Marine Mammal Science

# Notes

MARINE MAMMAL SCIENCE, **(*): ***–*** (*** 2016)

DOI: 10.1111/mms.12328

## Photogrammetry of blue whales with an unmanned hexacopter

**JOHN W. DURBAN,**[1] Marine Mammal and Turtle Division, Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanographic Atmospheric Administration, 89101 La Jolla Shores Drive, La Jolla, California 92037, U.S.A.; **MICHAEL J. MOORE,** Biology Department, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543, U.S.A.; **GUSTAVO CHIANG,** MERI Foundation, Lo Beltrán 2347, Vitacura, Santiago 7640392, Chile; **LEIGH S. HICKMOTT,** Open Ocean Consulting, 2 Borough House, 72 Borough Road, Petersfield, Hampshire, GU32 3LF, United Kingdom; **ALESSANDRO BOCCONCELLI,** Advanced Ocean Physics and Engineering Department, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543, U.S.A.; **GLORIA HOWES AND PAULINA A. BAHAMONDE,** MERI Foundation, Lo Beltrán 2347, Vitacura, Santiago 7640392, Chile; **WAYNE L. PERRYMAN,** Marine Mammal and Turtle Division, Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanographic Atmospheric Administration, 89101 La Jolla Shores Drive, La Jolla, California 92037, U.S.A.; **DONALD J. LEROI,** Aerial Imaging Solutions, 5 Myrica Way, Old Lyme, Connecticut 06371, U.S.A.

Baleen whales are the largest animals ever to live on earth, and many populations were hunted close to extinction in the 20th century (Clapham *et al.* 1999). Their recovery is now a key international conservation goal, and they are important in marine ecosystems as massive consumers that can promote primary production through nutrient cycling (Roman *et al.* 2014). However, although abundance has been assessed to monitor the recovery of some large whale populations (*e.g.*, Barlow *et al.* 2011, Laake *et al.* 2012) many populations are wide-ranging and pelagic, and this inaccessibility has generally impeded quantitative assessments of recovery (Peel *et al.* 2015).

To augment traditional abundance monitoring, we suggest that photogrammetric measures of individual growth and body condition can also inform about population status, enabling assessment of individual health as well as population numbers. Photogrammetry from manned aircraft has used photographs taken from directly above whales to estimate individual lengths (Gilpatrick and Perryman 2008) and monitor

[1]Corresponding author (e-mail: john.durban@noaa.gov).

growth trends (Fearnbach *et al.* 2011), and shape profiles can be measured to assess body condition to infer reproductive and nutritional status (*e.g.*, Perryman and Lynn 2002, Miller *et al.* 2012). Recently, Durban *et al.* (2015) demonstrated the utility of an unmanned hexacopter for collecting aerial photogrammetry images of killer whales (*Orcinus orca*); this provided a noninvasive, cost-effective, and safe platform that could be deployed from a boat to obtain vertical images of whales. Here we describe the use of this small, unmanned aerial system (UAS) to measure length and condition of blue whales (*Balaenoptera musculus*), the largest of all whales.

We used an APH-22 hexacopter (Aerial Imaging Solutions, Old Lyme, CT) to photograph blue whales in a known feeding area in the Gulf of Corcovado and Gulf of Ancud, southern Chile (Fig. 1; Hucke-Gaete *et al.* 2004). This hexacopter is described in detail by Goebel *et al.* (2015), and was used successfully during recent boat-based photogrammetry of killer whales by Durban *et al.* (2015). In our study, this small (<2 kg, 82 cm wingspan) hexacopter was deployed from an 18.6 m wooden-hulled boat. The hexacopter was operated within line-of-sight by a pilot using a 2.4 GHz radio control from the boat, and it was hand launched and retrieved from the foredeck of the vessel by a second person, who functioned as the ground station operator (Fig. 2). When one or more whales were sighted from the vessel, the animals were approached within 300 m, and after a sense of their surfacing behavior had been established, the hexacopter was launched to an altitude of 50–60 m to be ready overhead for the next surfacing. The pilot flew the UAS out to the whales from the ship until the animals were evident in the downward-looking video feed from the onboard camera (Olympus E-PM2 with M.Zuiko 25 mm F1.8 lens), which was transmitted in real time by 5.8 GHz radio link to the ground station. The ground station operator then advised the pilot on fine-scale adjustments to frame the animals as they surfaced, and the pilot used a remote link to trigger the capture of high-resolution

