conducted with the infrared sensor, along similar parallel lines and with a longitudinal overlap of 90% and lateral overlap of 75%. All thermal flights were also conducted at 60 m, resulting in an approximate on-ground sampling distance of 7 cm/pixel. The whole island was not imaged using the thermal camera, as UAS flights were truncated to clear the airspace for concurrent flights with the occupied aircraft. As such, we do not present detailed results of the thermal survey. Previous surveys in Canada indicated that grey seals are not disturbed by the overflight of the eBee UAS, and the sounds produced by the eBee at survey altitude are not detectable above ambient noise at seal colonies. While some studies have illustrated that pinnipeds can react behaviorally to the presence of UAS during both breeding and molting periods (Pomeroy et al. 2015), no reactions by gray seals to the fixed-wing UAS used in this study were noted.

APH-22

Sections of the island were also photographed using an APH-22 hexacopter, designed and constructed by Aerial Imaging Solutions of Old Lyme, Conn. The APH-22 is a small vertical take-off and landing UAS (2 kg, 81 cm wingspan), powered by a four-cell lithium polymer battery that drives six brushless electric motors. Depending on payload and environmental conditions, the aircraft can achieve flight durations of up to 25 min in cold environments. The aircraft's attitude, altitude, and heading are stabilized by an electronic control system that incorporates three gyros, three accelerometers, a magnetic compass, a barometric pressure sensor, a GPS receiver, and eight microprocessors. Unlike the eBee and Twin Otter, the APH-22 did not conduct a complete survey of the island. Instead, the island was subdivided into four quadrants with one grid or transect flown in each to collect imagery for identifying pup molt stages (Fig. 2).

The APH-22 was flown with an Olympus E-PM2 camera with 25 mm lens set to continually take still images at 2 s intervals. Mission planning was conducted using Mikrokopter's MikroKopter-Tool (v2 10c) software. Both grid and non-grid pre-programmed flights were conducted, as were manual control flights. The aircraft was launched and recovered by hand and also had a failsafe "return home" feature in case of loss of communications with the operator. It was flown by two trained personnel; one at the transmitter controls and one monitoring a ground station that displayed the live video feed as well as battery life and other instrument readouts.

Fig. 3. An orthomosaic of Muskeget Island derived from imagery obtained during fixed-wing UAS flights with the Canon s110 12MP RGB camera.

Several altitudes were explored, balancing objectives of high-quality imagery for inspection of individuals with optimal altitudes for greater area coverage. On 15 January, eight flights were conducted, with a total flight time of 123 min. Three of the flights were primarily flown at 100 m in altitude, one at approximately 75 m and the other between 25 and 45 m. At 100 m altitude, the camera configuration used resulted in an approximate on-ground sampling distance of 1.5 cm/pixel, 1.1 cm/pixel at 75 m, and 0.7 cm/pixel at 45 m.

Seal counts

Occupied aircraft

Images from the NOAA Twin Otter belly-mounted camera system were stitched together using Microsoft ICE (Image Composite Editor) v. 1.4.4 (64 bit). A total of eight composite images were produced that covered the island. Overlap between the composites was determined by visual inspection. These images were viewed and counted in Adobe Photoshop v. 2015.5. The count tool was used to mark and tally adults, pups, dead pups, and potential seals. The survey was counted by two independent observers.

Unoccupied aircraft systems

sensefly eBee

Images from the thermal and RGB eBee surveys were geotagged in the eMotion 2 program and then imported into separate projects within the Pix4D Mapper Pro analysis environment (http://www.pix4d.com). Geotagged images were calibrated, projected, and stitched together into a georeferenced orthomosaic of the island. Thermal images were stitched into a georeferenced orthomosaic scaled in degrees Celsius. Each orthomosaic was assessed for artifacts (e.g., blurring from moving animals) and corrected with overlapping images that did not contain the artifacts. An example orthomosaic of Muskeget Island derived from eBee imagery is presented in Fig. 3.

The RGB orthomosaic was gridded into 20 non-overlapping images and these sectioned images were imported into the iTag analysis application. Each section image was loaded and individual adults, pups, and perceived dead pups were counted. Tallies for each section image were automatically generated in iTag, as was a final grand total of counted seals for all 20 section images.

