Bering Okhotsk Seal Surveys (BOSS)
Joint U.S.-Russian Aerial Surveys for Ice-associated Seals, 2012-13

By Erin Moreland, Michael Cameron, and Peter Boveng

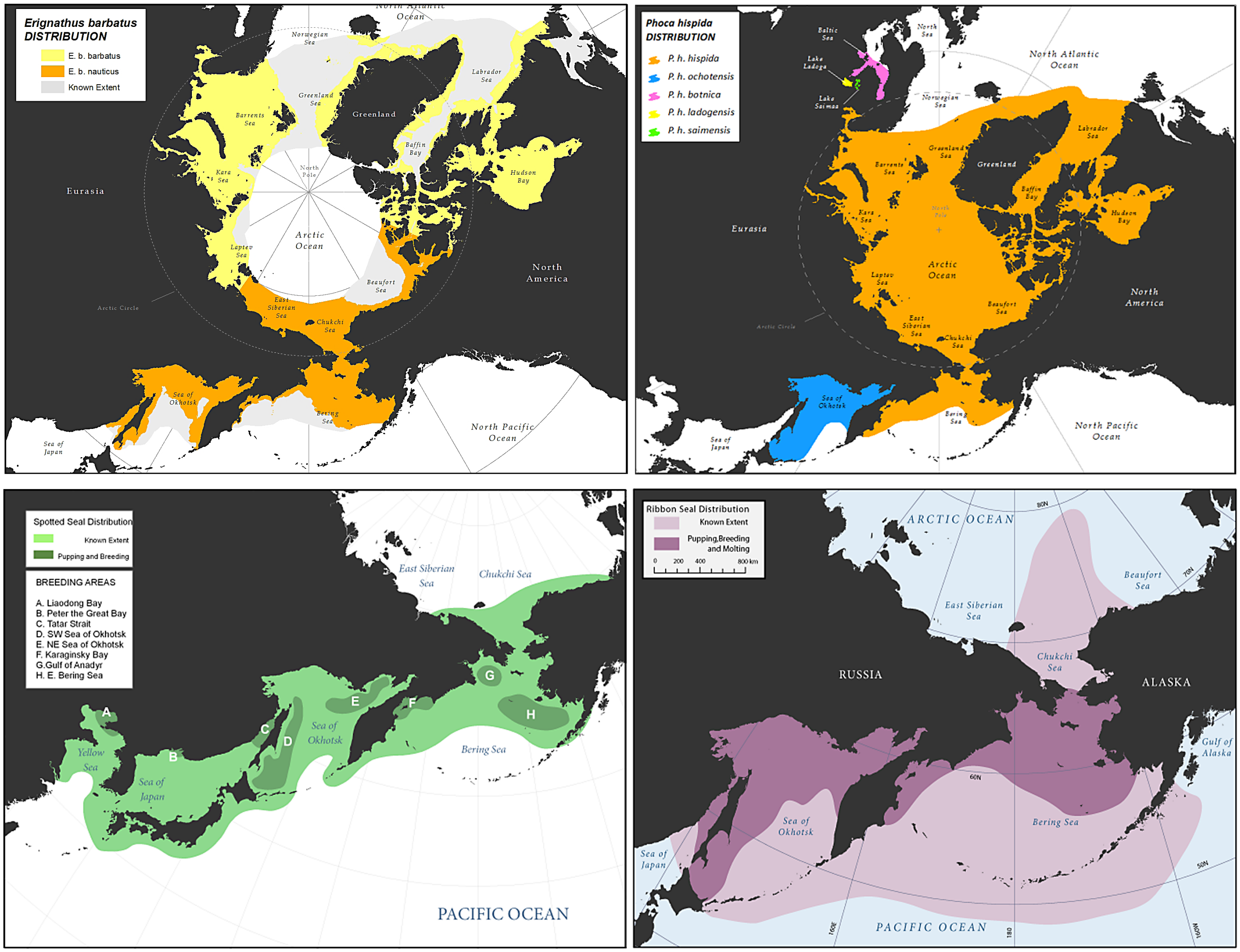

Figure 1. Distribution maps of bearded *(Erignathus barbatus)*, ringed (*Phoca hispida*), spotted (*Phoca largha*), and ribbon (*Histriophoca fasciata*) seals.

