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Comparison of methods to estimate grey seal pup production at different colonies

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Aerial surveys were flown in January and February 2016 to estimate grey seal pup abundance on Sable Island, along coastal Nova Scotia and in the Gulf of St Lawrence (GSL). Owing to a combination of circumstances (absence of ice in the GSL) and opportunities, different platforms were used to obtain counts of pups on different island colonies. The methods included the use of visual counts, oblique photography from low altitude helicopter flights, photographs using an unmanned aerial vehicle (UAV) and a large format aerial photographic camera. Images from the large format camera were the easiest to count, but this option was the most expensive and presented logistic challenges in coordinating positioning of the aircraft within the four week optimum time for photography of the colonies in the different regions. Images from the UAV were easy to count; the UAV was easy to deploy and did not disturb animals, but flights were limited in some cases by high wind speeds. Images from oblique photographs were suitable for counting, but also provided challenges in ensuring coverage of a colony, particularly if the colony was flat and without obvious landmarks. If only a few pups were present, visual counts were suitable, but at large colonies visual counts underestimated abundance.

Comparaison des méthodes pour évaluer la production de jeunes phoques gris dans différentes colonies

RÉSUMÉ

Des relevés aériens ont été effectués en janvier et février 2016 afin d'estimer l'abondance de phoques gris nouveau-nés sur l'île de Sable, le long de la côte de la Nouvelle-Écosse et dans le golfe du Saint-Laurent (GSL). En raison d'une combinaison de circonstances (absence de glace dans le GSL) et d'occasions, différentes plateformes ont été utilisées pour dénombrer les nouveau-nés des différentes colonies de l'île. Parmi les méthodes utilisées, notons le dénombrement visuel, la prise de vue oblique à partir d'hélicoptères à basse altitude et la photographie à l'aide d'un véhicule aérien sans pilote et d'une caméra grand format pour prise de vue aérienne. Il était plus facile de faire un dénombrement à l'aide des images obtenues avec cette caméra grand format, mais cette option était la plus coûteuse et présentait des difficultés logistiques lorsque venait le temps de coordonner la position de l'aéronef durant la période optimale de quatre semaines pour prendre des photos des colonies dans les différentes régions. Les phoques sur les images prises à l'aide du véhicule aérien sans pilote étaient faciles à compter; le véhicule était facile à déployer et ne perturbait pas les animaux, mais dans certains cas, les vols étaient limités en raison des grands vents. Les images obtenues par prise de vue oblique permettaient un bon dénombrement, mais présentaient également quelques défis. Il était difficile d'assurer une bonne couverture d'une colonie, particulièrement si la colonie s'étendait sur une surface plate, sans point de repère évident. Si seulement quelques nouveau-nés étaient présents, un dénombrement visuel était adéquat, mais dans les grandes colonies, cette méthode sous-estimait l'abondance.

INTRODUCTION

An understanding of population abundance and trend is critical for management and conservation. To obtain this information long term monitoring programs need to be established and maintained. Efforts to census pinnipeds have focussed on counting numbers of animals that are hauled out, usually visually or photographically, and applying a correction factor to this count or estimate to obtain an estimate of total population size. Researchers have continually tried to improve these methods, particularly as new technologies have been developed such as improvements in navigations systems, development of large format cameras with motion compensation, digital cameras combined with telemetry or demographic information to obtain an estimate of abundance (e.g. Bowen et al. 1987, Stenson et al. 2003, Gilbert et al. 2005, Hammill et al. 2007, Lonergan et al. 2011). However, whenever new methods are being considered, it is important to determine how the estimates compare to previous methods.

Aerial surveys are expensive and since they are often undertaken in remote areas, are associated with high levels of risk. This has led to exploring alternative methods to obtain information on abundance including remotely sensed imagery from satellites, or analyses of publicly available imagery that was obtained for other purposes but which contain information on marine mammals, for example Google Earth (Moxley, J., Bolgomolni, A., DiGiovanni, R., Hammill, M., Josephson, E., Moore, |K., Moore, M., Polito, M., Sette, L., Sharp, B., Waring, G., Gilbert, J., Halpin, P., Johnston, D. unpublished data). Recent developments in Unmanned Aerial Vehicles (UAV) have led to some investigations into their potential use for aerial surveys of marine mammals (e.g. Hodgson et al. 2013, Koski et al. 2015). In some situations, UAVs have the potential to reduce marine mammal survey costs and possibly provide an improved method for monitoring marine mammal populations (Hodgson et al. 2013), particularly if flights can be pre-programmed and a variety of different imaging systems used. In 2015, we explored the feasibility of using a small UAV to estimate grey seal abundance during the breeding season in the southern Gulf of St Lawrence (GSL). These tests were successful and in 2016, when a larger scale grey seal assessment was planned, we decided to include a UAV as an additional platform in order to evaluate its performance compared to the more standard techniques used to assess grey seals in the area.

