Short-beaked common dolphin (*Delphinus delphis*) total length estimation using laser photogrammetry off the southwest coast of Ireland

Seán A. O'Callaghan[1,2], Mags Daly[2] and Simon Berrow[1,2]

Corresponding author: seanocallaghan212@gmail.com

ABSTRACT

Measurements from 106 stranded short-beaked common dolphins along the Irish coast were taken between March 2017 and March 2023. Data were collected from the Irish Necropsy Project and Irish Cetacean Stranding Scheme. Total length measurements were gathered from 103 individuals where the tail flukes were still attached. These ranged between 96–238cm, mean 185.7cm, SD 31.43cm. Males (n = 58) ranged from 96–238cm, averaging 189cm, SD 34.64cm. Females (n = 40) measured 117.5–231cm, averaging 181cm, SD 25.80cm. Scaled dorsal fin photos were taken from stranded dolphins to formulate an equation to estimate the total length of live dolphins. The total lengths of 29 live common dolphins were estimated off the southwest coast of Ireland using laser photogrammetry and dorsal fin dimensions between March 2018–April 2019. Total lengths for three stranded dolphins with amputated tail flukes were also estimated. Dorsal fin base lengths were the most accurate predictor of total length R^2 = 0.78. Total length estimates ranged between 143.77–242.25cm, averaging 194.78cm, SD 20.05cm. The adoption of laser photogrammetry as a measurement tool warrants further exploration as a means to reduce potential disruption from aerial systems and enhance the utility of behavioural and photo-ID images. This study describes a non-invasive technique with a range of possible applications for understanding pod size structure and seasonality due to this species' approachable behaviour and inquisitive nature.

KEYWORDS: COMMON DOLPHIN; STRANDING; PHOTOGRAMMETRY; MORPHOMETRICS; IRELAND

INTRODUCTION

The short-beaked common dolphin (*Delphinus delphis*) has a wide distribution within temperate and tropical waters across its range (Perrin, 2018). In the North Atlantic Ocean, the species occurs from the Straits of Gibraltar in the south, to extralimital records in Norway and Iceland in the north, with most sightings recorded between latitudes 49–55°N and longitudes 20–30°W (Murphy *et al*., 2013). Despite indications in recent years of an expanded northern range, associated with rising sea-surface temperatures which are driven by climate change (Evans and Waggitt, 2020; Astarloa *et al*., 2021), common dolphin occurrence is understood to vary between seasons with sea-surface temperature (Campbell *et al*., 2015).

Common dolphins are the most frequently sighted and stranded dolphin species in Ireland where they occur year-round in coastal and offshore habitats (Rogan *et al*., 2018; O'Connell and Berrow, 2020). An estimated 33,215 individuals (95% CI 19,844–55,595, CV 41.52) were present within the Irish Exclusive Economic Zone (EEZ)

[1] Atlantic Technological University, Galway City Campus, Dublin Road, Galway, Ireland, H91 T8NW.
[2] Irish Whale and Dolphin Group, Merchants Quay, Kilrush, Clare, Ireland, V15 E762.

between 2015–17 (Rogan *et al*., 2018). The species mates and calves within Irish waters (Rogan, 2016). Size and sex segregation within groups is known to occur throughout the year (Rogan and Mackey, 2007; Fernández-Contreras *et al*., 2010). The calving period appears to occur between July–September (Murphy and Rogan, 2006). Common dolphins feed on a variety of small shoaling fish and cephalopods which overlap with the diets of other inshore Irish cetacean species, often forming mixed feeding associations with large baleen whales (Brophy *et al*., 2009; Ryan *et al*., 2014).

The health of an individual cetacean can be directly linked to its morphology so that body size is indicative of the animal's general reproductive fitness, feeding success and survival probability (Groskreutz *et al*., 2019; Castrillon and Nash, 2020; Adamczak *et al*., 2021; Stewart *et al*., 2022). Morphometric data from cetaceans in Ireland have primarily been collected from stranded and bycaught individuals (Murphy and Rogan, 2006; O'Connell and Berrow, 2020) with some historical data available from large whale species killed though commercial whaling (Fairley, 1981; Ryan, 2022). Photogrammetry enables non-invasive collection of morphometric data from live animals at sea that may better represent the population, not influenced by young, old or sick individuals that often strand which may bias measurements.

Common dolphins can grow between 150–225cm in total length (Perrin, 2018). They exhibit sexual dimorphic traits, with males generally larger than females (Murphy *et al*., 2006; Leander *et al*., 2021). Sexual maturity in the northeast Atlantic occurs on average at 11.9 years and 206cm in length for males and at 8.2 years and 188cm for females (Murphy *et al*., 2005; Murphy *et al*., 2009). Between 1990–2003, 252 common dolphins were examined as strandings or bycatch in the albacore tuna (*Thunnus albacares*) driftnet fishery in Irish waters (Murphy and Rogan 2006, Rogan and Mackey 2007). These animals ranged from 93–231cm in total length, for males (n = 137) length ranged from 105–231cm, while females (n = 99) were between 93–230cm (Murphy and Rogan, 2006). Common dolphin birth size was on average 108.8cm (n = 6) (Murphy and Rogan, 2006). Murphy and Rogan (2006) showed negative allometric growth of dorsal fin base length (DBL) in female common dolphins while the dorsal fin height (DH) displayed isometric growth. DBL in male dolphins was isometric in growth but the DH was allometric. As such, the dorsal fin showed more obvious dimorphic features compared with other body parts in this region of the northeast Atlantic.