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APH-22

Images from each APH-22 flight were processed by first using an R script to combine each image number with its log file information from the aircraft. The resulting geodata file, with position and orientation of each photo, was used to combine images into a georeferenced orthomosaic using a beta version of ESRI's Drone2Map. Both these orthomosaic.tiff files and individual images were used for molt-stage analysis but were not used for the seal census, since complete coverage was not the objective.

Molt stage comparison

To evaluate the performance of each platform in identifying molt stage characteristics, a point was picked in a relatively dense section of each island quadrant and 100 pups staged within the imagery from each platform at that location. Molt stage was assessed by a single analyst. The gray seal molt progression has typically been characterized by five well-documented stages (Kovacs and Lavigne 1986; Bowen et al. 2003). Given the variability of the image quality from the three platforms, four additional transitional stages were used when the analyst could not confidently place a pup into one of the five established stages. There were a total of nine stages utilized used in this analysis: I; I/II; II; II/III; III; III/IV; IV; IV/V; and V. The higher the percentage of pups staged with certainty indicated which images were most useful in obtaining pup molt stage information and therefore the preferred platform.

Results

Raw imagery comparisons

A qualitative assessment of image quality from all three platforms is presented in Figs. 4–8, in an effort to provide examples of expected image quality across platforms used in the present study. Specifically, regional images containing adults and pups were enlarged and assessed for clarity in these terrain types: interior frozen grass and sand (Fig. 4), low-lying shrubs (Fig. 5), beach debris (Fig. 6), and coastal unfrozen grass and sand (Fig. 7). In general, the APH-22 presented the best image quality, providing detailed views of seals with enough clarity to confidently resolve molt stage in pups. Adults and pups are also easily discernable in both Twin Otter and eBee imagery, with slight variations in clarity between platforms. Molt stage is also discernable in much of the Twin Otter and eBee imagery. Figure 8 is a thermal camera frame of the same beach debris area and clearly indicates how well gray seals are detected with this sensor. Thermal imagery may be especially useful for gray seal population assessments, as explored more fully by Seymour et al. (2017).