The grey seal (*Halichoerus grypus*) is distributed throughout the North Atlantic extending from the northeastern United States to Labrador in the west, and from the United Kingdom to the Murmansk region in Russia and south throughout the Baltic Sea and along the coast of France in the east, with reports of recent sightings from Greenland (Härkönen et al. 2007, Rosing-Asvid 2010). Grey seals were abundant throughout their range historically, but underwent significant declines in some areas as early as the 2^{nd} Century. Since the middle of the 20^{th} Century, most populations have shown remarkable recovery (Härkönen et al. 2007, Lavigueur and Hammill 1993, Bowen et al. 2007, Hammill et al. 2007, Thomas et al. 2007). Numbers also appear to be increasing in American waters, a result of seasonal migration of animals from Canada, as well as increases in local pup production.

The northwest Atlantic grey seal is considered to form a single population (Boskovic et al. 1996), although within Canadian waters it is subdivided into three components for management considerations: Sable Island, GSL, and Coast of Nova Scotia (Fig. 1). Sable Island, Nova Scotia, located approximately 300 km east of Halifax (44.8 N, 60.8 W), is home to the largest breeding colony of grey seals in the world (Bowen et al. 2007).

A relatively small number of animals breed on isolated islands along the Nova Scotia Eastern shore (Mansfield and Beck 1977); significant culling efforts, particularly in the Basque Island area limited pup production in this area to the low 100's. The Basque Islands no longer exist due to erosion, but pupping continues on Bowen's Ledge and White Islands. A new colony was discovered on Hay Island in 1993 by J. Conway (pers. comm. DFO, Halifax) (Fig. 1) and in recent years, four small colonies have also appeared along the southwestern shore of Nova Scotia near Seal Island. Taken together, these colonies along the Eastern and southwestern shores of Nova Scotia have been grouped for now and are referred to as Coastal Nova Scotia (CNS) (Hammill et al. 2007).

In the GSL, grey seals have traditionally had their young on the pack-ice located between Prince Edward Island and Nova Scotia (from Northumberland Strait to Cape Breton), on beaches and/or small islands in the Northumberland Strait and western Nova Scotia, and/or on Deadman Island in the central GSL. In recent years, ice cover has been quite variable, and many animals have responded by moving onto islands for pupping which has led to the formation of relatively new colonies (e.g. Anticosti , Brion, Saddle, Pictou Islands)(Fig. 1).

While Sable Island has been surveyed photographically since 1989, the increased use of land in the GSL and more colonies along eastern Nova Scotia has necessitated a change in assessment methods. Early GSL assessments relied on visual strip transect surveys to estimate the number of seals on the ice. These estimates were corrected for pups born after the surveys had been completed to obtain an estimate of total on-ice pup production. The small numbers of animals born on the small islands were added in to this total. In January 2016, there was very little ice in the southern GSL. A few pups were observed on the ice, but the majority were observed on several islands and several different techniques were used to estimate abundance in these areas. We also had an opportunity to estimate pup abundance at three sites using a small UAV. The objective of this study is to compare estimates obtained using this platform to those obtained using other previously used methods from larger manned platforms.

MATERIALS AND METHODS

Four methods were employed to obtain estimates of abundance: photographs from a fixed wing UAV, visual counts and oblique photographs from a helicopter, and photographs using a large format camera mounted in a purpose modified aircraft (Fig 2-4). Not all methods were applied at all sites. All photographs were read twice, by a single reader and the average was taken.

VISUAL SURVEYS

Visual surveys were flown in a Bell 429 twin engine helicopter. The aircraft flew at an altitude of 60 m (200 feet) AGL (Above Ground Level) and about 30 m (100 feet) away from the colony. Two observers were seated on the left side of the aircraft, one in the front, the second in the back. Pups were counted by each observer as the aircraft slowly circled the colony at a speed of approximately 20 knots. After the survey had been completed, an average of the two counts was recorded.

OBLIQUE PHOTOGRAPHIC SURVEYS

Similar to the visual surveys, the helicopter circled a colony and animals on the beach were photographed using a Nikon camera [36.3 megapixels digital SLR Nikon D800 with a 35 mm lens (Zeiss, Distagon T* 2/35) (resolution 5 cm), and/or a Canon camera [16.0 megapixels digital Canon PowerShot SX160 IS](resolution 13 cm @ 50 mm zoom). The imagery on the Nikon was clearer, so if imagery was available from both cameras, the Nikon imagery was counted.