Common dolphins have been studied using aerial photogrammetry since 1988, first from helicopters, but more recently using unmanned aerial vehicles (UAVs) or drones (Perryman and Lynn, 1993; Leander *et al*., 2021). Drones have made aerial photogrammetry and the collection of aerial images and video less expensive, while also reducing the risk to researchers in aircraft, but it is limited to low wind speeds (< 10 m/s) and no precipitation (Fiori *et al*., 2017; Johnston, 2019). However, it is possible to collect morphometric data from animals at the sea's surface using laser photogrammetry with adapted standard boat-based fieldwork equipment (Durban and Parsons, 2006; Rowe and Dawson, 2008; Webster *et al*., 2010). Laser photogrammetry has helped determine sex, sexual dimorphic features and growth rates of bottlenose dolphins (*Tursiops truncatus*) (Currey *et al*., 2008; Rowe and Dawson, 2008; 2009; Rowe *et al*., 2010; Cheney *et al*., 2018). This technique has also been used to differentiate between populations of killer whales (*Orcinus orca*) and Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) (Durban *et al*., 2017; van Aswegen *et al*., 2019). Short-finned pilot whale (*Globicephala macrorhynchus*), false killer whale (*Pseudorca crassidens*), pygmy killer whale (*Feresa attenuata*) and melon-headed whale (*Peponocephala electra*) were also identified to species level using measurements of body parts to reduce the potential for misidentifications between blackfish species and to quantify sexually dimorphic features (Yahn *et al*., 2019; 2023).

Laser photogrammetry has also enabled total length estimates to be produced for free swimming bottlenose dolphins, killer whales, long-finned pilot whales (*Globicephala melas*) and Hector's dolphins (*Cephalorhynchus hectori*) (Rowe *et al*., 2010; Webster *et al*., 2010; Cheney *et al*., 2018; Durban *et al*., 2017; Wong and Auger-Méthé, 2018; van Aswegen *et al*., 2019). The blowhole to dorsal fin (BH-DF) measurement has typically been used to estimate over half the body length of small odontocetes or approximately one-third of a sperm whale's (*Physeter macrocephalus)* total length, but suitable images can be difficult to obtain, being subject to environmental conditions and animal behaviour (Gordon, 1990; Dawson *et al*., 1995; Cheney *et al*., 2018; Durban *et al*., 2017; van Aswegen *et al*., 2019; Yahn *et al*., 2019). However, dorsal fin measurements have successfully been used to estimate total length for bottlenose dolphins, Hector's dolphins and long-finned pilot whales (Rowe *et al*., 2010; Webster *et al*., 2010; Wong and Auger-Méthé, 2018).

Common dolphins have a short BH-DF distance and often swim too fast to obtain scaled images displaying both the blowhole and dorsal fin in the same photo. As such, the dorsal fin represented a measurable target exposed higher above sea level during most surfacing sequences, which allowed for a greater number of opportunities to capture suitable images from boats low to the waterline (Durban and Parsons, 2006; Rowe *et al*., 2010; Webster *et al*., 2010; Wong and Auger-Méthé, 2018; Yahn *et al*., 2019). The dorsal fin was therefore selected in this study to determine the overall length of free-swimming common dolphins.

The ability to gauge the size structure of a population, individual growth rates and sex provide invaluable data to conservation organisations who otherwise would only be able to gather such information from dead individuals. While common dolphins are frequently recorded in Ireland, many life-history questions remain unanswered. Stranded individuals provide an opportunity to gather empirical data and samples, but pod size composition, sexual composition and age class is poorly understood at sea, given the limited number of recorded bycatch incidents (Murphy and Rogan, 2006; O'Brien *et al*., 2009). Laser photogrammetry length estimates may help provide answers to these critical life-history questions (Murphy and Rogan 2006; Brophy *et al*., 2009).

This study aims to: (1) develop a laser photogrammetry monitoring tool where stranded common dolphins are used to estimate the total body length of live individuals at sea based on dorsal fin measurements; and (2) use laser photogrammetry to non-invasively monitor common dolphins in Irish waters to help identify population size structure, growth rates and pod size composition.

METHODS

Empirical morphometric data collection

Morphometric data were collected opportunistically from dead common dolphins found stranded along the Irish coast by members of the Irish Whale and Dolphin Group (IWDG) stranding network or after recovery by the Irish Small Vertebrate Necropsy Project (2017-19) (Levesque *et al*., 2021). A standardised scaled photograph protocol was developed where a scale (ruler or measuring tape) was placed over the dorsal fin of a dead dolphin where dorsal fin height and dorsal fin base length were clearly visible at a 90° angle (Fig. 1). Total length measurements taken as a straight-line between the lower mandible to tail fluke notch were recorded where possible (O'Connell and Berrow, 2012).