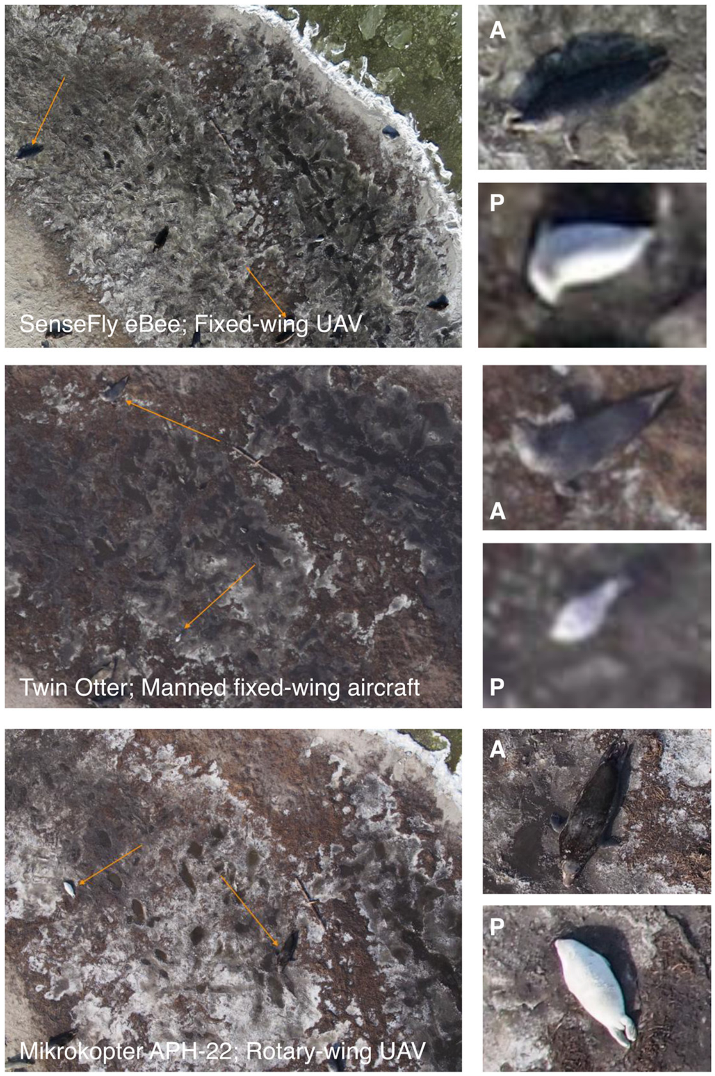
Seal counts

In general, variation in seal counts from the Twin Otter and eBee platforms was small, with the greatest difference in dead pup count (45.4%) (Table 1). Variation between analysts within a platform was greater than variation across platforms. Specifically, between-analyst variation in adult counts was greater in magnitude with the Twin Otter compared to the eBee platform (8.1% versus 0.2%), while between-analyst variation in pup counts was greater with the eBee compared to the Twin Otter platform (5.2% versus 0.9%).

Molt stage comparisons

The APH-22 UAS was the preferred platform for capturing molt stage information, with 87% of pups being staged with certainty (Table 2).

Fig. 4. Single images and enlarged sections of adult (A) and pup (P) gray seals at Muskeget Island in coastal frozen grass and sand habitat (41°19.987′N; 70°18.253′W). Orange arrows indicate location of animals in enlarged images.



Discussion

The results of the present study provide a comparative look at how surveys of seals from manned aircraft compare with those conducted using UAS. Colony counts for both Twin Otter and eBee platforms were quite similar, with greatest variation in counts of dead seals. The detection of dead pups is challenging from the air, and observer experience and lighting conditions may be important factors for explaining these differences. Future studies should ground-truth the number of dead pups compared to those obtained from aerial imagery in sample plots to evaluate how well pup mortality rates are measured via aerial imagery. Interestingly, variation in counts by different observers was greater than variation in counts across platforms. Some of the variation across platforms is likely due to the staggered timing of flights with each platform, where the availability or detectability of adults or pups may change with time. This may be especially true for the coastal margins of the

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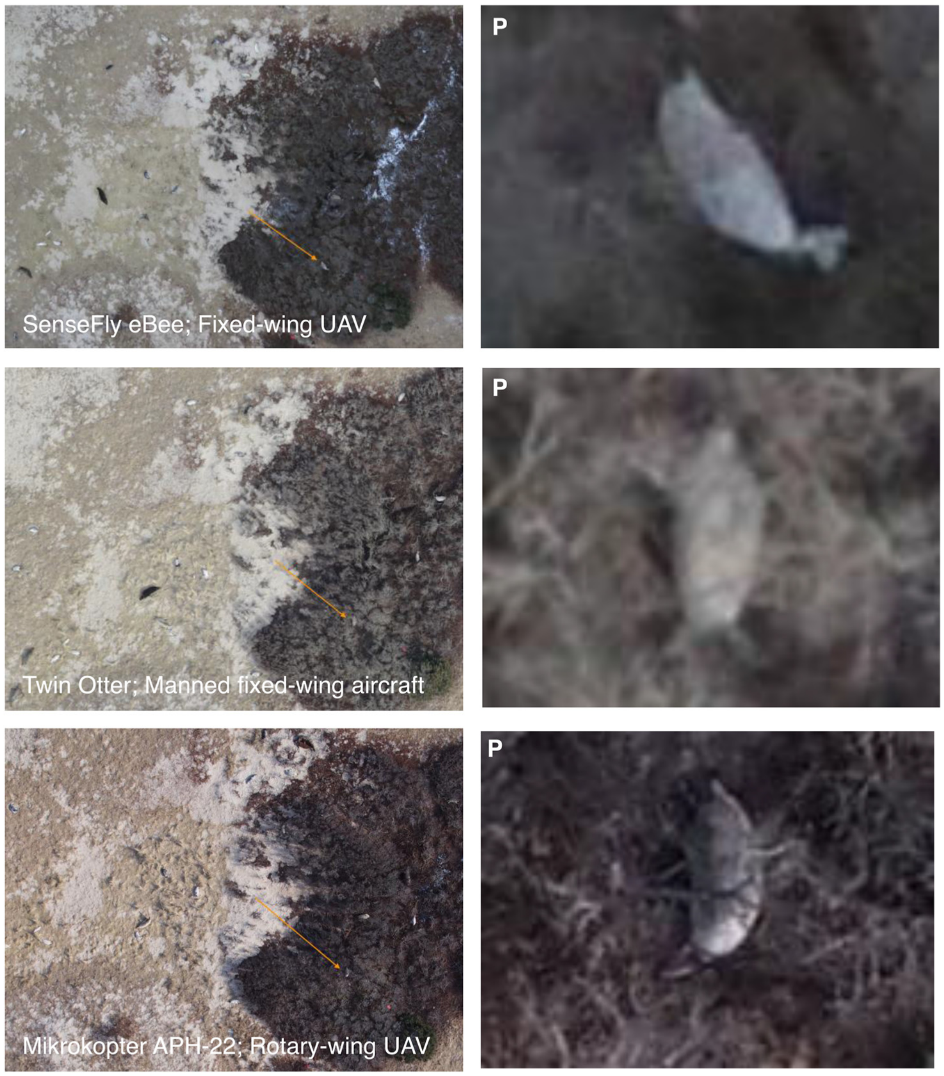
Fig. 5. Single images and enlarged sections of gray seal pups (P) at Muskeget Island in low shrubs (41°20.269′N; 70°18.221′W). Orange arrows indicate location of animals in enlarged images.