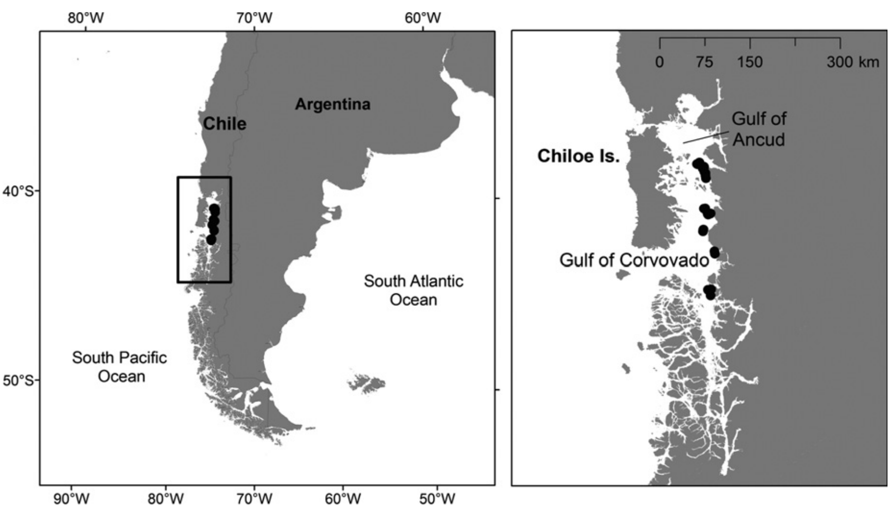


*Figure 1.* Map showing the location of the study area in southern Chile (left), with closed circles indicating the locations in the Gulf of Corcovado and Gulf of Ancud (right) where a small, unmanned hexacopter was launched from a boat to take aerial photographs of blue whales.

(16 MP) still images on the camera's flash memory, which provided a resolution of <2 cm from our operational altitudes (Durban *et al*. 2015).

In the period 22 February to 8 March 2015, we attempted 59 flights over blue whales, 37 of which were successful in collecting whale images. No change in the behavior of the whales was observed when the hexacopter was overhead. Whale dive times typically lasted 8–12 min, and flights averaging 12.1 min (maximum = 17.3 min) were conducted in an attempt to overlap with at least 1–2 surfacing bouts. The total distance flown during a flight averaged 1,286 m (maximum = 3,336 m), but the distance to the pilot was less (typically <300 m and always <500 m) as the boat was continuously maneuvered to enable line-of-site piloting. Flights were restricted to times when wind speeds were <8 m/s (15 knots).

Image measurements were calculated as previously described, using altitude and focal length to scale from image pixels to real measurements (Fearnbach *et al*. 2011) using altitude estimates from the air pressure sensor on the hexacopter (Durban *et al.* 2015). The accuracy of this approach was validated by seven measurements (on four different days) of the overall length of the research ship of approximate whale length (18.6 m). From altitudes of 50–56 m, the average measurement bias was just 0.03 m (range = 0.8 m), representing <0.002% (range <5%) of the total length of the boat. Estimates of individual whale length showed similar consistency. Whales were measured for body length from rostrum tip to tail notch in images that showed a flat surfacing orientation (Fig. 3). Individual whales were identified based on unique pigmentation patterns and distinctive scars (*e.g.* Gilpatrick and Perryman 2008). A total of 22 individual whales were measured in 1–7 images, and six whales with 4–7 repeat measurements all showed variability of <5% (range = 3.0%–4.3%) around average body lengths ranging from 18.9 m to 22.1 m.

We selected the longest body length measurement image of each whale as the most robust to negative bias, which could occur if the whale was angled towards the surface or had a rounded back during surfacing (*e.g.*, Fearnbach *et al.* 2011). The 22 whales ranged in length from 14.4 m to 23.6 m (Fig. 4). The two shortest animals in the data set (estimated lengths of 14.4 m and 15.5 m) appeared from field observations to be dependent calves; the two presumed mothers had lengths of


*Figure 2.* Photograph of the hexacopter being hand retrieved from the foredeck of the 18.6 m wooden boat by a ground station operator (MM) with pilot (JD) close by.

