Sexually dimorphic measurements from stranded and bycaught specimens contribute to the characterization of group composition in free-ranging common dolphins (*Delphinus* spp.) from aerial images

Samantha G. M. Leander[1], John W. Durban[2], Kerri Danil[3], Holly Fearnbach[4], Trevor W. Joyce[5], Lisa T. Ballance[6]

[1]*University of San Diego. San Diego, CA*

[2]*Southall Environmental Associates, Inc., Aptos, CA*

[3]*Marine Mammal and Turtle Division, Southwest Fisheries Science Center, National Marine Fisheries Service, La Jolla, California*

[4] *SR³ SeaLife Response, Rehab, and Research, Des Moines, WA*

[5] *National Academies of Science, Engineering, and Medicine, Washington, D.C.*

[6]*Marine Mammal Institute, Hatfield Marine Center, Oregon State University, Newport, Oregon*

Correspondence: 5998 Acala Park, San Diego, CA 92110, USA

Email: sgm.leander@gmail.com

Short-beaked (*Delphinus delphis delphis*) and long-beaked (*D. d. bairdii*) common dolphins are the most commonly sighted cetaceans in waters off California (Barlow, 2016; Campbell et al., 2015; Carretta and Chivers, 2005; Heyning and Perrin, 1994). Despite the frequency of sightings, little is known about the demographic structure of their schools. This information is important for understanding risks: for example, *D. d. delphis* is the most commonly entangled species in California's thresher shark and swordfish drift gillnet fishery (Carretta and Chivers, 2005; Carretta et al., 2017), and vulnerability to entanglement may be related to the sex of individuals (Danil et al., 2010; Perryman and Lynn, 1993). Additionally, there is evidence that male *D. d. bairdii* are more susceptible to domoic acid toxicity, which could be attributed to sex, age, or reproductive class segregation (Danil et al., 2021; de la Riva et al., 2013).

Information on the demographic structure in free-ranging schools of these two subspecies is mostly limited to noting presence or absence of calves, which can be distinguished from other individuals by their smaller total length and close association with another dolphin presumed to be their mother (Cañadas and Hammond, 2008; Chivers et al., 2016; Perryman and Lynn, 1993). Reproductively mature male *Delphinus* spp. can be identified via the presence of a postanal hump, a keel between the anus and the flukes (Heyning and Perrin, 1994; Neumann et al., 2002). However, the postanal hump is located on the underside of the body, making identification of sex difficult from the typical vantage point of a boat-based observer. Previous studies have characterized sex composition another small delphinid, *Cephalorhynchus hectori*, through molecular analysis of biopsy samples (Oremus et al., 2013) and by using an underwater pole-mounted camera system to determine sex (Webster et al., 2009). In *D. d. delphis* and *D. d. bairdii*, determination of sex composition using biopsies is of more limited utility, since the large group sizes typical of both subspecies render sampling an entire group impossible. Furthermore, sex-specific behaviors might affect the likelihood of an individual of a particular sex being biopsied (Kellar et al., 2013). Similar sampling considerations also apply to boat-based underwater camera systems with these subspecies.

This study suggests the potential of photogrammetric measurements from aerial images to fill key data gaps on common dolphin group composition. Aerial photogrammetry from manned aircraft has been used routinely to measure body size of cetaceans (Fearnbach et al., 2011; Fortune et al., 2012; Pitman et al., 2007), including *Delphinus* spp. (Chivers et al., 2016; Perryman and Lynn, 1993). Additionally, drones now offer more opportunities for photographically sampling cetaceans from the air (Durban et al., 2015), with the benefit of minimizing disturbance (Christiansen, Rojano-Doñate, et al., 2016). Drones are increasingly being used to obtain precise morphometric measurements of cetaceans (Christiansen et al., 2020; Christiansen, Dujon, et al., 2016; Dawson et al., 2017; Durban et al., 2016; Fearnbach et al., 2020; Groskreutz et al., 2019), providing an opportunity to characterize demographic school composition of large dolphin schools. Here we present an example of how data from stranded and fisheries bycaught common dolphins can be used to develop sexually diagnostic measurements of *Delphinus* spp. in Southern California and demonstrate how these measurements can be applied to drone-derived aerial images of free-ranging individuals to provide information on demographic composition.