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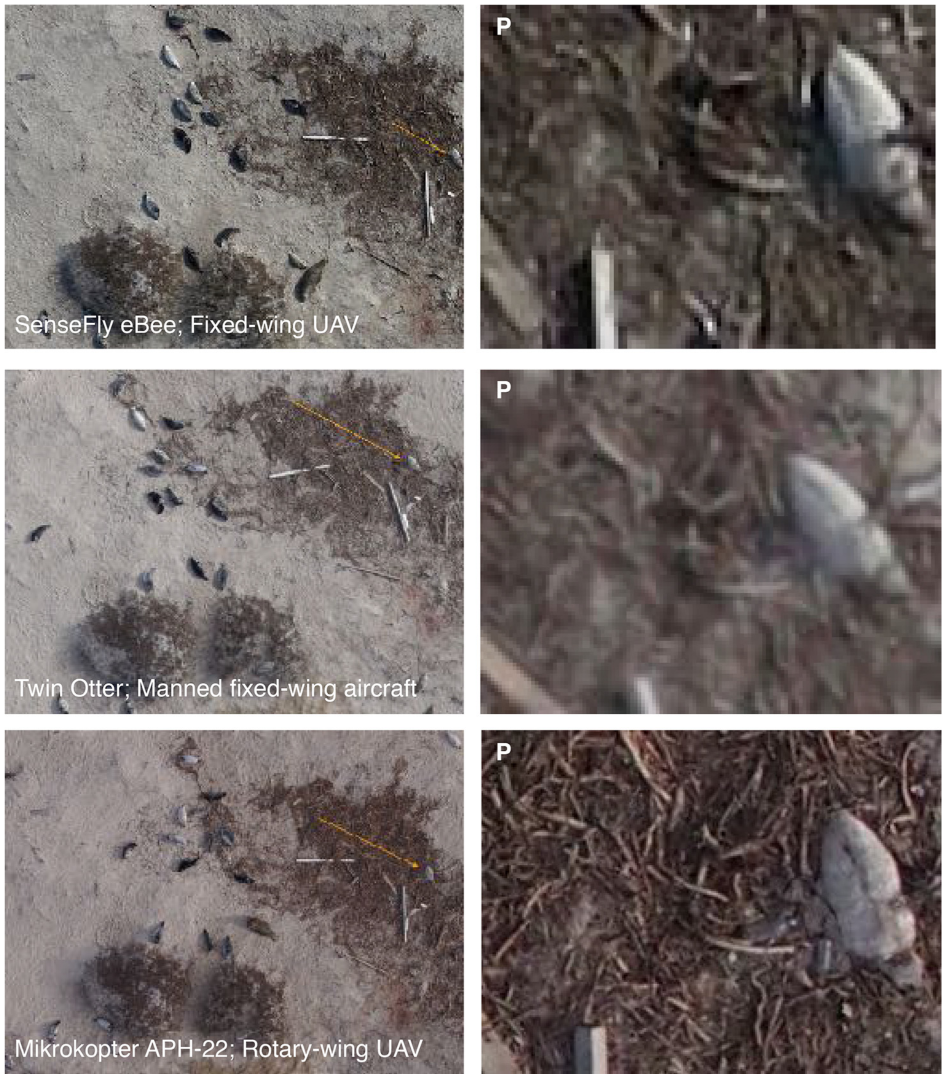
island, where adult seals may periodically enter the water for short periods of time, unlike the pups. Variation across observers may also be due to different interpretations of life stage, as large pups may be mistaken for small female adults, or vice versa.