VERTICAL PHOTOGRAPHIC SURVEYS

The digital photographic (RGB 16 bit digital files) censuses of Hay, and Pictou islands were completed from an altitude of approximately 420 m, using a Microsoft Vexcel UCX camera in Motion compensation camera housing. The camera was integrated with in-flight GPS. Complete coverage of the islands was achieved by flying a series of parallel transects with 60% forward and 20% lateral overlap among adjacent photographs. Each island was photographed during one sortie to minimize double counting of pups due to movement among transects. A digital surface model (DSM) of all islands was used in the orthorectification process using INPHO OrthoMaster, OrthoVista and Seam Editor. The DSMs of all islands was down sampled to 5 m, except Hay Island which was at 6 cm to demonstrate the potential value of DSM. The 3 cm resolution of the photographs was maintained in the mosaic. During the seam editing it was decided that should a seal be seen crossing a seam line the seam would be moved to include the entire animal. A total of 235 seals were edited into the orthophotos across all islands. All orthophotos were projected in UTM Zone 20. Pups were counted from mosaic tiles in ESRI ArcView 10.2.2. The locations of live pups were marked in a single ArcGIS layer to avoid double counting.

UAV SURVEYS

Saddle, Hay and Pictou Islands were also surveyed using a small UAV (Sensefly eBee). The UAV is a fixed wing type, with wingspan of 96 cm. With payload it weighs approximately 0.7 kg (Fig. 2a). It is powered by an electric motor, with flight duration of approximately 40 minutes under ideal conditions. The radio modem has up to 3 km range (but limited by Line of Sight restrictions). We tested two platforms, a Canon S110 RGB (3 cm ground resolution) and a Sensefly Thermomap (ground resolution 8 cm) thermal camera. Only the visual imagery is included here.The UAV was programmed to fly between 75 and 100 m AGL (Above Ground Level). On Saddle and Hay Islands, the UAV criss-crossed the islands with overlapping transects to allow stitching together of an island map (Fig. 2a). Individual photos overlapped ~75% on both axis. Pictou Island was too large to cover completely, and the seals were limited primarily to the beach, so surveys over this area were largely around the coastal area, beginning at the western end of the island and continuing to about ¾ of the way towards the east.

For each island, one seamless mosaic image was produced from the ortho-rectified photographs. The UAV imagery was stitched together using Pix4Dmapper to create mosaics, terrain models and reflectance maps/temperature indices. Pups were counted in ESRI ArcView 9.3. The locations of live pups were marked in a single ArcGIS layer to avoid double counting.

TEMPORAL DISTRIBUTION OF BIRTHS

Pupping in grey seals is spread over an extended period. Therefore, in order to compare estimates of pup numbers made on different dates, it is necessary to correct the survey estimates for the timing of births. The temporal distribution of births is estimated from the duration of developmental stages of pups and the temporal shift in the proportion of each developmental stage (Bowen et al. 2007). Grey seal pups are classified into five developmental stages based on pelage colour and body shape (Bowen et al. 2003). Here, we use the five stages defined by Bowen et al. (2003) and used in previous pup production estimates (Bowen et al. 2007). The first date of pupping used expert opinion based on the age of the oldest pup observed during the first staging event.

Stage 1- animals very thin, movements uncoordinated, and the fur has a yellowish hue from the placental fluids (Mean duration in days: 3.0, SE=0.59);

Stage 2- animals are thin, although they are beginning to show signs of fattening, a distinct neck is still visible, movements are more coordinated and the pelage no longer has a yellowish hue (Mean=3.1, SE=0.62)

Stage 3- the fur is white in colour and the animals have become so fat that a distinct neck is no longer discernable; no sign of moult (Mean=11.9, SE=2.4).

Stage 4-The fur has become discoloured, assuming a grey tinge, and lanugo is lost, beginning around the head and flippers. When the amount of fur loss exceeds approximately the equivalent of 1 hand on the back, or has progressed beyond the head, the animal is considered a stage 4. (Mean duration=5.3, SE=1.07)

Stage 5 The final stage, all lanugo has been lost. Animals begin leaving the colony during this stage.

The proportion of pups in each moult stage was assessed by repeated staging surveys. On Sable, the stage surveys were conducted weekly by experienced observers in 13 locations throughout the colony. On the smaller breeding colonies experienced observers walked through the colony from one end to the other, or flew over the colony at low altitude and assigned pups to stages. The change in the proportion of pups in each of the age dependent categories was determined. Estimates of the number of pups in each concentration can then be corrected for pups born after the survey was flown by:

$$N_i = N_{unco}/P_i \quad (1)$$

where:

N_{uncor} = the uncorrected estimate for survey *i*;

P_i = the proportion estimated to have been born prior to survey ***i***.

The estimates of N_{uncor} and P_i are independent and therefore the error variance of the quotient is given by (Mood et al. 1974):

$$V_i = N_{uncor}^2 x\, V_p/P_i^4 + V_n/P_i^2 \quad (2)$$

where:

V_p = the variance in the proportion estimated to have been present prior to survey *i*;

V_n = the variance in the uncorrected estimate for survey ***I***.