Measurements were taken from stranded and bycaught *D. d. delphis* and *D. d. bairdii* collected from the waters off California (32º to 42ºN latitude, 126º to 117º W longitude) between 1962 and 2018 (Chivers, 2018). Three criteria were developed to identify measurements that could be identified and measured accurately in aerial photographs. To be considered, the measurement must: (1) be restricted to the dorsal side of the body, (2) have start and end points easily distinguishable in aerial photographs, and (3) reflect a part of the body that is at times flat when viewed vertically while the animal is swimming. Although error associated with photogrammetric measurements tends to be small (Dawson et al., 2017; Scott and Perryman, 1991), the smaller the measurement, the greater the influence of this measurement error. Accordingly, we avoided measurements that were typically less than 50 cm (e.g., rostrum length). As a result, three morphometric measurements were selected: standard total body length (hereafter "total length"), an "anterior" length measurement from tip of the rostrum to anterior insertion of the dorsal fin, and a "posterior" length measurement between the anterior insertion of the dorsal fin and the fluke notch (Figure 1). If field and lab measurements were available for the same specimen, preference was given to lab measurements (following Chivers, 2018; Norris, 1961). To identify sexually dimorphic measurements, adult specimens were identified by total length, as defined in Heyning & Perrin (1994, Table 1), who used physical maturity (fusion of all vertebral epiphyses to the centra) or proxies thereof (sexual and cranial maturity combined) to classify specimens as adults. Sample sizes stratified by sex and species are provided in Figure 2.

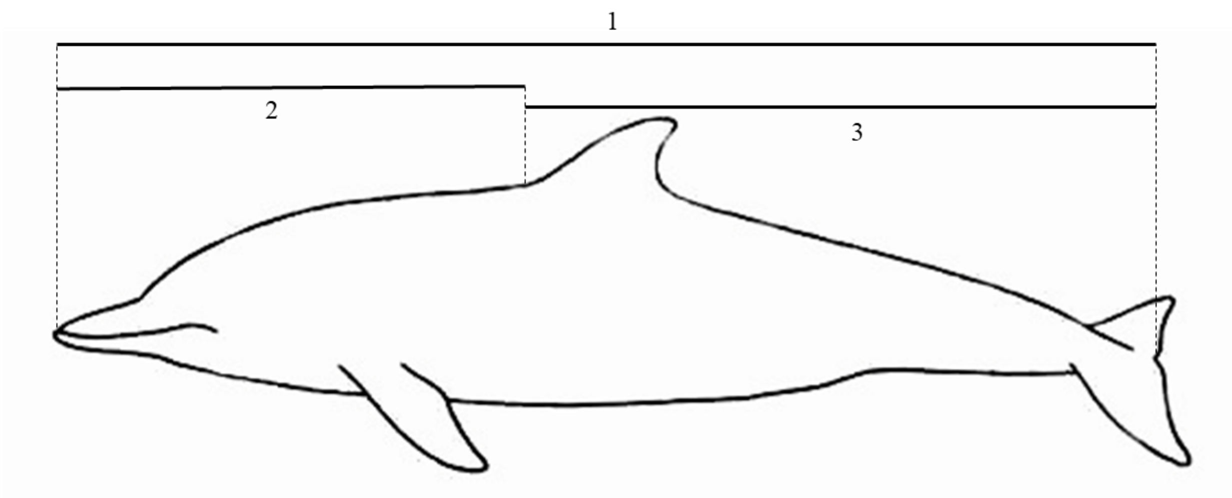


Figure 1 Measurements selected for analysis, as measured in stranded and bycaught individuals: 1) *Total Length* (standard total body length, or tip of the rostrum to fluke notch), 2) *Anterior Length* (tip of the rostrum to anterior insertion of the dorsal fin), and 3) *Posterior Length* (anterior insertion of the dorsal fin to fluke notch). Revised from Chivers (2018).