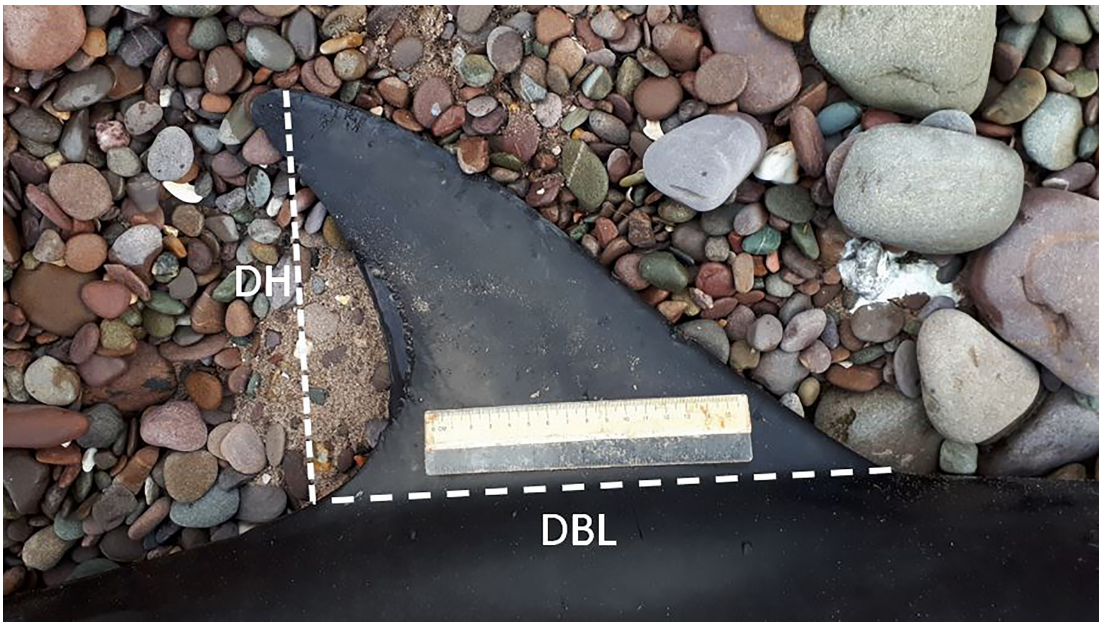


Fig. 1. A scaled dorsal fin image with a 150mm ruler to obtain remote measurements, with dorsal fin base length (DBL) and dorsal fin height (DH) indicated. [Photograph by Seán A. O'Callaghan]

Laser photogrammetry

Two Z-Bolt Emerald Galaxy (GX-5) 532nm lasers were fixed 50mm apart within a custom-built aluminium frame attached to the inverted tripod mount of a Canon 650D DSLR with a Canon zoom lens EF 70–200mm 1:2:8 L ultrasonic (see Appendix 1). The laser scale was calibrated by projecting both laser dots onto a flat surface perpendicular to the camera before being manually checked against a 150mm ruler's scale. The range used during these calibrations reflected how close the target species would approach the camera at ≤10m (checked at 5 and 10m). The lasers were not fully collimated (aligned straight when the laser was pointed forward), similar to Webster *et al*. (2010). The left laser was angled slightly away from the right to ensure the laser dots were scaled at 50mm and parallel when projected onto targets 5–10m from the camera. The accuracy of the frame was assessed in the field before and after data were collected.

Fieldwork was undertaken during good sea conditions (≤ Beaufort 3) during the spring and summer months in Dingle Bay, Co. Kerry and off Union Hall, Co. Cork, off the southwest coast of Ireland. Small eco-tourism, whale-watching and research vessels (< 14m) were used as opportunistic platforms to gather data. These included a 13.1m hard-bottom Aquastar vessel (MV *Blasket Princess*), a 10.9m catamaran (MV *Holly Jo*) and 6–11.5m rigid inflatable boats (RIBs). Common dolphins were targeted as they approached the vessels from both port and starboard sides to obtain side-profile images with the laser scale before reaching the bow (Fig. 2). Individual dolphins were differentiated when identifiable features were noted during different surfacing sequences to determine how many different dolphins could be used to produce measurement estimates.

Fig. 2. Image of surfacing common dolphin with a 50mm scale projected onto it. [Photograph by Seán A. O'Callaghan]

Measuring images

Measurements were made retrospectively using the visible scale in the AragoJ software (version 0.6.1) by SAO'C (Alexio *et al*., 2020). Each image with a scale set (using a ruler or laser dots) was measured once the scale was clearly visible in the image and the animal was at approximately 90° to the camera. Two sets of measurements were then obtained from each image: (1) dorsal fin base length (DBL) from the anterior rise to the posterior end of the fin; (2) dorsal fin height (DH) at 90° from the fin's highest point to the marked DBL line (Fig. 1).

Measurements for each fin were replicated three times by SAO'C where the scale was reset each time. Measured lines were marked on each replicate to produce an averaged measurement estimate and coefficient of variation. Each measurement was taken from the pixel where the colour crossover occurred between the fin and the background to ensure maximum precision and consistency in the estimated values. Values were populated on a Microsoft Excel 2013 worksheet and averaged for further analysis.

Measurement error assessment

Measurement error arising from an increase in distance and/or deviation from a 90° angle was assessed using a common dolphin carcass. Three images with both lasers present on the animal's dorsal fin were taken at 90° at similar distances to those expected at sea (5, 7.5 and 10m). The DH and DBL were then measured with three replicates for each image to assess the range from which reliable estimates of the dorsal fin could be made.

Total length estimation

The relationship between total length and the dorsal fin morphometrics of stranded common dolphins was assessed using DH and DBL mean values. Both sets of measurements were visualised using scatterplots in the statistical software language R in RStudio (version 1.2.5033) (R Development Core Team, 2020). The stranding dorsal fin data were tested for normality using the Shapiro-Wilk Test to assess its appropriateness for a linear regression. A linear regression was then applied to the stranding data grouped together for males, females and unsexed individuals, where both dorsal fin and total length measurements were available to create a regression equation to determine the total length of free-swimming common dolphins at sea, irrespective of sex. DH and DBL were used as predictors of total length by determining the proportion of the R^2 value between the predictors to select the variable best suited to determine length estimates.