Bearded, spotted, ribbon, and ringed seals are key components of Arctic marine ecosystems and they are important subsistence resources for northern coastal Alaska Native communities. Although these seals are protected under the Marine Mammal Protection Act (MMPA) and bearded and ringed seals are listed as threatened under the Endangered Species Act (ESA), no reliable, comprehensive abundance estimates are available for any of the species. Obtaining reliable abundance estimates for ice-associated seals is vital for developing sound plans for management, conservation, and responses to potential environmental impacts of oil and gas activities and climate change. The Bering Okhotsk Seal Surveys (BOSS) project addressed the most critical need for fundamental assessment data on ice-associated seals (also known as ice seals) in the Bering and Okhotsk Seas. The abundances of these species are very poorly documented. Improved monitoring of ice seals is fundamental for the National Marine Fisheries Service (NMFS) to meet its management and regulatory mandates for stock assessments under the MMPA and extinction-risk assessments under the ESA.

The best way to estimate the abundances of ice-associated seals is to conduct aerial photographic and sightings surveys during the reproductive and molting period when the geographic structure of the population reflects the breeding structure and the greatest proportions of the populations are hauled out on the ice and are available to be seen. The distributions of these seals are broad and patchy (Fig. 1), and so surveys must cover large areas. Similarly, the extent, locations, and conditions of the sea ice habitat change so rapidly that any surveys must be conducted in a relatively short period of time. The expense and logistic complexity of these surveys have been the primary impediments to acquisition of comprehensive and reliable estimates.