Table 1 Range of total length (Figure 1, measurement 1) for adult male and female *Delphinus* spp. in the Southern California Bight (Heyning and Perrin, 1994).

	Male	**Female**
D. d. bairdii	202-235cm	193-224cm
D. d. delphis	172-201cm	164-193cm

All three measurements exhibited interspecific differences (Figure 2). Specifically, *D. d. bairdii* had longer median lengths than *D. d. delphis* in all three measurements. However, the measurements varied in the extent of sexual dimorphism within subspecies. For each measurement, we quantified sexual dimorphism by calculating the percentage of adult males that were longer than 95% of the adult females. For both subspecies, posterior length showed the greatest degree of sexual dimorphism, as 58.7% and 37.3% of adult *D. d. bairdii* and *delphis* males, respectively, were longer than 95% of adult females. Total length showed the next greatest degree of sexual dimorphism (*D. d. bairdii*: 45.5%; *D. d. delphis*: 34.7%), driven largely by the component contributed by posterior length, and anterior length showed the lowest degree of sexual dimorphism (*D. d. bairdii*: 22.7%; *D. d. delphis*: 2.0%).

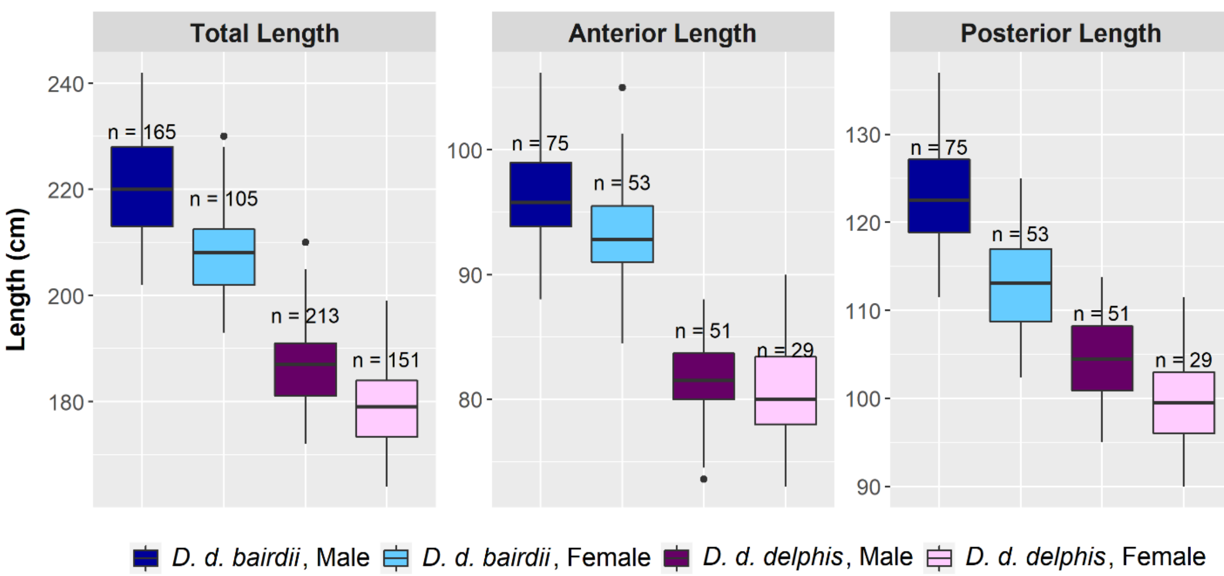
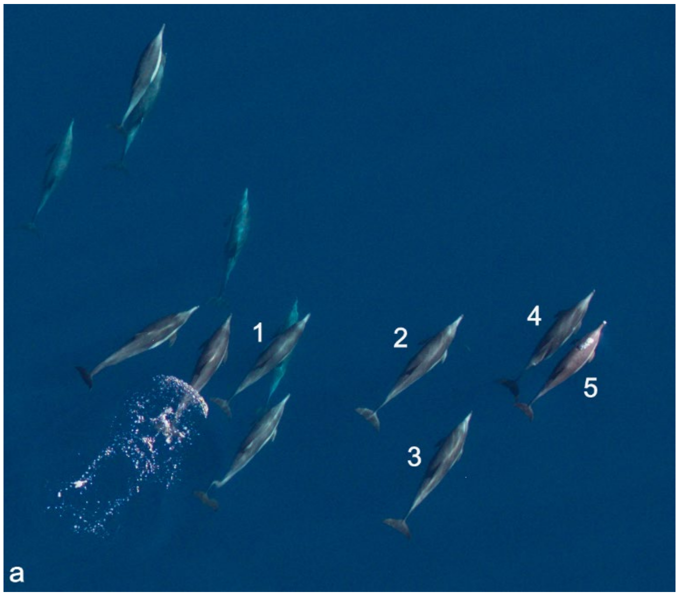