RESULTS

The large format photographs were taken at relatively high altitude. The imagery was clear, and animals could be identified to stage with relative ease. The authors were not present when the large format camera aircraft flew over Pictou and Hay Islands, but they were onsite during the survey of Sable Island. There was no response from the animals (grey seals and horses) to the aircraft, during the very brief period it was over any single animal. The visual and oblique photographs were taken at lower altitudes from a helicopter, which moved slowly around the pupping colony. Males located on the beach rapidly entered the water, but were seen to return after the aircraft had passed and moved further along the shore. Females had varied reactions, ranging from looking up at the aircraft to entering the water if it was close. Those females that left returned to the shore and their pup after the aircraft had moved further down the beach. Pups responded to the aircraft by moving, at most, 1-2 m away from their original position. For visual surveys, this disturbance was a useful cue to detect pups that were resting near a piece of ice or snow, or near rocks or trees and blended in with their surroundings. The Nikon camera had higher resolution than the Canon, and imagery was easier to analyse (Fig. 4). Pups could be identified to stage with ease. A major challenge with the oblique imagery was that overlap was not complete in all cases. Where there was overlap, time was lost in image interpretation trying to identify reference points to minimize double counting. Where imagery did not overlap, animals may have been missed.

The UAV criss-crossed each site repeatedly (Fig. 2). No flight response was noted for adults or pups. Occasionally, females would look up. In the Saddle and Pictou Island area, there are 100+ Bald Eagles present during the pupping season. It is not clear if the females were responding to the passing overhead of the UAV or the eagles. The eagles did not appear to respond to the presence of the UAV. Imagery from the UAV cameras was georeferenced and easy to interpret, with pups counted and classified to stage.

The survey using the large format camera was flown prior to the surveys using the other platforms. As a result, a higher adjustment for new births was applied to the large format counts than to the estimates from other platforms. Counts from the large format camera and the UAV were similar and estimates from both platforms were generally higher than counts from the oblique camera and the visual counts (Table 1).

It was estimated that more than 85% of the pups were born for most of the survey except for the survey of Pictou Island on the 15 January, where the estimated proportion of pups born was 41% (Table 3). There was no significant difference in the counts adjusted for the proportion of birth during the survey between UAV and large format photographs on Hay Island, but both methods provided adjusted estimates that were higher than the estimate provided by oblique photographs. On Saddle Island, the adjusted count was significantly higher from UAV photographs than the visual estimate. UAV provided adjusted estimates that were not significantly different than the adjusted estimates provided by large format and oblique photographs on Pictou Island. Both oblique adjusted estimates were similar on Henry Island and significantly higher than the visual estimate.

DISCUSSION

The methods used to evaluate the pup production of GSL grey seals has evolved over time since assessments began in the early 1980s. Early studies used mark-recapture methods based on live recaptures at Sable Island of marked animals in the year of their birth, or by the resighting or recovery of marked animals from shot samples in the same or subsequent years to marking (Myers et al. 1997, Hammill et al. 1998). Aerial surveys were initiated in 1996 using techniques similar to those used to assess harp seals (Stenson et al. 2003), where extensive reconnaissance is carried out to detect all concentrations, systematic surveys are flown to estimate the number of animals present on the ice, and a parallel set of surveys are completed to work out the proportion of pupping that has occurred since the counting survey was flown (Hammill et al. 2007).

Historically, less than 1% of the pups in the GLS were born on land, with the remainder born on the ice in Northumberland Strait between Prince Edward Island and Nova Scotia (Fig. 1). However, since the early 1990s, ice cover has become more variable (Bajzak et al 2011, Johnston et al. 2005), making it more difficult to find suitable ice in the Northumberland Strait area (Fig. 1, 5). Since the 1990s, the proportion of births occurring on the islands has been quite variable, but there has been a trend towards increased use of terrestrial areas for pupping.

The gold standard to obtain information on the number of animals at the pupping colonies is to use a large format camera. The imagery obtained is georeferenced, the quality is normally very high, and the imagery is easy to interpret. Unfortunately, the large format camera is also the most costly, involving expensive repositioning of the aircraft from its home base and maintaining it on standby until suitable weather conditions are available. An additional challenge is that the grey seal pupping season begins in December in parts of its range (southwest Nova Scotia) and ends in February (GSL). To minimize the adjustment factor for pups born after the survey has been completed and hence to increase precision, surveys should be timed differently for each region, necessitating an extended survey window. To minimize costs, the most effective strategy would be to survey as many as the colonies as possible in a short time. However, if surveys are flown early in the season the correction factor is large while if they are flown later, it will be necessary to estimate departure rates. On Sable Island, pups go to sea for first time 9 to more than 21 days after weaning (Noren et al. 2008), but it is not known if Sable is representative of other colonies.