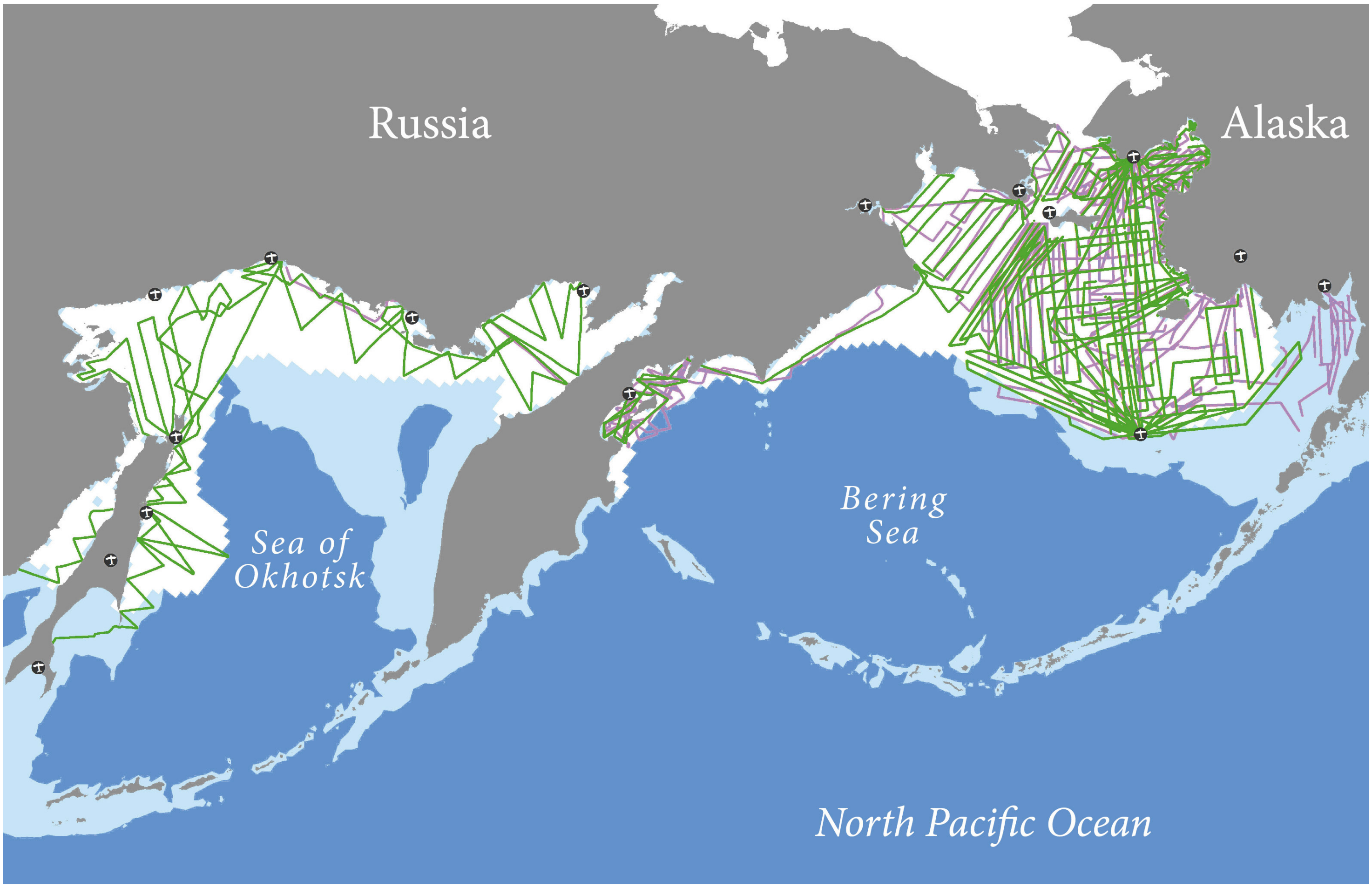

Figure 2. BOSS 2012 (pink) and 2013 (green) survey track lines in the Bering and Okhotsk seas covering more than 90,000 km (56,000 miles) completed during the joint U.S.-Russian survey effort. The 500-m isobath is in light blue and April 2013 ice extent is in white.

Scientists at the Alaska Fisheries Science Center's National Marine Mammal Laboratory (NMML) Polar Ecosystems Program (PEP) collaborated with colleagues from the State Research and Design Institute for Fishing Fleet ("Giprorybflot") in Saint Petersburg, Russia, to conduct synoptic aerial surveys of ice-associated seals in the Bering and Okhotsk Seas. Conducting spring-time surveys in those areas will yield abundance estimates for the entire population of ribbon seals, and all but a small fraction of the spotted seal population. For bearded seals, the surveys included the large and important fraction of the population that overwinters and breeds in the Bering and Okhotsk Seas. The U.S. Bureau of Ocean Energy Management provided critical financial support in 2012 and 2013 to complete the U.S. surveys of the central and eastern Bering Sea. Surveys for the portions of the bearded and ringed seal populations that breed in the Chukchi and Beaufort seas will require a separate and subsequent survey with different seasonal timing.

Two years of survey effort were required to achieve adequate precision (CV= 0.1) for abundance estimates and to ensure that sufficient periods of suitable weather occurred during survey periods. Aerial surveys for bearded, spotted, ribbon, and ringed seals were conducted in spring 2012 and 2013. In the United States and Russia combined, the teams flew more than 47,000 nautical miles (nmi) (90,000 km) of survey track (Fig. 2). The completion of this project marks the largest survey of ice-associated seals ever completed and will provide the first comprehensive estimates of abundance for bearded, spotted, ribbon, and ringed seals in the Bering Sea and Sea of Okhotsk.

Survey Effort

Surveys were conducted using digital cameras and thermal imagers mounted in the belly ports of two U.S. and one Russian fixed-wing aircraft from 6 April to 23 May 2012 and 4 April to 9 May 2013.

In 2013, U.S. surveys consisted of flights originating from airports in Nome, Bethel, and St. Paul Island, Alaska. The U.S. team also utilized an airstrip in Gambell, on St. Lawrence Island, to reach the most remote areas of sea ice in the central Bering Sea. The Russian team began Sea of Okhotsk surveys from Khabarovsk in Tatar Strait in early April 2013 and worked their way through Shelikhov Bay and into Karaginsky Bay. Surveys of the western Bering Sea began in mid-April from Ossora, Russia, on the Kamchatka Peninsula and worked their way north to the Bering Strait. The Russian aircraft carried a large, cooled thermal imager, Malakhit-M, which was paired with three fixed, digital, single-lens reflex (SLR) cameras fitted with 50-mm lenses (Fig. 3). Onboard observers also collected images with hand-held SLR cameras with zoom lenses. The Russian team completed 32 flights from 13 airports and flew more than 12,000 nmi (23,000 km).