Figure 2 Length measurements of aerially measurable morphometrics for adult *Delphinus* spp. specimens (stranded and fisheries bycaught individuals) collected from waters off California. *Total Length* is tip of the rostrum to fluke notch, *Anterior Length* refers to the length between the

tip of the rostrum and the anterior insertion of the dorsal fin, and *Posterior Length* refers to the length between the anterior insertion of the dorsal fin and the fluke notch (Figure 1). Whiskers reflect the full range of distribution, boxes mark the 25-75% quantiles of the data, and the midline represents the median.

To demonstrate the application of these metrics, we generated photogrammetric measurements from free-ranging dolphins at sea, sampled in an aerial image collected by an octocopter drone (APO-42, Aerial Imaging Solutions, New Lyme, Connecticut) launched from a 20-meter boat that approached dolphin groups from horizontal distances of approximately 90m. The drone carried a micro 4/3 digital camera (Olympus E-PM2) and flat lens (25 mm F1.8 Olympus M. Zuiko) in a gimballed mount to collect vertical images of dolphins from an altitude of ~60 m to provide a water-level pixel resolution of <2 cm (Durban et al., 2015). Pixel measurements of dolphin morphometrics were converted to distance units using their ratio to the known size of the camera sensor (4,608 pixels = 17.3 mm wide) and were then scaled to true size (scale = altitude / focal length) using an onboard laser altimeter with typical error of ~0.1% (Dawson et al., 2017). The fluke notch is often difficult to distinguish in aerial images. Instead, the trailing edge of the fluke was marked, adding an estimated 2.5 cm to posterior length (Perryman and Lynn, 1993). For this study, this was considered too small a difference to affect interpretation of the data.

In the example image shown in Figure 3a, the anterior insertion of the dorsal fin was clearly visible, confirming the ability to measure anterior and posterior lengths in aerial photographs, as well as total length, despite a camera altitude of 58 m (190 ft). In this example image, five individuals were considered flat enough for approximately unbiased measurements. Two of the five measured individuals had a posterior length longer than 95% of the analyzed stranded and bycaught adult females (Figure 3b). As such, we concluded these individuals were likely males.