The UAV surveys produced high-resolution imagery that was easy to interpret, but larger number of images was needed to be gathered compared to the large format camera. This meant that the UAV had to repeatedly crisscross the colony to obtain the necessary data. Grey seals showed no response to the presence of the UAV, even when the device landed amongst them, with most of the disturbance resulting from our movements among animals to retrieve the device in the more crowded colonies (e.g. Hay Island). In other colonies, where there was considerable space not used by animals, this disturbance was avoided. Overall, the UAV spent more time flying onsite to obtain the data compared to the large format camera aircraft, but flying times were less if shuttle time to get onsite and offsite are included. Also, with the helicopter and UAV, it was relatively easy to travel to the survey site and set up and undertake survey flights, rather than the more complicated logistics of calling in the large format survey camera based several hundred kilometres away.

Four challenges faced using this particular UAV were temperature, the need to fly only line of sight, limited endurance and wind velocities. During our flights, we encountered temperatures around -10 to -15°C, which required heat pads to keep the ground control station computer warm. The limitation on line of site flight is a regulatory issue. For this particular UAV, flying endurance was approximately 25 minutes. Moreover, the UAV could not fly in wind speeds greater than 25 knots that are often exceeded during the winter in the GSL. The need to keep the UAV in sight had little impact on the smaller Hay Island and Saddle Island colonies, but was problematic for Pictou Island with its tree cover and much larger area. At Pictou Island, the large format camera was able to photograph the entire island, whereas the flight path of the UAV was limited to the coastal portion of the island, with some seals not being surveyed inland from the coast among the trees and at the westernmost end of the colony. Therefore, the UAV estimate is thought to be slightly negatively biased compared to the large format. However, this recognised negative bias could be corrected in future survey by increasing the inland coverage of the island

The lowest estimates were obtained using visual counts and oblique photographs. Visual methods should not be used to estimate abundance at colonies that have more than a few 10's of animals, unless it is possible to land and walk among them. The oblique photograph method adjusted for births provided no significant difference in estimates of abundance compared to the UAV method at Pictou Island. However, oblique images collected on the same day as UAV images provided a lower count and a significantly lower estimate at Hay Island. This likely resulted from the topography of the two locations and the need to produce a complex mosaic of images that is used to record counts in ArcGIS. The production of this complex mosaic is simpler for the UAV method which provides a precise position of the platform and is closer to the real position on the ground of the vertical images. Furthermore, the vertical images provide a less distorted reproduction of the real distribution of the animals and visual reference points that are used to match and estimate the overlap of adjacent images. At Pictou Island, animals are concentrated around the shore, with only a few animals occurring inland, providing a narrow band of animals limited by trees and shoreline that can be covered in a limited number of parallel transects. These provide easily identifiable reference points for matching images in a mosaic (a similar source of bias for the UAV compared to large format). Therefore, at Pictou, it is relatively easy to obtain complete coverage of the shoreline and to find reference points to create to the mosaic of images used in ArcGIS to record counts. However, at Hay Island, animals use the entire area of the island where the relief is flat and the low vegetation provides few reference points. Any error in position and the distortion of oblique images make the creation of the mosaic more complex and reduce the quality of the pup images on the photographs. This reduced their detectability and likely introduces a negative bias. Furthermore, the oblique photographs were taken from inside the helicopter. Having to take photographs through the aircraft windows contributes to some distortion of the imagery making it more difficult to detect pups. Overall, visual counts and oblique photography could be used when seals are spread linearly with easily identifiable landmarks such as narrow shorelines, and when few animals are present (particularly in the case of visual counts). However visual or oblique photography are likely to provide unreliable estimates when seals spread over wide areas with limited landmarks. In these cases UAVs represent an effective alternative.

The grey seal is the only species that regularly breeds on both land and ice. The appearance of new colonies in recent years underlines how adaptable this species appears to be. This also poses challenges in trying to assess abundance of this species. The large format camera has not been used extensively in the GSL due, in part, to expense, the complicated logistics in positioning aircraft, variable environmental conditions and extended pupping season. The UAV was an effective tool in this study, since it could be positioned rapidly and inexpensively and provided high quality imagery for counting grey seals. Since pups can be staged on the imagery, repeated flights could also be used to complete the staging surveys to improve estimates of the proportion born. Developing a set of reference photographs for counting and stage classification may also be useful for future use since experience levels among readers is likely to vary. Nevertheless, some improvements could be made including a larger, heavier UAV that has a greater range and more autonomy in covering the relatively small area for this survey.

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TABLES

Table 1. Uncorrected counts of pups (SE) at Hay, Saddle and Pictou Island colonies during 2016. Counts are the average of two counts from each photograph by a single reader.