Figure 3. BOSS 2012 Russian survey aircraft (Antonov AH-38-100) and camera setup showing a downward facing Nikon D3X and two oblique Nikon D300s. The cooled thermal imager, Malahit-M, is in a separate compartment of the aircraft.

Figure 4. NOAA Twin Otter (right) with belly port camera setup: three Canon 1Ds Mark III dSLR cameras paired with three FLIR SC645 thermal imagers.

Figure 5. Aero Commander survey aircraft and instrument setup (top): two Nikon D3X digital SLR cameras paired with two FLIR SC645 thermal imagers.

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Table 1. Instrument and camera resolution of U.S. and Russian BOSS 2012 and 2013 survey efforts.

	Russian Surveys	U.S. Surveys	
Aircraft	Antonov AH-38-100	NOAA Twin Otter DHC-6	Aero Commander AC-690
Thermal Imager	Malahit-M	FLIR SC645	FLIR SC645
Digital SLR Cameras	Nikon D800, D300, D3X	Canon 1Ds Mark III	Nikon D3X
SLR Lens	50mm	100mm	100mm
Survey Altitude	200-250m	300m	300m
Thermal Swath	500m	470m	280m
SLR Swath	500m	390m	237m
SLR Image Resolution	2-7 cm/pixel	1.9-2.1 cm/pixel	2.0-2.5 cm/pixel

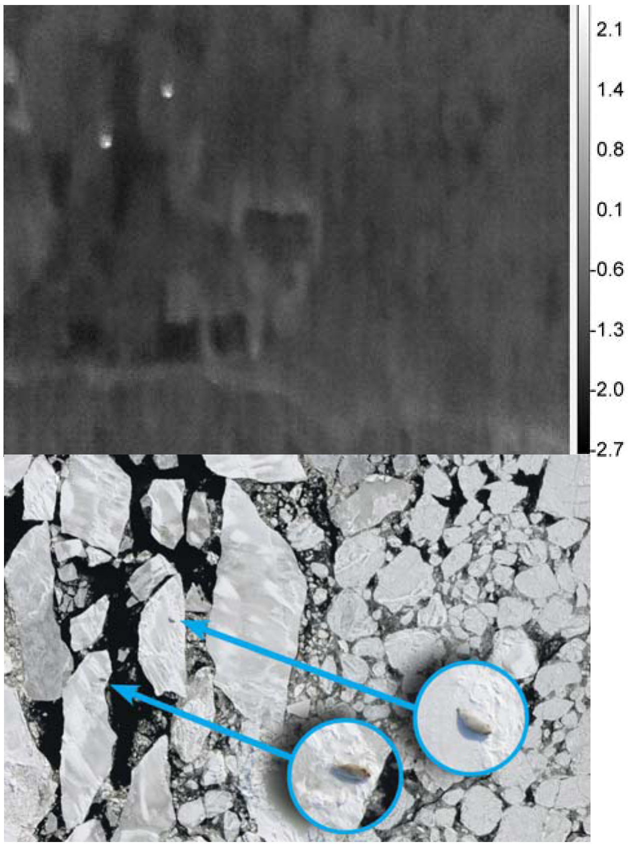

Figure 6. Example of two adult bearded seals detected using thermal imagery.

Most U.S. flights lasted 4-8 hours and were flown at an altitude of 1,000 ft (300 m) to maximize the area surveyed while maintaining the required imaging resolution and minimizing the chance of disturbance to seals and other wildlife. A NOAA Twin Otter (N56RF) aircraft housed three FLIR SC645 thermal imagers, which recorded continuous data in the 7.5-13.0 µm wavelength. Each thermal imager was paired with a Canon Mark III 1Ds digital single-lens reflex camera fitted with a 100-mm Zeiss lens. All six instruments were mounted in an open-air belly port (Fig. 4). The combined thermal swath width was approximately 1,500 ft (470 m) at an altitude of 1,000 ft. A contracted Aero Commander aircraft (Fig. 5) carried two sets of paired thermal imagers (SC645) and digital SLR cameras (Nikon D3X) and surveyed a maximum swath width of approximately 900 ft (280 m). In 2013 the two aircraft flew a total of 36 surveys covering more than 17,000 nmi (32,090 km) of trackline and collected about 913,000 images. Combined with the 2012 survey effort, the U.S. BOSS team covered 31,000 nmi of trackline and collected 1.8 million images.

