Technical Reports of the Institute of Cetacean Research (2024) pp. 46–49

Technical Report-Note (not peer reviewed)

An overview of studies at the Institute of Cetacean Research on individual identification and photogrammetry of Antarctic blue whales based on drone surveys

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In recent years, the use of small drones has become prevalent in marine mammal surveys, establishing them as a standard tool in the fields of morphology and animal behavior studies (Fiori *et al.*, 2017). The Japanese Abundance and Stock structure Surveys in the Antarctic (JASS-A) conducted by the Institute of Cetacean Research (ICR) (Isoda *et al.*, 2020) has also introduced drone technology for the study of large whales in the Antarctic. This paper reports progress in the use of drone technology for i) the identification of individual blue whales based on aerial photography, and ii) measurements of blue whales′ body length and body condition using photogrammetry.

In JASS-A, Phantom Pro 4 (DJI China) and Inspire 2 (DJI China) drones have been used primarily for photographing Antarctic blue whales, *Balaenoptera musculus intermedia*. The Drone Inspire 2 was equipped with a laser rangefinder SF11/C (LightWare LiDAR LLC, U.S.), which allowed estimating the distance to the sea surface using LiDAR (Light Detection and Ranging) technology. It also had a Global Positioning System (GPS) receiver EM506 (Globalsat, Taiwan) and an Inertial Measurement Unit (IMU) MiniIMU-9 v5 (Pololu Corporation, U.S.). Each data was recorded every second on a logger and were used for photogrammetry study. This altitude measuring system is identical to that used by Dawson *et al.* (2017) in their study on southern right whales, *Eubalaena australis*, in Auckland Islands and has proven useful in reducing observation error. Furthermore, it enables the attainment of accurate morphometric measurements and comparison with data from other individuals and populations (Bierlich *et al.*, 2021a).

The equipment used and the number of individuals photographed by year are summarized in Table 1. Figure 1 shows photographs of the drone in flight. A more detailed video of the drone flight in the Antarctic Ocean can be seen at the following URL:

https://www.youtube.com/watch?v=mjj-0OdolDE&t=27s

Individual identification

Blue whales possess unique mottled pigmentation, which allows for individual identification from clear photographs captured from a vessel (Sears *et al.*, 1990). The research vessels used in the JASS-A program are relatively large (700 GT) (Isoda *et al.*, 2020). When the vessels approach blue whales, the whales tend to swim away at increased speeds. This makes it difficult to capture clear dorsal/lateral images, as splashing often obscures the pigmentation patterns. In contrast, drones capture clear images of whales swimming undisturbed. This aerial perspective provides a unique view of the whale's dorsal/lateral parts.

From Figure 2, examination of photographs of two individuals taken by drone Phantom Pro 4 demonstrated that each individual has an identifiable mottling pattern behind the blowhole. Additionally, large white scars, likely resulting from contact with pack ice, were also use-

Table 1
Austral summer season, survey areas, type of drones used and the number of Antarctic blue whales photographed during the past four JASS-A surveys.

Season Survey Area	2019/20 Area IIIW: 000°–015°E	2020/21 Area IIIW: 015°E–035°E	2021/22 Area VIE: 130°W–120°W	2022/23 Area VIE: 145°W–130°W	Total
Drone	Phantom Pro 4	Phantom Pro 4	Inspire 2 with altitude measuring system	Inspire 2 with altitude measuring system	
Number of photographed Antarctic blue whales	2	10	2	7	21

Figure 1. A drone Phantom Pro 4 flying over an Antarctic blue whale during the 2020/2021 JASS-A survey (left). Scene of retrieving the drone Inspire 2 at the bow deck of the research vessel *Yushin-Maru* No.2 during the 2021/2022 JASS-A survey (right). When retrieving, the drone is caught by hand. For safety, the person catching the drone uses a full-face helmet and cut-resistant gloves.