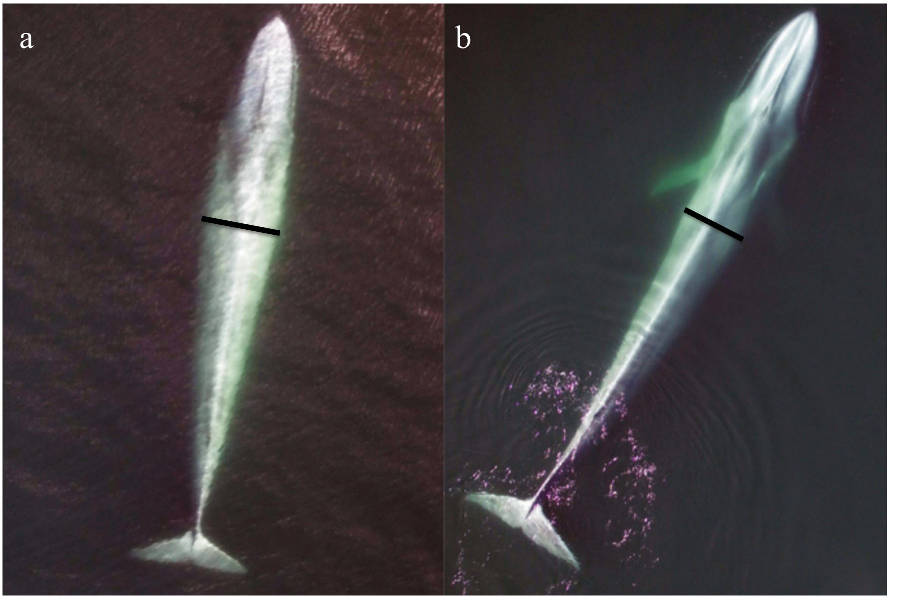


*Figure 3.* Example overhead photographs of two blue whales in a flat orientation as they are about to the break the surface to breath; (a) shows a whale in robust body condition, (b) shows a whale in lean condition (see Fig. 4). Body length measurements were made from the tip of rostrum to the tail notch and body width measurements were taken at the point on the whales' body that equaled 40% of the body length from the rostrum (solid reference lines). Images taken from altitudes of 50–60 m using an Olympus E-PM2 camera mounted on the APH-22 hexacopter.

22.7 m and 22.2 m, respectively. These measurements were consistent with lengths of blue whales previously measured using photogrammetry from manned aircraft (Gilpatrick and Perryman 2008), particularly for those whales photographed in the Eastern Tropical Pacific (females with calves averaged 22.4 m in length), which have been genetically linked to the whales feeding off southern Chile (Torres-Florez *et al.* 2014). Body width measurements were also taken at the point on the whales' body that equaled 40% of the body length from the rostrum, where widths were variable in whales of adult size (Fig. 3, 4). These measurable differences between whales likely indicated individual variability in body condition (Fig. 3).

This was the first study to use an unmanned aircraft to obtain quantitative photogrammetric measurements from large whales. It demonstrated the utility of a small hexacopter to be safely and efficiently deployed from a large boat platform to quickly position a camera above whales, which spent limited time at the surface. This builds on the successful use of the same aircraft from a smaller boat to study gregarious killer whales (Durban *et al.* 2015). Although hexacopter operations have a limited scale compared to wide-ranging manned aircraft, this study again demonstrated the hexacopter to be noninvasive, with a limited sound footprint (Goebel *et al.* 2015) that enables photographs to be obtained from lower altitude than manned aircraft without disturbing the whales. As a result, high resolution images can be coupled with onboard estimates of altitude to resolve differences in whale morphometrics

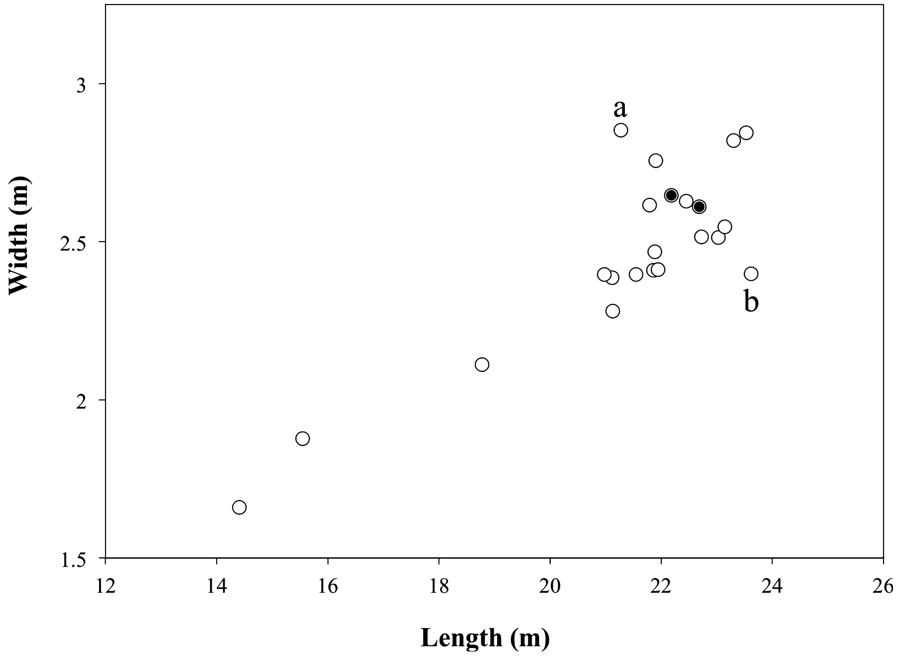


*Figure 4.* Photogrammetry measurements of body length from rostrum tip to tail notch, and width at 40% of the body length from the rostrum, for 22 individual blue whales. Labels indicate a notably robust (a) and a lean (b) whale, that were outliers from the general trend (see Fig. 3 for photographs of these same whales). Closed circles indicate two presumed adult females, which were accompanied by the two smallest whales that appeared to be dependent calves.