Instrument-Based Surveys

The National Marine Mammal Laboratory's Bering Sea pack ice surveys for ice-associated seals have progressed from ship-based helicopter flights reliant on observer-collected data in 2007 and 2008 to instrument-only surveys on long-range, fixed-wing aircraft in 2012 and 2013. The BOSS project capitalized on recent advances in technology by pairing thermal and high-resolution digital SLR imagery. This allowed surveys to be conducted at altitudes too high for onboard observers to identify species, reducing disturbance to animals while maintaining equivalent survey swath width and allowed greater flexibility to explore species misclassification. Using long-range fixed-wing aircraft has also made it possible to achieve greater coverage of the survey area in a shorter period of time, improving our estimates by minimizing the change in sea ice habitat during the survey window.

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Advanced thermal-imaging technology was used on both the U.S. and Russian survey aircraft to detect the warm bodies of seals against the background of the cold sea ice (Fig. 6). High-resolution digital images will be used to identify the species of seals detected by the thermal imagers. Aircraft and instrument details are provided in Table 1.

Thermal Detection

Thermal detection of seals on ice has been accomplished through similar semi-automated techniques. Preliminary analysis of 2012 data for both the U.S. and Russian surveys was based on setting a temperature threshold and manually reviewing potential seal hot spots. The U.S. approach used temperature profiles to select thermal frames to evaluate (Fig. 7), while the Russian technique relied on software to identify hot spots, which were then manually reviewed and matched to SLR imagery.