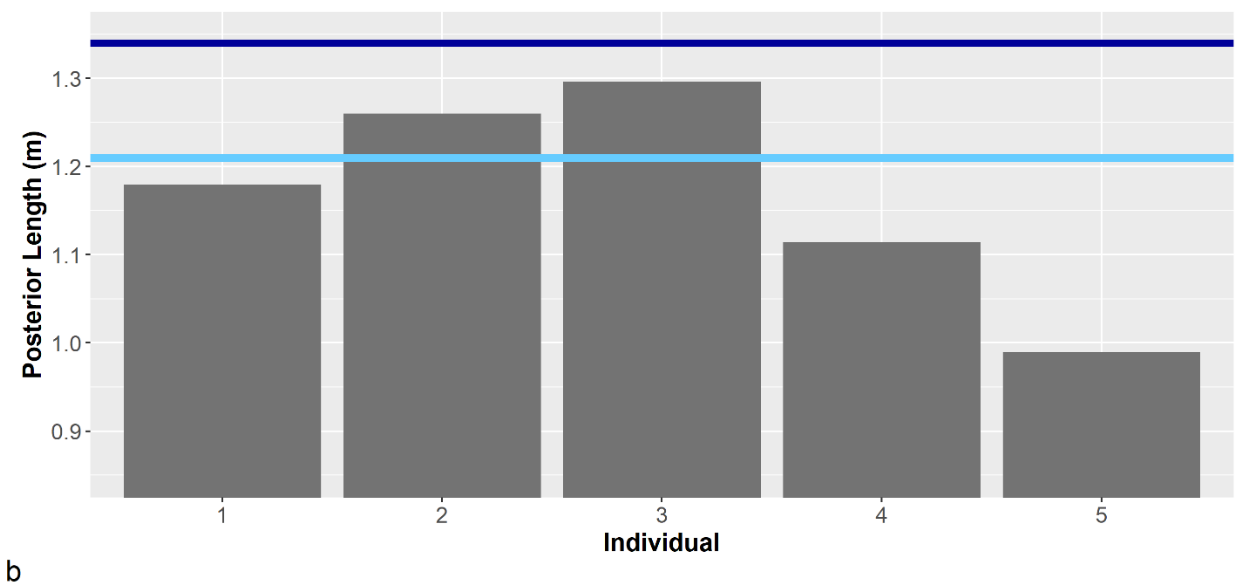


Figure 3 a) Aerially photographed *D. d. bairdii* group, taken at an altitude of 58m (190ft). Individuals considered to be in approximately flat surfacing orientation are numbered corresponding to measurements in panel b. b) Posterior length (anterior insertion of dorsal fin to fluke) measured from the image. The light blue line marks the 95th percentile (1.21m) of

analyzed stranded and bycaught females and the dark blue line marks the 95th percentile (1.34m) of analyzed stranded and bycaught males. Individuals 2 and 3 are most likely males, since their posterior length is larger than 95% of the analyzed stranded and bycaught females.

Our results will facilitate characterization of group composition in aerially photographed *Delphinus* spp. schools off Southern California. Here we demonstrated the ability of this method to identify likely large adult males in one example aerial image. This image was collected during ongoing photogrammetry sampling that collected several hundred to nearly 2000 images for each school sampled. We anticipate that, by applying the methods detailed here to all images from the same school, we will be able to measure the length composition of a large portion of individuals within the school. In addition to estimating the length distributions, we will also now be able to identify likely large adult males, providing greater insight into the demographic composition of schools.

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REFERENCES

Barlow, J. P. (2016). Cetacean abundance in the California Current estimated from ship-based line transect surveys in 1991-2014. *NOAA Administrative Report LJ-16-01*. https://doi.org/LJ-2016-01.

Campbell, G. S., Thomas, L., Whitaker, K., Douglas, A. B., Calambokidis, J., & Hildebrand, J. A. (2015). Inter-annual and seasonal trends in cetacean distribution, density and abundance off southern California. *Deep-Sea Research Part II: Topical Studies in Oceanography*, *112*, 143–157. https://doi.org/10.1016/j.dsr2.2014.10.008

Cañadas, A., & Hammond, P. S. (2008). Abundance and habitat preferences of the short-beaked common dolphin Delphinus delphis in the southwestern Mediterranean: Implications for conservation. *Endangered Species Research*, *4*, 309–331. https://doi.org/10.3354/esr00073

Carretta, J. V, & Chivers, S. J. (2005). Preliminary estimates of marine mammal mortality and biological sampling of cetaceans in California gillnet fisheries for 2004. *NOAA Administrative Report LJ; 05-10*.