with high precision (within centimeters). The data we collected demonstrate the potential for obtaining repeated estimates of length and width to monitor changes in growth and body condition of blue whales over time, and this utility should also extend to other whale species. As large whales recover from exploitation and approach carrying capacity (*e.g.*, Laake *et al.* 2012) we will see them respond to variability in the environment (*e.g.*, Perryman *et al.* 2002). Monitoring individual growth and condition will therefore be important for understanding population dynamics and monitoring responses to environmental change, and we anticipate that portable UAS platforms, like the hexacopter used here, will become key research tools.

## Acknowledgments

We thank María Francisca Cortés Solari, Rafaela Landea Briones, MERI Foundation, and the Woods Hole Oceanographic Institution Access to the Sea Fund for funding this work. We also appreciate the support of Pesquera Los Elephantes, Thomas and Jose Montt, and the crew of the M/V *Centinella*. This research was conducted under Chilean Permit MERI-488-FEB-2015.

## Literature Cited

Barlow, J., J. Calambokidis, E. A. Falcone, *et al*. 2011. Humpback whale abundance in the North Pacific estimated by photographic capture-recapture with bias correction from simulation studies. Marine Mammal Science 27:793–818.

Clapham, P. J., S. B. Young and R. L. Brownell, Jr. 1999. Baleen whales: Conservation issues and the status of the most endangered populations. Mammal Review 29:37–62.

Durban, J. W., H. Fearnbach, L. G. Barrett-Lennard, W. L. Perryman and D. J. LeRoi. 2015. Photogrammetry of killer whales using a small hexacopter launched at sea. Journal of Unmanned Vehicle Systems 3:131–135.

Fearnbach, H., J. W. Durban, D. K. Ellifrit and K. C. Balcomb III. 2011. Size and long-term growth trends of endangered fish-eating killer whales. Endangered Species Research 13:173–180.

Goebel, M. E., W. L. Perryman, J. T. Hinke, D. J. Krause, N. A. Hann, S. Gardner and D. J. LeRoi. 2015. A small unmanned aerial system for estimating abundance and size of Antarctic predators. Polar Biology. doi:10.1007/s00300-014-1625-4.

Gilpatrick, J. W., and W. L. Perryman. 2008. Geographic variation in external morphology of North Pacific and Southern Hemisphere blue whales (*Balaenoptera musculus*). Journal of Cetacean Research and Management 10:9–21.

Hucke-Gaete, R., L. P. Osman, C. A. Moreno, K. P. Findlay and D. K. Ljungblad. 2004. Discovery of a blue whale feeding and nursing ground in southern Chile. Proceedings of the Royal Society of London B: Biological Sciences 271:170–173.

Laake, J. L., A. E. Punt, R. Hobbs, M. Ferguson, D. Rugh and J. Breiwick. 2012. Gray whale southbound migration surveys 1967–2006: An integrated re-analysis. Journal of Cetacean Research and Management 12:287–306.

Miller, C. A., P. B. Best, W. L. Perryman, M. F. Baumgartner and M. J. Moore. 2012. Body shape changes associated with reproductive status, nutritive condition and growth in right whales *Eubalaena glacialis* and *E. australis*. Marine Ecology Progress Series 459:135–156.

Peel, D., M. Bravington, N. Kelly and M. C. Double. 2015. Designing an effective mark–recapture study of Antarctic blue whales. Ecological Applications 25:1003–1015.

Perryman, W. L., and M. S. Lynn. 2002. Evaluation of nutritive condition and reproductive status of migrating gray whales (*Eschrichtius robustus*) based on analysis of photogrammetric data. Journal of Cetacean Research and Management 4:155–164.

Perryman, W. L., M. A. Donahue, P. C. Perkins and S. B. Reilly. 2002. Gray whale calf production 1994–2000: Are observed fluctuations related to changes in seasonal ice cover? Marine Mammal Science 18:121–144.

Roman, J., J. A. Estes, L. Morissette, *et al*. 2014. Whales as marine ecosystem engineers. Frontiers in Ecology and the Environment 12:377–385.

Torres-Florez, J. P., R. Hucke-Gaete, R. LeDuc, *et al*. 2014. Blue whale population structure along the eastern South Pacific Ocean: Evidence of more than one population. Molecular Ecology 23:5998–6010.

Received: 16 December 2015
Accepted: 5 April 2016