RESULTS

Stranding data

Between March 2017 and March 2023, dorsal fins were photographed with a scale present on 106 common dolphin stranded along the Irish coast. Of these, 83 had intact dorsal fins from which both measurements (DH and DBL) were taken (Fig. 3). Images were collected from 58 males, 40 females and five where the sex could not be determined due to scavenger damage (Haelters *et al*., 2016; O'Callaghan *et al*., 2020). Three further males had amputated tail flukes which suggests the dolphins may have been bycaught and prevented true total length measurements (Chen *et al*., 2011; Peltier *et al*., 2016; Murphy *et al*., 2019). These dolphins were included in the length estimates for unknown-sized live common dolphins photographed at sea.

The overall length of the stranded common dolphins (n = 103) that were measured where the tail fluke was intact with a measuring tape and scaled dorsal fin photos ranged from 96–238cm (mean 185.7cm, SD 31.44cm). When divided by sex, males (n = 58) ranged from 96–238cm (mean 189cm, SD 34.64cm) and females (n = 40) ranged from 117.5–231cm (mean 181cm, SD 25.80cm) (Fig. 4). Unsexed dolphins (n = 5) ranged from 135–212cm (mean 185.2cm, SD 33.30cm).

The dorsal fin measurements varied depending on the dolphin's sex. Male DH (n = 50) ranged from 9.43–24.10cm, averaging 17.25cm, SD 4.31cm, while females (n = 33) ranged from 9.05–22.47cm, averaging 15.73cm, SD 3.31cm (Fig. 5). Male DBL (n = 58) ranged from 16.27–36.18cm with a mean of 27.36cm, SD 5.12cm, while female DBL (n = 39) ranged from 16.36–31.65cm, averaging 24.74cm, SD 4.07cm (Fig. 5).

Measurement error

Measurement error arising from increasing distance and/or angle from 90° to the posterior and anterior end of a common dolphin dorsal fin was also assessed. The overall mean values for DH and DBL between 5–10m remained constant when images were taken at 90° to the dorsal fin. Variation of 20mm in the DBL measurements occurred with the estimated length increasing by 24mm between 5–7.5m and dropping by 4mm between 7.5–10m, resulting in an R^2 value of 0.58. The mean DH measurements displayed an overall increase of 17mm when photographed between 5–10m with a R^2 value of 0.99 (see Appendix 2).

Measurement error increased with distance and deviation from a 90° angle. This indicates that underestimates were smallest when photographed from a distance of 5m and ranged from 1–18mm, while overestimates between 4–33mm were recorded at a distance of 10m, which indicates an increasing level of inaccuracy with increasing angles. Coefficient of variation (CV) % values of 0.69% were noted for DH between 5–10m in distance and 1.23% for DBL. Measurement error for deviated angles ranged from 0.83–2.56% for DH and 2.36–3.15% for