Carretta, J. V, Moore, J. E., & Forney, K. A. (2017). Regression tree and ratio estimates of marine mammal, sea turtle, and seabird bycatch in the California drift gillnet fishery: 1990-2015. *NOAA Technical Memorandum, NOAA-TM-NMFS-SWFSC-568*. https://doi.org/10.7289/V5/TM-SWFSC-568

Chivers, S. J. (2018). Marine mammal life history: guide to biological sample collection and data archive. *NOAA Technical Memorandum NMFS-SWFSC-594*.

Chivers, S. J., Perryman, W. L., Lynn, M. S., Gerrodette, T., Archer, F. I., Danil, K., … Dines, J.

P. (2016). Comparison of reproductive parameters for populations of eastern North Pacific common dolphins: Delphinus capensis and D. delphis. *Marine Mammal Science*, *32*(1), 57–85. https://doi.org/10.1111/mms.12244

Christiansen, F., Dawson, S., Durban, J., Fearnbach, H., Miller, C., Bejder, L., … Moore, M. (2020). Population comparison of right whale body condition reveals poor state of the North Atlantic right whale. *Marine Ecology Progress Series*, *640*, 1–16. https://doi.org/10.3354/meps13299

Christiansen, F., Dujon, A. M., Sprogis, K. R., Arnould, J. P. Y., & Bejder, L. (2016). Noninvasive unmanned aerial vehicle provides estimates of the energetic cost of reproduction in humpback whales. *Ecosphere*, *7*(10), e01468. https://doi.org/10.1002/ecs2.1468

Christiansen, F., Rojano-Doñate, L., Madsen, P. T., & Bejder, L. (2016). Noise levels of multi-rotor unmanned aerial vehicles with implications for potential underwater impacts on marine mammals. *Frontiers in Marine Science*, *3*, 277. https://doi.org/10.3389/fmars.2016.00277

Danil, K., Berman, M., Frame, E., Preti, A., Fire, S., Leighfield, T., … Lefebvre, K. (2021). Marine algal toxins and their vectors in southern California cetaceans. *Harmful Algae*, *In press*.

Danil, K., Chivers, S. J., Henshaw, M. D., Thieleking, J. L., Daniels, R., & St Leger, J. A. (2010). Cetacean strandings in San Diego County, California, USA: 1851-2008. *Journal of Cetacean Research and Management*, *11*(2), 163–184.

Dawson, S. M., Bowman, M. H., Leunissen, E., & Sirguey, P. (2017). Inexpensive aerial photogrammetry for studies of whales and large marine animals. *Frontiers in Marine Science*, *4*, 366. https://doi.org/10.3389/fmars.2017.00366

de la Riva, G. T., Johnson, C. K., Gulland, F. M. D., Langlois, G. W., Heyning, J. E., Rowles, T. K., & Mazet, J. A. K. (2013). Association of an unusual marine mammal mortality event with Pseudo-nitzschia spp. blooms along the Southern California coastline. *Journal of Wildlife Diseases*, *45*(1), 109–121. https://doi.org/10.7589/0090-3558-45.1.109

Durban, J. W., Fearnbach, H., Barrett-Lennard, L. G., Perryman, W. L., & Leroi, D. J. (2015). Photogrammetry of killer whales using a small hexacopter launched at sea. *Journal of Unmanned Vehicle Systems*, *3*(3), 131–135. https://doi.org/10.1139/juvs-2015-0020