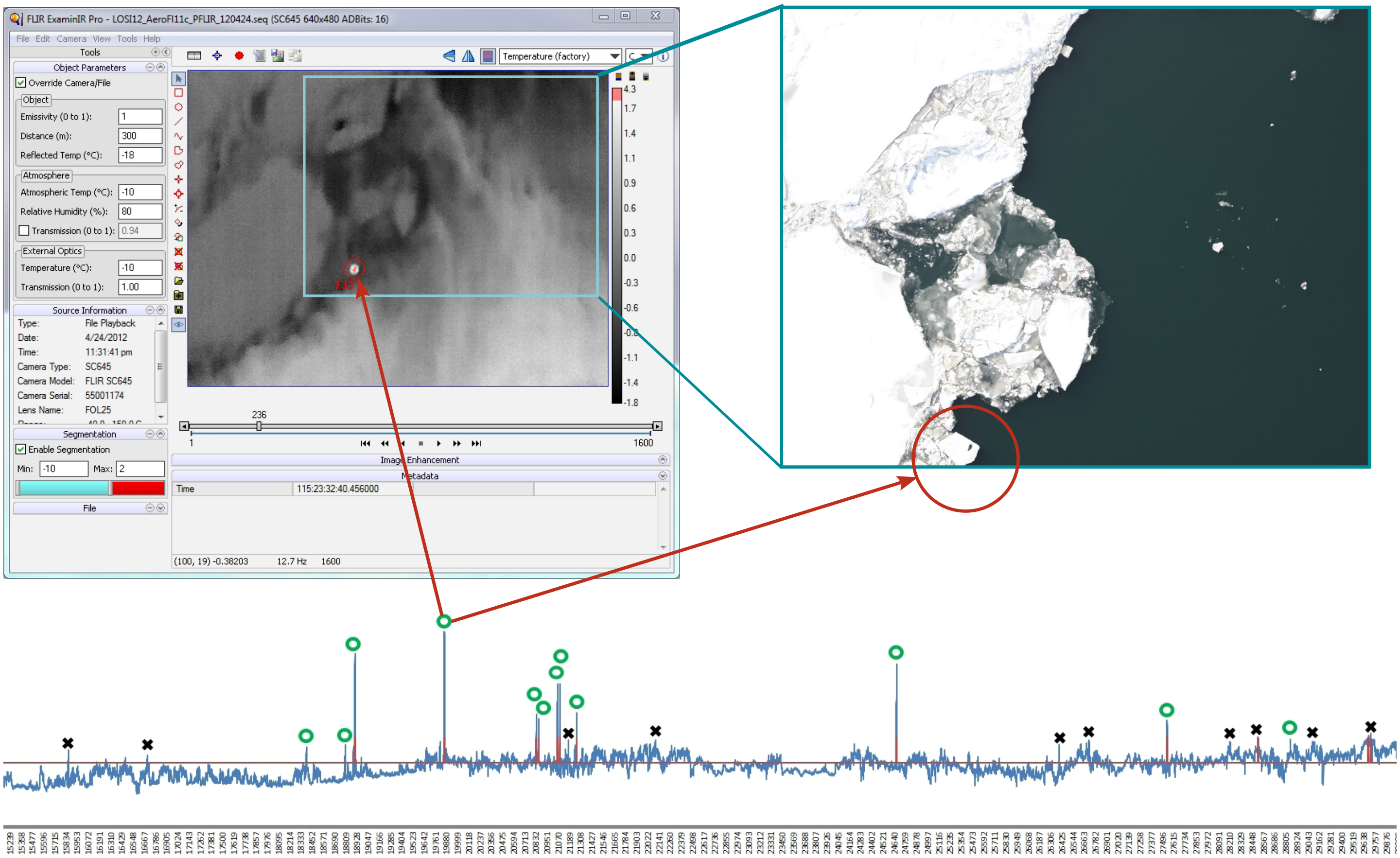

Figure 7. The U.S. hot spot detection method utilized a temperature threshold applied to a plot of maximum pixel temperature per frame to identify which thermal frames to evaluate. Digital SLR images were matched using the timestamps and ice features to locate the source of the thermal signature.

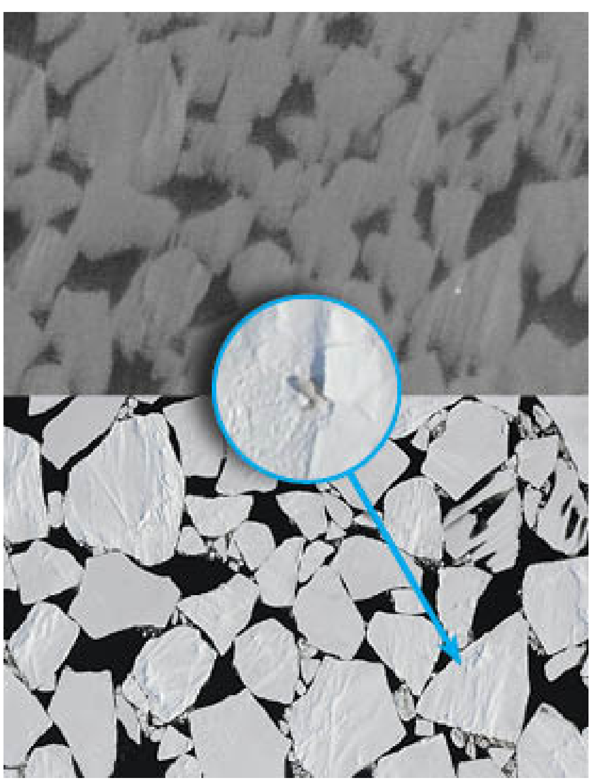

Figure 8. Example of an animal (seal pup) likely to be missed during a manual review of SLR imagery, but easily detected using thermal imagery.

High-resolution digital imagery is being used to identify seal species and differentiate hot spots generated by seals from anomalous thermal signals (false positives caused by melt pools, dirty ice, etc). These images also provide an opportunity to estimate detection probability and examine species misclassification rates. Thermal detection error for the U.S. method was determined by conducting a manual review of 10% of the SLR images included in a preliminary dataset from the 2012 survey effort (11,724 out of 117,225 images). The threshold approach detected 94% of the 70 seal groups found through manually reviewing images. In contrast, visually searching the SLR imagery for seals found 80.5% of the seal groups detected using thermal imagery. Thermal detection is particularly useful in detecting animals that are well camouflaged (Fig. 8).