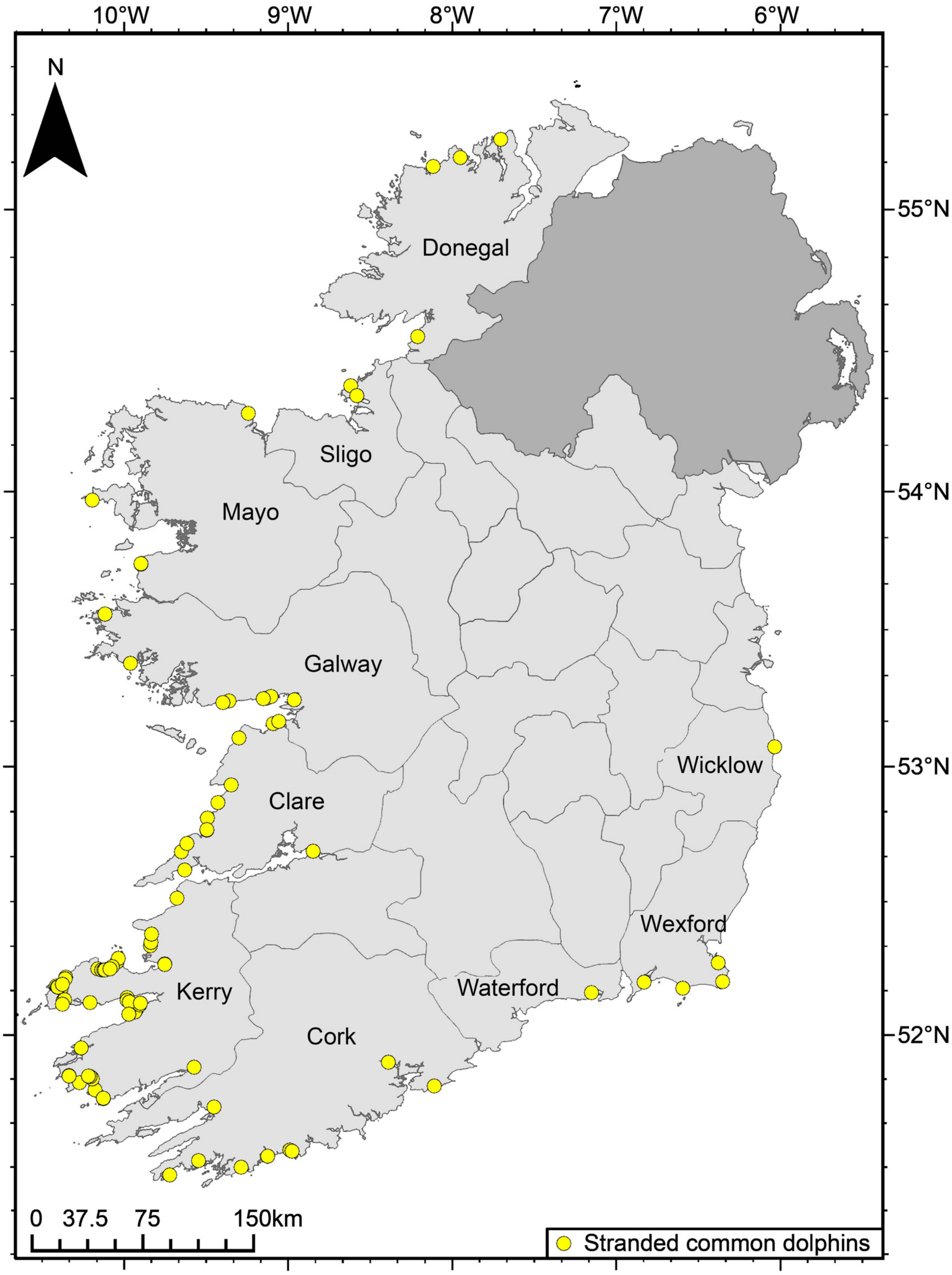


Fig. 3. Location of stranded common dolphins in Ireland (2017–23) from which measurement data was used in this study.

DBL (see Appendix 2). Angles < 80° or > 110° obscured the dorsal fin so that appropriate measurements could not be obtained.

Live dolphin length estimates

Fieldwork involving live common dolphins was undertaken opportunistically off the southwest Irish coast between February 2018 and April 2019 (Fig. 6). Pod sizes ranged from approximately 10 to > 50 individuals, including one maternal group, with both adults and calves present. A total of 29 individuals were photographed where the

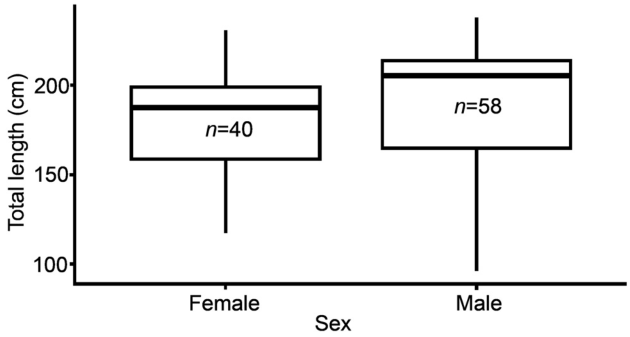


Fig. 4. Total body length (cm) of stranded common dolphins when sex was known for female (n = 40) and male (n = 58) individuals.

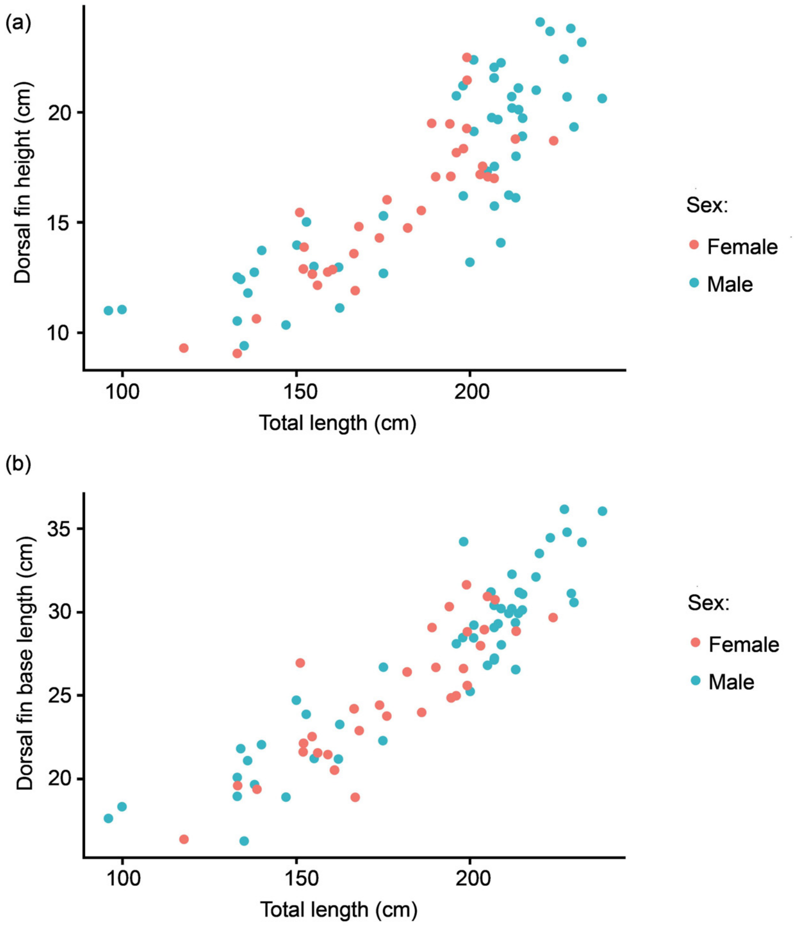


Fig. 5. Total length measurements plotted against (a) dorsal fin height and (b) dorsal fin base length for stranded male and female common dolphins.

laser scale was clearly visible and the dorsal fin was at an appropriate angle so that DH and DBL measurements could be made. One image was selected per dolphin for measurement estimates. No re-sighted dolphins were measured more than once.