Durban, J. W., Moore, M. J., Chiang, G., Hickmott, L. S., Bocconcelli, A., Howes, G., … LeRoi, D. J. (2016). Photogrammetry of blue whales with an unmanned hexacopter. *Marine Mammal Science*, *32*(4), 1510–1515. https://doi.org/10.1111/mms.12328

Fearnbach, H., Durban, J. W., Barrett-Lennard, L. G., Ellifrit, D. K., & Balcomb, K. C. (2020). Evaluating the power of photogrammetry for monitoring killer whale body condition. *Marine Mammal Science*, *36*(1), 359–364. https://doi.org/10.1111/mms.12642

Fearnbach, H., Durban, J. W., Ellifrit, D. K., & Balcomb, K. C. (2011). Size and long-term growth trends of endangered fish-eating killer whales. *Endangered Species Research*, *13*(3), 173–180. https://doi.org/10.3354/esr00330

Fortune, S. M. E., Trites, A. W., Perryman, W. L., Moore, M. J., Pettis, H. M., & Lynn, M. S. (2012). Growth and rapid early development of North Atlantic right whales (Eubalaena glacialis). *Journal of Mammalogy*, *93*(5), 1342–1354. https://doi.org/10.1644/11-MAMM-A-297.1

Groskreutz, M. J., Durban, J. W., Fearnbach, H., Barrett-Lennard, L. G., Towers, J. R., & Ford, J. K. B. (2019). Decadal changes in adult size of salmon-eating killer whales in the eastern North Pacific. *Endangered Species Research*, *40*, 183–188. https://doi.org/10.3354/ESR00993

Heyning, J. E., & Perrin, W. F. (1994). Evidence for two species of common dolphins (genus Delphinus) from the eastern North Pacific. *Contributions in Science*, *442*, 1–35.

Kellar, N. M., Trego, M. L., Chivers, S. J., Archer, F. I., Minich, J. J., & Perryman, W. L. (2013). Are there biases in biopsy sampling? Potential drivers of sex ratio in projectile biopsy samples from two small delphinids. *Marine Mammal Science*, *29*(4), E366–E389. https://doi.org/10.1111/mms.12014

Neumann, D. R., Russell, K., Orams, M. B., Baker, C. S., & Duignan, P. (2002). Identifying sexually mature, male short-beaked common dolphins (Delphinus delphis) at sea, based on the presence of a postanal hump. *Aquatic Mammals*, *28*(2), 181–187.

Norris, K. S. (1961). Standardized methods for measuring and recording data on the smaller cetaceans. *Journal of Mammalogy*, *42*(4), 471. https://doi.org/10.2307/1377364

Oremus, M., Hamner, R. M., Stanley, M., Brown, P., Scott Baker, C., & Constantine, R. (2013). Distribution, group characteristics and movements of the critically endangered Maui's dolphin Cephalorhynchus hectori maui. *Endangered Species Research*, *19*, 1–10. https://doi.org/10.3354/esr00453

Perryman, W. L., & Lynn, M. S. (1993). Identification of geographic forms of common dolphins (Delphinus delphis) from aerial photographs. *Marine Mammal Science*, *9*(2), 119–137. https://doi.org/https://doi.org/10.1111/j.1748-7692.1993.tb00438.x

Pitman, R. L., Perryman, W. L., LeRoi, D., & Eilers, E. (2007). A dwarf form of killer whale in Antarctica. *Journal of Mammalogy*, *88*(1), 43–48. https://doi.org/10.1644/06-MAMM-A-118R1.1

Scott, M. D., & Perryman, W. L. (1991). Using aerial photogrammetry to study dolphin school structure. In *Dolphin Societies: Discoveries and Puzzles* (pp. 227–241).

Webster, T. A., Dawson, S. M., & Slooten, E. (2009). Evidence of sex segregation in Hector's dolphin (Cephalorhynchus hectori). *Aquatic Mammals*, *35*(2), 212–219. https://doi.org/10.1578/AM.35.2.2009.212