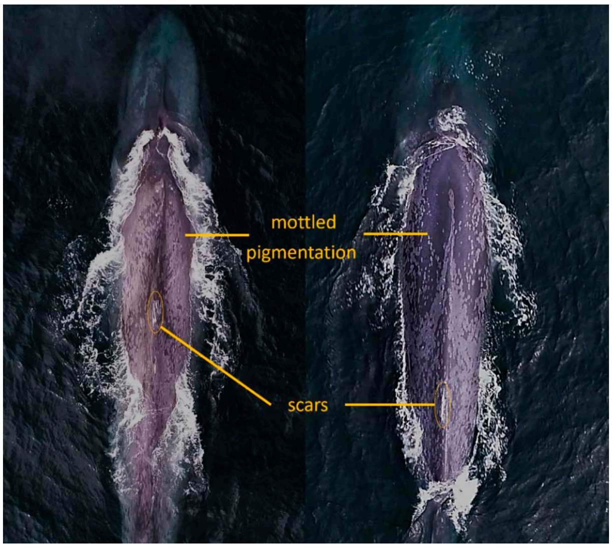

Figure 2. Individual identification of Antarctic blue whales by differentiated mottled pigmentations photographed by Phantom Pro 4. The mottling pattern on the dorsal is clearly visible and easily identifiable. The white scar is also a clue for individual identification.

ful for identifying individuals. Sears *et al.* (1990) reported that such large scars remained unchanged over an eight-year period. However, smaller scars tend to disappear within two years, necessitating caution when identifying individuals across different seasons. Our comparison of drone-captured images of two individuals indicates that these dorsal mottling patterns allow for easy and reliable individual identification.

In the application of photo identification using aerial imagery by drones, it is essential to cross-reference these images with existing catalogs of dorsal/lateral mottling photographs. Due to the significant difference in photographic angles between pictures taken from drones and pictures taken from vessels, the same mottled patterns may appear different. To investigate this, we obtained lateral pictures obtained from vessels and aerial pictures taken from drones from the same individuals. A future task is to conduct comparative analyses of both types of photographs to determine whether the same individuals can be reliably identified using both methods.

Photogrammetry

The use of drones has enabled non-lethal measurement of whale body length (BL), leading to a surge in research on body length and body condition since the 2010s (e.g., Durban *et al.*, 2015; Christiansen *et al.*, 2016). Body condition is a crucial indicator reflecting an animal's survival strategy, adaptive capacity and prey availability (Stevenson and Woods, 2006; Konishi *et al.*, 2008; Solvang *et al.*, 2017). Drone-based studies have introduced various indices for body condition. For example, the Body Area Index (BAI) (Burnett *et al.*, 2019), which standardizes the whale's dorsal surface area by dividing it by BL, and the Body Condition Index (BCI) (Christiansen *et al.*, 2018), which calculates the body volume. BAI, calculated using Equation 1, is a relative indicator where higher values indicate better body condition. Due to its low uncertainty and high precision, BAI is used for comparisons between individuals and populations (Bierlich *et al.*, 2021b).

$$BAI = [SA/(HT \times BL)^2] \times 100 \qquad \text{Equation 1}$$

Where:
SA=Surface area (m^2) (the area shown in white in Figure 3)
HT=Head-tail range (proportion of total length used, typically 0.7 for 20–90% in blue whales)
BL=Body length (m)

The surface area (SA) was estimated by approximating the whale's body as a series of trapezoids between 20% and 90% of the total body length and obtaining the sum

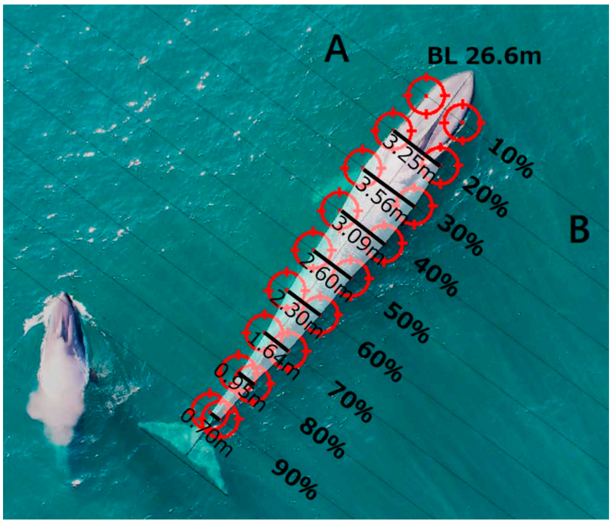

Figure 3. A lens-distortion corrected photograph used for measuring body length (BL) and width at 10% intervals of the BL (black thick lines) using MorphoMetriX (Ver.2.1.2). The red circles indicate the endpoints for measuring the body width. The flight altitude at the time of capture was 52.5 m. Letters A and B indicate the mirror sides. The measurements for this individual were based on the body width from side A edge to side B edge. MorphoMetriX (Ver.2.1.2) can handle one-sided measurements (from the edge of one side to the center) when the edge of one side of the whale is obstructed, e.g., by waves, glare and other factors.

of those areas. The drone Inspire 2 with altitude measuring system was used for the photogrammetry study.