The estimated DH for live common dolphins ranged from 14.13–24.49cm, averaging 17.86cm, SD 2.27cm, while the DBL ranged from 22.25–35.99cm, with a mean of 28.39cm, SD 3.09cm (Fig. 7; Appendix 3). The DH for dolphins with amputated tail flukes (n = 2; one dolphin was removed due to scavenger damage) were 17.35 and 17.57cm. The DBL (n = 3) ranged from 19.27–26.18cm with a mean of 23.50cm, SD 19.92cm. The lengths measured for these bycaught dolphins (to the point of amputation) were 160, 183 and 200cm.

The length distribution combining male and female stranded common dolphins displayed a normal distribution (Shapiro-Wilk Test: W = 0.97; p = 0.11; n = 85). Sixteen dolphins were removed from the sample due to extensive scavenger damage to the apex of the dorsal fin, most likely caused by red foxes (*Vulpes vulpes*) (Fig. 3; Haelters *et al*., 2016; O'Callaghan *et al*., 2020).

A linear regression was applied to DH against total body length of stranded common dolphins, resulting in a significant positive relationship between both measurements ($R^2 = 0.71$; p = < 0.05; n = 85). When applied to DBL, an additional significant positive relationship was identified ($R^2 = 0.78$; p = < 0.05; n = 85) which indicated a strong relationship between DBL and total length.

DBL was chosen as a better predictor of overall total length from these data due to its higher R value (see Appendix 4). A regression equation was used to estimate live common dolphin length:

$$Y = 30.2828 + 5.8897 * (DBL)$$

Using this equation for live common dolphins photographed at sea (n = 29), total lengths ranged from 166.33–242.52cm with a mean of 197.48cm ± 18.17cm SD (Table 1).

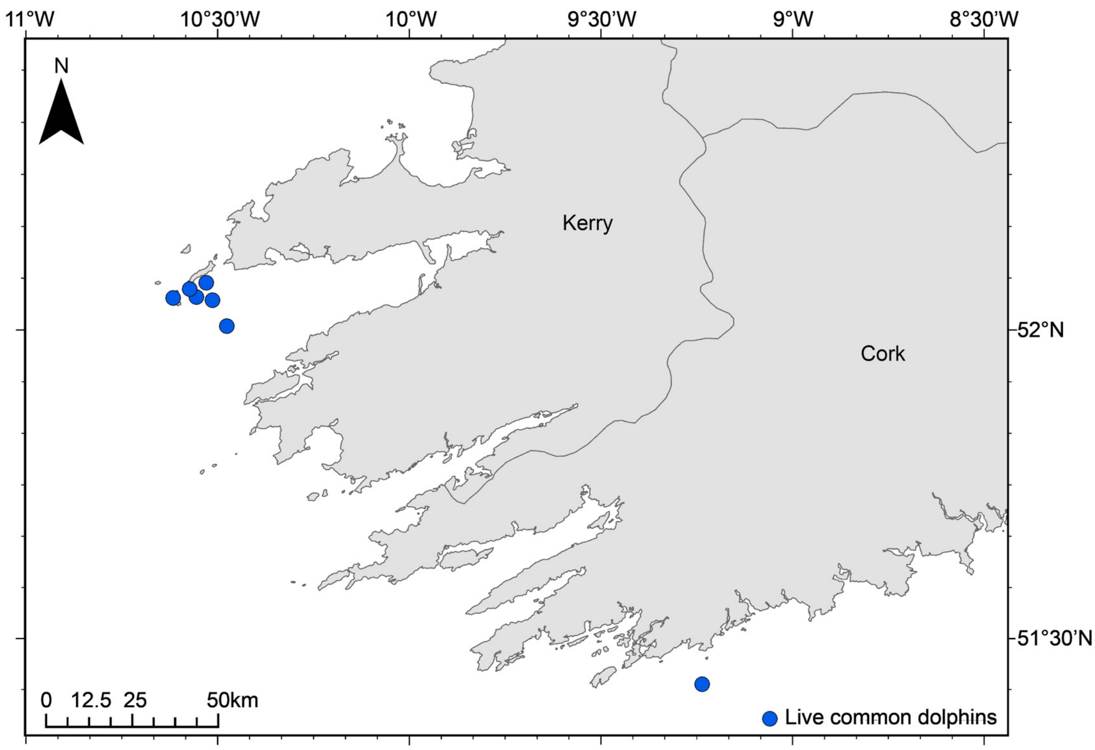


Fig. 6. Locations where live common dolphins were photographed to obtain total length estimates off Kerry and Cork in southwest Ireland in Feb/Mar 2018 and April 2019.

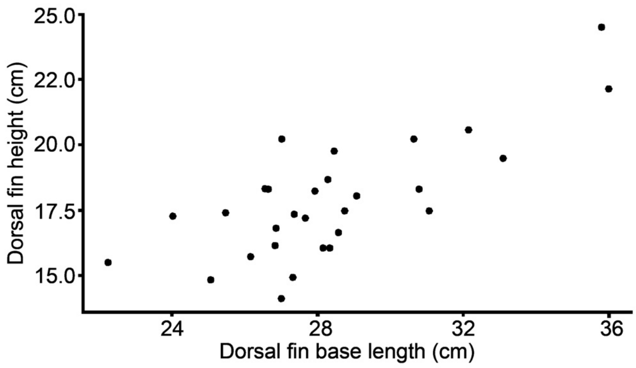


Fig. 7. Live common dolphin dorsal fin measurement estimates (n = 29).