The APH-22 UAS proved to be a better platform for quantifying molt stage of individual pups compared to the eBee UAS and the Twin Otter. This is mainly due to the APHs ability to hover over animals and to fly at lower altitudes with the objective of photographing individual characteristics. Molt-stage data could still be collected by fixed-wing UAS or manned aircraft, albeit with slightly more uncertainty. UAS may be preferable to manned aircraft for obtaining molt stage because the former are more flexible in the timing and location of flights. This operational flexibility is extremely valuable for developing accurate pup production curves at emerging seal colonies. Repeated flights over the pupping season can reveal the pace of pup production, essential for the development of an overall population

Fig. 6. Single images and enlarged sections of gray seal pups (P) at Muskeget Island in beach debris habitat (41°20.058′N; 70°17.518′W). Orange arrows indicate location of animals in enlarged images.



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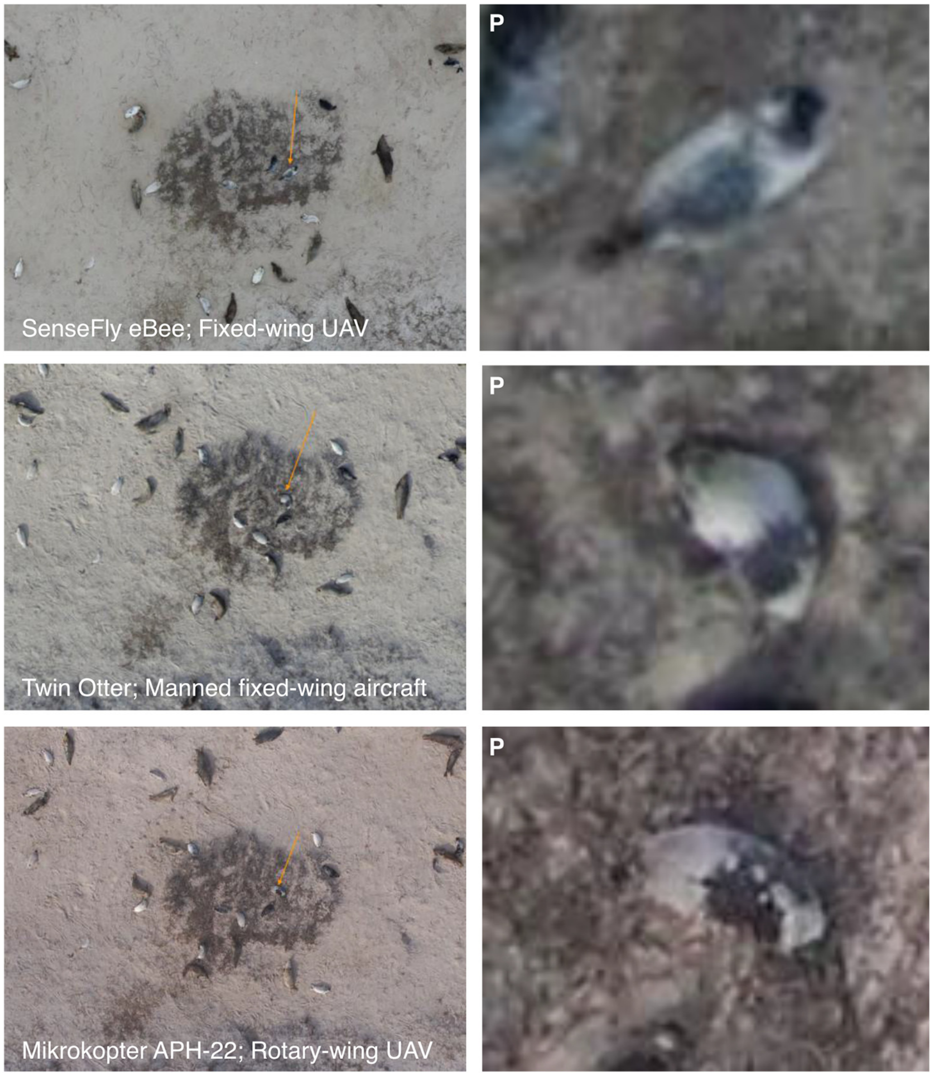
model. Thermal imaging holds great promise for enumerating populations of gray seals (e.g., Seymour et al. 2017), and may also be useful to refine estimates of dead pups by comparing accurate locations of known dead animals within RGB and thermal imagery. Unfortunately, accurate locations of known dead animals were not recorded by ground crews precluding further analysis.