Date	Visual	Oblique	UAV	Large Format
Hay Island				
12 Jan				1833
15 Jan				2002
28 Jan		1834 (16)	2327 (24.0)	
Saddle Island				
22 Jan	1219			
25 Jan			2370 (46)	
Pictou Island				
15 Jan				2095 (1)
26 Jan			3811 (0)	
30 Jan		3588 (32)		
Henry Island				
23 Jan	538 (23)			
26 Jan		701 (5)		
1 Feb		748 (26)		

Table 2. Pup stages and dates at Saddle, Pictou and Hay Islands.

Date	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Total
Hay Island						
21 Jan	1	99	32	18	5	65
23 Jan	2	227	120	60	52	261
28 Jan	5	995	560	479	560	1699
Saddle Island						
22 Jan	9	70	137	2	2	220
26 Jan	0	26	302	59	19	406
30 Jan	0	4	350	65	20	439
Pictou Island						
22 Jan	28	328	261	14	2	633
26 Jan	14	293	397	78	18	800
30 Jan	7	25	577	43	32	684
8 Feb	4	20	222	148	81	475
Henry Island						
23 Jan	6	76	156	15	1	254
26 Jan	3	50	202	38	7	300
1 Feb	2	24	102	52	27	207

Table 3. Counts of pups (SE) at Hay, Saddle and Pictou Island colonies in 2016, proportion of pupping complete and adjusted pup estimate.

Date	Visual	Oblique	UAV	Large Format	Proportion (SE)	Adjusted pup estimate (SE)
Hay Island						
12 jan				1833	0.8 (0.042)	2,291 (120)
15 jan				2002	0.89 (0.034)	2,249 (85,9)
28 jan		1834 (15.6)			1 (0.001)	1,834 (1.8)
28 Jan			2327 (24.0)		1 (0.001)	2,327 (2.3)
Saddle Island						
22 Jan	1219				0.96 (0.020)	1,268 (26.6)
25 Jan			2370 (46)		1 (0.006)	2,381 (13.6)
Pictou Island						
15 Jan				2095 (0.7)	0.41 (0.095)	5,089 (1174.2)
26 Jan			3811 (0)		0.86 (0.158)	4,436 (814.1)
30 Jan		3588 (31.8)			0.93 (0.127)	3,871 (531.1)
Henry Island						
23 Jan	538 (23)				0.92 (0.047)	587 (39.3)
26 Jan		701 (4.9)			0.96 (.031)	732 (24.1)
1 Feb		748 (25.7)			0.99 (0.011)	756 (27.4)