The bycaught dolphins (n = 3) were estimated to be 143.78, 177.76 and 184.48cm in length (physical measurements for these individuals to the fluke amputation were 183, 200 and 160cm). As such, just one of these bycaught dolphins displayed a length estimate larger than the physical measurement to the point of amputation as expected: 184.48cm estimated length vs. 160cm actual measurement, indicating that 24.5cm had been removed from the individual's total length.

DISCUSSION

This study demonstrates the value of systematically collecting stranding data to retrospectively ensure consistency across dorsal fin measurements from dead common dolphins. These measurements provided the basis to produce the length estimation equation for live common dolphins using laser photogrammetry at sea. Taking remote and retrospective measurements with a scale reduced the scope for error and bias when measuring dorsal fin features between stranding recorders in the field. It also ensured the data were consistent and of high-enough quality to undertake this study, even though some strandings could not be measured in a laboratory or by the same person and even when data were submitted by members of the general public.

This study successfully used the DBL measurement to estimate the total length of live common dolphins at sea. The length estimates indicate that the majority of the live common dolphins in this study were sexually mature at 69% (n = 22) (> 188cm in length for a sexually mature female; Murphy and Rogan, 2006) and 45% (n = 10) were juveniles. There were two estimated dolphins larger than the maximum length of 231cm reported by Murphy and Rogan (2006) which may indicate a slight size shift for this species or an increased presence of larger males in Irish waters, but the majority of the estimated sample were within the size threshold for the species. As such, this technique can provide useful data on the species' age class dynamics within pods of live dolphins at sea.

Most of the stranding data came from Co. Kerry which reflects the collection effort of the Irish Small Vertebrate Necropsy Project and stranding network data collectors who contributed to this study. In addition, this was where a large number of common dolphin strandings occur relative to the rest of Ireland (McGovern *et al*., 2016). Strandings were well distributed across all seasons and included animals from the south, northwestern and eastern coasts (Fig. 3).

The use of obvious body features to estimate the total length of an animal is not only useful for sightings of live animals but can also be applied to dead individuals who are missing posterior or anterior sections of their body (particularly the tail fluke) (Chen *et al*., 2011). These data may otherwise be lost, which could be significant when trying to estimate the length and age of bycaught individuals. Here we calculate the total body length of three individuals where true total length measurements could not be obtained as the tail fluke had been amputated.

Just one of the three stranded common dolphins with amputated tail flukes produced a length estimate greater than the physical measurement taken from the carcass. The underestimate of total length for the other two dolphins with amputations by 22.2–39.2cm may be explained by the individual variability of dorsal fin sizes and corresponding total length values for this species and/or the placement of the scale in the photograph used to make the retrospective measurement. The individual with a 183cm physical measurement to the point of amputation (estimated total length 143.78cm) displayed the measuring tape used to set the retrospective scale closer to the camera on the dolphin's flank rather than on the dorsal fin itself which would reduce the overall scale size projected onto the dorsal fin in AragoJ. A larger stranding sample size to account for dorsal fin size and scale projection variability compared to the complete total length values may help reduce such errors in future.

The common dolphin's quick surfacing speed and split-second surfacing time when approaching vessels meant that the dorsal fin presented the best opportunities to routinely gather measurements to estimate total length. The smaller laser scale (50mm) used in this study was developed to maximise opportunities for capturing images with both laser dots present on the smaller dorsal fin of common dolphins (especially calves) in comparison with 100–235mm laser scales previously used on other dolphins and larger species (Durban and Parsons 2006; Rowe *et al*., 2010; Webster *et al*., 2010; Durban *et al*., 2017; van Aswegen *et al*., 2019). The 50mm scale would likely increase the chance of capturing measurable laser scales on smaller cetacean species, such as porpoises, in addition to dolphin neonates or calves.

No negative behavioural reactions were noted while using the laser scale on live common dolphins that approached the vessels. Additionally, the wavelength output of the lasers (532nm) has not been found to damage the eyes of dolphins (Zorn *et al*., 2000). Drones have been successfully used to estimate the length of common dolphins elsewhere and can be used to record the behaviour of measured dolphins in addition to their pod composition (Castro *et al*., 2021; Leander *et al*., 2021; Durban *et al*., 2022). There are constraints when using drones at sea, due to the potential to disturb the dolphins, depending on the height of flights and associated noise output (Christiansen *et al*., 2016; Castro *et al*., 2021; Laute *et al*., 2023). In addition, battery lifespan can be short (< 30 mins) and drone flights require favourable conditions with low wind and no precipitation in order to locate pods and produce high-quality photos for accurate measurements (Christiansen *et al*., 2016; Fiori *et al*., 2017; Johnston, 2019; Ramos *et al*., 2019; Giles *et al*., 2020; Castro *et al*., 2021; Leander *et al*., 2021; Aubin *et al*., 2023; Laute *et al*., 2023).