The results of the present comparison provide insight into the use of small UAS for assessment of some gray seal colonies in the NEUS. Image quality and seal counts between the occupied aircraft and fixed-wing UAS were similar, indicating that no compromises in data quality are made when using the more flexible UAS. While all platforms assessed could be used to assess molt stage in seals, the multicopter platform was clearly best-suited to this science requirement. The results of the present comparison mirror those found in other comparisons between manned and unoccupied surveys for pinnipeds. For example,

Fig. 7. Single images and enlarged sections of adult (A) and pup (P) gray seals at Muskeget Island in coastal unfrozen grass and sand habitat (41°19.987′N; 70°18.253′W). Orange arrows indicate location of animals in enlarged images.



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Hammill et al. (2017) found that UAS-based imaging of gray seal breeding colonies provided accurate counts and assessments of pup stages. In that study, the UAS survey provided better data than oblique imagery from occupied helicopters, and produced results that were on par with manned aircraft surveys using large-format cameras (Hammill et al. 2017).

Our results indicate that no single platform is optimal for assessing seal colonies and life history stages of animals in those colonies. Occupied aircraft are fast, have high endurance, and are especially useful for assessing multiple colonies across a broad coastline, or where landing sites or other access needs for UAS are unavailable. In comparison, the UAS provide a cost-effective way to survey the small colonies in the NEUS. UAS systems are easy to transport, can survey areas similar to those attained by occupied aircraft in a relatively short time, and do not present any compromises in image quality. Small UAS also provide for

Fig. 8. A sample thermal image from the senseFly eBee survey of Muskeget Island.

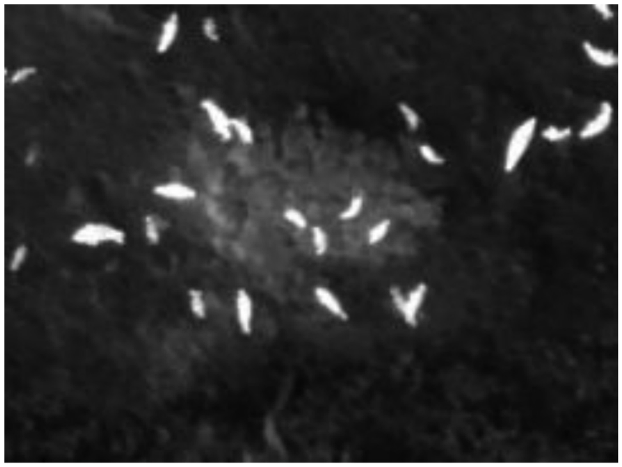

Table 1. Total counts of gray seals (adults, pups, and dead pups) for both occupied and unoccupied aircraft surveys at Muskeget Island, Massachusetts.

Platform	Source	Adults	Pups	Dead	Total
Twin Otter	Analyst 1	2342	3788	47	6117
	Analyst 2	2160	3821	67	6048
	Variation (%)	8.1	0.9	35.1	2.1
eBee UAS	Analyst 1	2235	3570	102	5907
	Analyst 2	2239	3762	79	6080
	Variation (%)	0.2	5.2	25.4	2.9
Comparison	Variation (%)	0.6	3.7	45.4	2

Table 2. Staging results for gray seals pups from occupied and unoccupied aircraft surveys at Muskeget Island.

		Pups staged with certainty	
Platform	Pups	Number	Percentage (%)
Twin Otter	82	63	77
eBee UAS	101	70	69
APH-22 UAS	112	97	87

essentially on-demand remote sensing, useful for coastal emergency response missions, such as marine animal strandings or oil spills. The fixed-wing eBee system was well-suited to larger (i.e., colony scale) mapping and the APH-22 multirotor UAS was useful for focused photography of individual animals.

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