Snowflake Testing

The U.S. surveys collected thermal imagery at a rate of 6 frames per second and SLR imagery at an interval of 1 – 1.4 seconds, maximizing the write speed of the camera cards. This resulted in the collection of 5.4 TB of thermal video and 1.8 million images (16.8 TB) over the 2-year project. In an effort to reduce the collection of extraneous imagery and improve efficiency of image processing, we have been exploring an automated thermal detection system called "Snowflake." This system triggers the collection of thermal and SLR images when a seal-like thermal signature is detected. The system can be used in flight or as a post-processing module to replace the threshold detection approach described above. The current version of Snowflake detects 94.5% of the seals found with the threshold detection and 98.6% of the seal groups found by manual review of SLR imagery.

Figure 9. The characteristic bands on the coats of ribbon seals are not necessarily clearly visible in an aerial image. The images on the top right and bottom right were taken with a Canon 1Ds Mark III fitted with a Zeiss 100 mm lens from 1,000 ft during BOSS 2012. In the top right image, a species identification expert would likely rely on the clearly visible bands to conclude that the seal is *certainly* a ribbon seal. In the bottom right image, a species identification expert would rely on a combination of body shape, head size, flipper size and shape, and what could be one or more faint bands to conclude that the seal is *likely* a ribbon seal.

Future improvements to Snowflake focus on reducing the false-positive trigger rate, tracking and projecting GPS data for each hot spot, and improved SLR camera control for in-flight triggering. We are also exploring machine vision cameras as an alternative to professional off-the-shelf SLR cameras. This would allow greater camera control, access to additional data to improve the filtering out of anomalous hot spots, and improved efficiency of data download, processing, and management.

Species Identification

The different characteristics that distinguish these ice-associated seal species can sometimes be difficult to discern from imagery taken at survey altitude. For example, the characteristic bands on the coats of ribbon seals will not always be visible in a photo, depending on the orientation of the seal and angle of the image (Fig. 9). The identifying characteristics of spotted and ringed seals can be even more difficult to discern from aerial photos. Although typically ignored in population estimates, errors can be common when attempting to identify similar-looking seal species from aerial photographs.

We are accounting for species misidentification in our abundance model by estimating misclassification probabilities for species identified in the images. Several ice seal experts with NMML's Polar Ecosystems Program have identified the species of more than 600 seals detected by thermal imagers and photographed during the 2012 surveys. To learn more about the factors driving the species identification process, our experts are also recorded the specific morphological characteristics that are visible in each image. In addition, experts ranked their confidence in each species identification as "positive," "likely," or "guess." By replicating the species-identification process with multiple observers for each seal, and assuming that a positive species-identification is the correct species, this allows the probabilities of correct (and incorrect) species identification to be estimated and accounted for in our final estimates of population abundance for each species.

Once this analysis is complete, not only will we have a better understanding of the frequency of ice seal species misidentification errors from aerial photos, but we also will be able to properly adjust our population estimate and variance for each species accordingly. In addition, we will gain a better understanding of the specific morphological characteristics most commonly used to identify each species from aerial transect surveys.

Abundance Estimation

Analyzing abundance from thermal video and digital photography presents several statistical challenges due to incomplete detection, false positives, and species misidentification. Novel statistical approaches are currently being developed by statisticians with the Polar Ecosystems Program to deal with these challenges. The process involves running a spatial model in the background describing how animal abundance varies over the survey area, while actual counts are a function of a number of additional factors including random variability and incomplete detection. For multi-species surveys, our approach handles incomplete species observations due to structural uncertainties (i.e. not all thermally detected animals are photographed) and species misclassifications. We plan to build on this hierarchical modeling framework to include a temporal dimension to account for changing sea ice conditions that occur within our survey window. The final step will be to incorporate data collected by our Russian collaborators to ultimately provide the most comprehensive estimates of abundance for bearded, spotted, ribbon, and ringed seals in the Bering Sea and the Sea of Okhotsk.

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