In this study, we preliminary calculated BAI for a mother Antarctic blue whale photographed by drone Inspire 2 on 16 January 2023. The BL and width at each 10% interval of the body length were measured using MorphoMetriX (Ver.2.1.2) (Torres *et al.*, 2020). The measurements required the flight altitude at the time of capture, focal length, sensor size, and the number of pixels from the tip of the rostrum to the notch of the fluke for BL. Figure 3 shows the entire body immediately after breathing. This was extracted using a VLC media player (Ver. 3.0.8.0). Based on the time and position at the time of extraction, the distance from the sea surface measured by LiDAR and the tilt of the aircraft were obtained. After correcting for the tilt, the flight altitude was calculated to be 52.5 m. The focal length was fixed at 14 mm during the flight to capture 4K video (3840×2160 pixels). The onboard camera was the ZENMUSE X5S (DJI, China), equipped with a MICRO 4/3 sensor, and the lens was the Olympus M. ZUIKO DIGITAL 14–42 mm 1 : 3.5–5.6 (Olympus, Japan). The wide-angle lens caused distortion in the images, which was corrected using the video editing software Defishr (Ver.1.0) to prevent interference with accurate measurements. From the corrected images, the number of pixels from the tip of the rostrum to the notch of the fluke and from the edge of the body to the other edge was counted.

The BL of this individual was estimated to be 26.6 m. Commercial whaling data for Antarctic blue whale showed sexually mature females averaged 25.59 m in length (range: 23.4–28.2 m) (Mackintosh and Wheeler, 1929; Pastene *et al.*, 2019). This suggested that the estimated body length of this individual was within that range. The BAI of this animal was measured at 12.35. Barlow *et al.* (2023) used Monte Carlo ANOVA to analyze BAI values for three blue whale populations on the feeding ground. They reported the following results: Eastern North Pacific (ENP) blue whales had a BAI of 13.02 (95% CI: 12.74–13.33), New Zealand pygmy blue whales 14.36 (95% CI: 13.84–14.77), and Chilean blue whales 12.67 (95% CI: 12.21–13.23). The Antarctic blue whale mother in our study showed the lowest value which was closest to that of the Chilean blue whales.

It is generally observed that the body condition of mother whales deteriorates when accompanied by calves (the case of our study) due to energy allocation for nursing (Christiansen *et al.*, 2016). Barlow *et al.* (2023) provided valuable insights into blue whale body condition across different ecosystems. Of particular interest is their observation that New Zealand pygmy blue whales, which do not migrate seasonally, showed the best body condition. This finding offers an important point of comparison for understanding the body condition of the Antarctic blue whales in our study. Antarctic blue whales, which undergo seasonal migration, may be more vulnerable to changes in the distribution and abundance of prey caused by climate change. The relatively low BAI value we observed in our study individual aligns with this hypothesis. Furthermore, the record low sea ice extent observed in February 2023 (Purich and Doddridge, 2023) (year in which the picture was taken) and the predicted rapid ocean warming (Naughten *et al.*, 2023) could significantly impact the feeding environment of Antarctic blue whales. Under these circumstances, monitoring body condition, in addition to abundance, has become increasingly important for resource management.

However, due to the difficulty of accessing the Antarctic Ocean, collecting sampling data on the body condition of baleen whales in this region remains challenging. The utilization of drones in the JASS-A program serves as a valuable data sampling platform and provides a globally significant research opportunity. Given that this study focused on a mother with a calf, which is a special case, and the limited number of data points, we will move to conducting measurements of other individuals collected in JASS-A and analyze the body condition of Antarctic blue whale populations. It is also crucial to accumulate data on various whale species, not limited to Antarctic blue whales. This will enable us to assess the body condition of whales and evaluate whether the changing Antarctic Ocean continues to function as a healthy feeding ground.

ACKNOWLEDGEMENTS

We thank Y. Fujise, K. Matsuoka, T. Tamura and T. Hakamada (ICR) for their support in conducting the experiments and the preliminary analyses. We also thank Captains C. Ohkoshi, H. Kasai, N. Abe and crew members (Kyodo Senpaku) as well as the researchers who participated in JASS-A surveys and worked on the drone experiment. We also acknowledge H. Murase (Tokyo University of Marine Science and Technology) for his advice on photo identification. We are grateful to L.A. Pastene (ICR) for his assistance in preparing this report and the TEREP editorial team for editorial checking.

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