FIGURES

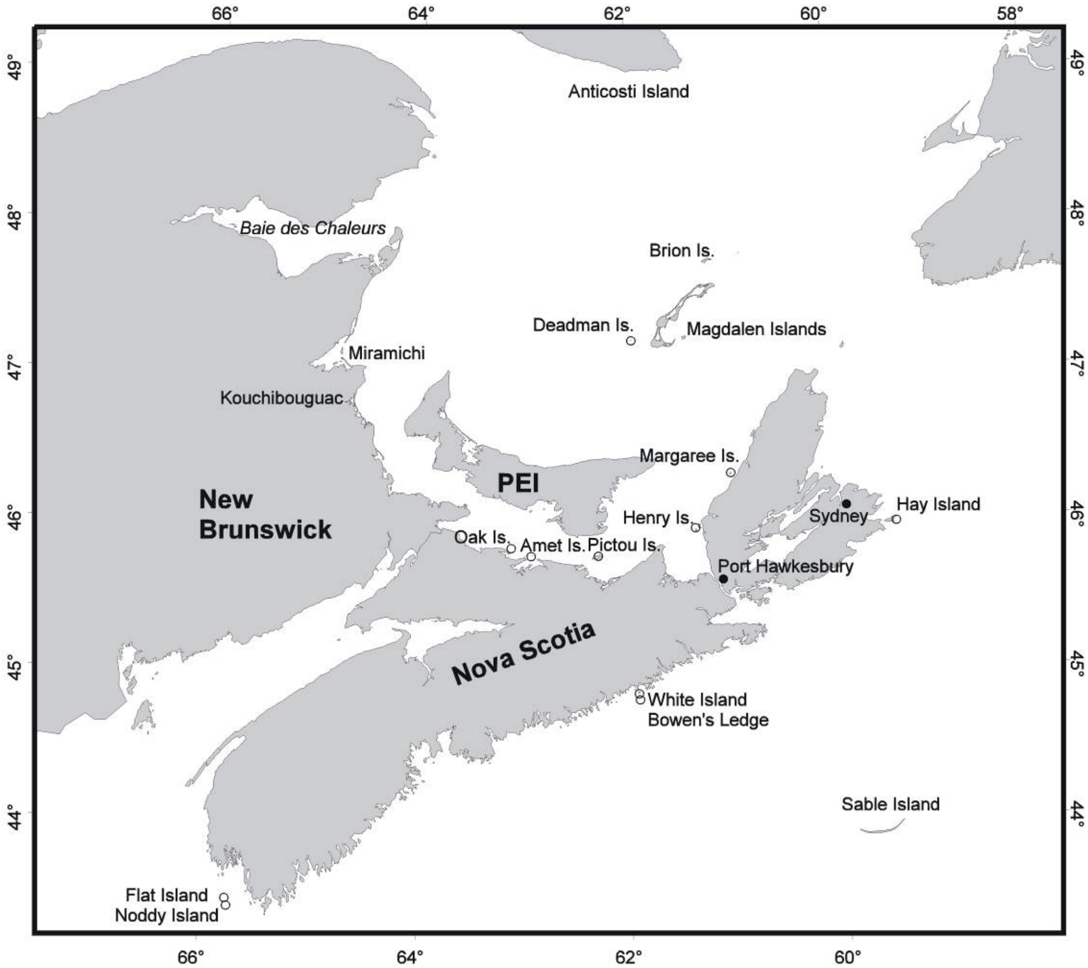

Figure 1. Map of study area. PEI is short for Prince Edward Island Saddle Island is located just to the west of Amet Island beside the peninsula.

Figure 2a. The Sensefly eBee used to complete surveys of grey seals in the Gulf and on Hay Island.

Figure 2b. Launch and recovery of Sensefly eBee from Saddle Island.

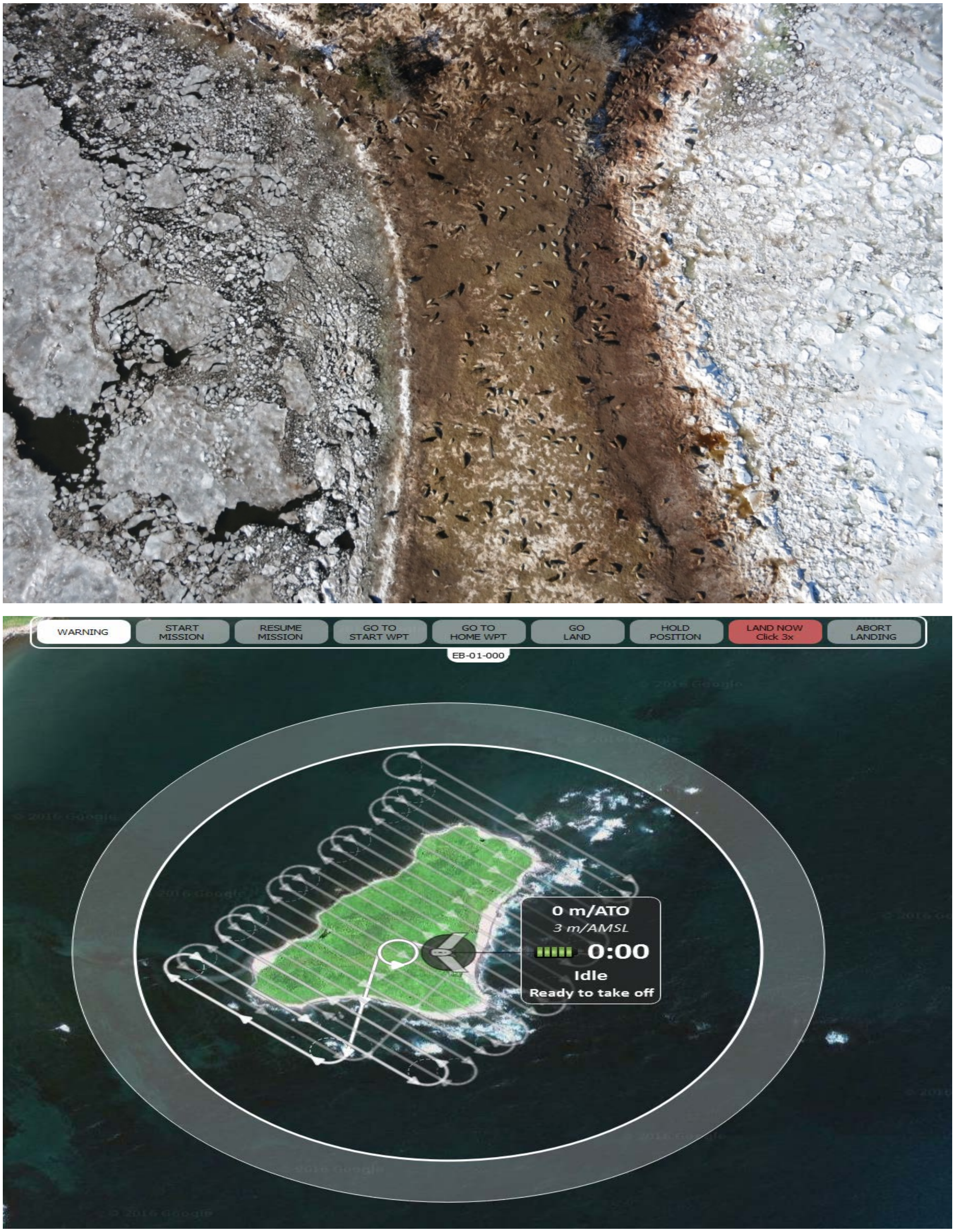

Figure 2c. Imagery from Saddle Island, taken using the Canon S110 RGB (3 cm ground resolution) camera mounted in the Sensefly ebee. The UAV was programmed to fly between 75 and 100m AGL (Above Ground Level).

Figure 3. Bell 429 helicopter used for visual, oblique photographic and stage determination surveys.

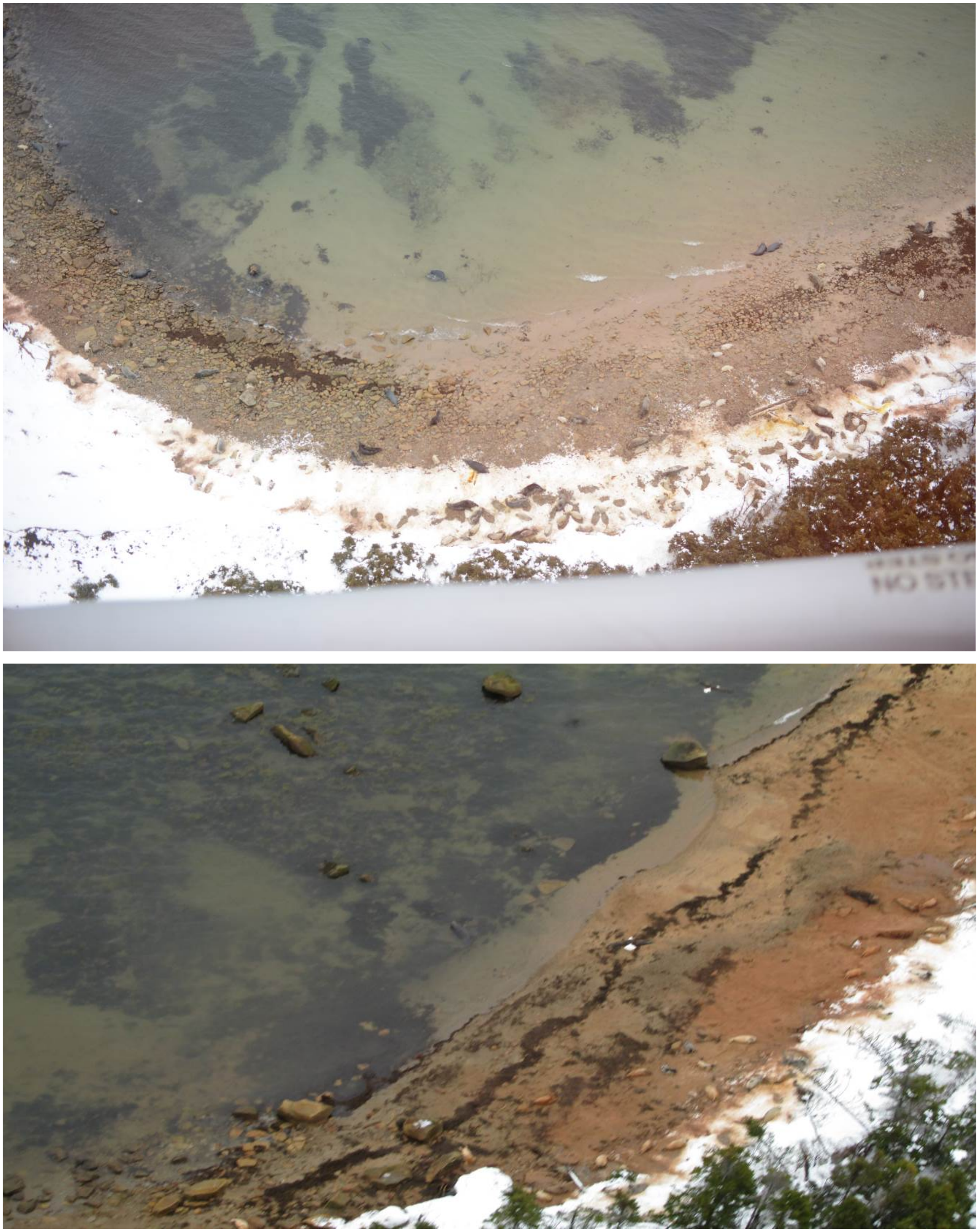

Figure 4. Oblique photographs of seals at Henry Island, using a Nikon (D800)(top) and a Canon (Canon Powershot SX160 IS)(bottom) camera

Figure 5. Aerial photographs taken from an altitude of approximately 420 m, using a large format aerial survey camera (Microsoft Vexcel UCX camera) in a motion compensation camera housing.