The use of laser photogrammetry to estimate the length of common dolphins provides a cost-effective alternative to drone photogrammetry. Standard small cetacean fieldwork equipment can be used (with slight adjustments) without the time required to develop new skills to safely operate a drone at sea and also to obtain the associated licenses (Rowe *et al*., 2010; Webster *et al*., 2010; Leander *et al*., 2021). Laser photogrammetry was facilitated by the common dolphin's typically inquisitive and approachable behaviour which enabled data collection even in marginal conditions from small vessels. Most information on the size structure of this species has come from dead individuals, either through bycatch or from strandings. These snapshots may not reflect the full seasonal and spatial variability displayed by this species which live measurement estimates can help to assess.

Laser photogrammetry can aid population monitoring efforts and provide data on the size structure of pods, including potential seasonal or spatial variability in common dolphin sizes. In addition, it may enable identification of sex using dimorphic features and provide quantitative data on size, growth rates and age class, all of which are key metrics to help monitor common dolphin populations off Ireland and elsewhere in the northeast Atlantic. Linking these life-history metrics to live dolphins can help conservation organisations actively monitor the health of populations at sea rather than relying on dead individuals which have been removed from the population. The methodology developed in this study demonstrates how to systematically collect morphometric data from stranded carcasses and apply it in a practical way to estimate the size of live or bycaught individuals. Applying these techniques to measurement estimates using standard photography equipment could lead to the accessible collection of critical life-history data for common dolphins and other cetacean species.

ACKNOWLEDGEMENTS

Morphometric data from individual stranded dolphins was obtained with the support of the IWDG Cetacean Stranding Network through former IWDG Strandings Officer Mick O'Connell. Special thanks are due to Louise Overy, Rosemary Hill, Nick Massett, Janette and John O'Callaghan, Vinny Hyland, Bogna Griffin, Ger Scollard, John Mark Dick, Kieran Mullin, Christina Winkler and Cuan O'Callaghan for gathering data. Support from Mick Sheeran of Eco Marine Tours, Jimmy Flannery of Dingle Sea Safari and Nick Massett was invaluable when collecting field data off the coast of Kerry and Colin Barnes of Cork Whale Watch when collecting field data off the coast of Cork. Thanks also to Tommy Evans of Torc Precision Engineering Limited, Killarney, Co. Kerry, for manufacturing the laser frames. Some biological data were collected through the 2017–19 Vertebrate Necropsy and Sample Recovery service contracts, funded by the European Maritime and Fisheries Fund and led by the Marine Institute, in partnership with the National Parks and Wildlife Service and the Department of Culture, Heritage and the Gaeltacht. This data collection was made possible by IWDG stranding coordinator Stephanie Levesque and supported by Jim O'Donovan from the Regional Veterinary Laboratory Cork, Department of Agriculture, Food and the Marine. The Z-Bolt lasers used in this study were purchased by the IWDG to support SAO'C's BSc (Hons) thesis in the Atlantic Technological University (formerly Galway-Mayo Institute of Technology).

REFERENCES

Adamczak, S. K., Holser, R. R., Costa, D. P., Berens McCabe E. J., Wells, R. S., 2021. Body composition of common bottlenose dolphins in Sarasota Bay, Florida. *Front. Mar. Sci.* 8. [Available at: *https://doi.org/10.3389/fmars.2021.615773*]

Alexio, F., O'Callaghan, S. A., Ducla Soares, L., Nunes, P., Prieto, R., 2020. AragoJ: A free, open-source software to aid single camera photogrammetry studies. *Methods Ecol. Evol.* 11(5): 670–677. [Available at: *https://doi.org/10.1111/2041-210X.13376*]

Astarloa, A., Louzao, M., Andrade, J., Babey, L., Berrow, S., Boisseau, O., Brereton, T., Dorémus, G., Evans, P. G. H., Hodgins, N. K., Lewis, M., Martinez-Cedeira, J., Pinsky, M. L., Ridoux, V., Saavedra, C., Santos, M. B., Thorson, J. T., Waggitt, J. J., Wall, D., Chust, G., 2021. The Role of Climate, Oceanography, and Prey in Driving Decadal Spatio-Temporal Patterns of a Highly Mobile Top Predator. *Front. Mar. Sci.* 8. [Available at: *https://doi.org/10.3389/fmars.2021.665474*]

Aubin, J. A., Mikus, M.-A., Michaud, R., Mennill, D., Vergara, V., 2023. Fly with care: belugas show evasive responses to low altitude drone flights. *Mar. Mam. Sci.* 39(3): 718–739. [Available at: *https://doi.org/10.1111/mms.12997*]

Brophy, J. T., Murphy, S., Rogan, R., 2009. The diet and feeding ecology of the short-beaked common dolphin (*Delphinus delphis*) in the northeast Atlantic. SC/61/SM/14 presented to the IWC Scientific Committee, Madeira, 2009. [Available from the Office of this Journal.]

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 Res. II* 112: 143–57. [Available at: *https://doi.org/10.1016/j.dsr2.2014.10.008*]

Castro, J., Borges, F. O., Cid, A., Laborde, M. I., Rosa, R., Pearson, H. C., 2021. Assessing the behavioural responses of small cetaceans to unmanned aerial vehicles. *Rem. Sens*. 13: 156. [Available at: *https://doi.org/10.3390/rs13010156*]

Castrillon, J., Nash S. B., 2020. Evaluating cetacean body condition; a review of traditional approaches and new developments. *Ecol. Evol.* 10(12): 6144–62. [Available at: *https://doi.org/10.1002/ece3.6301*]

Chen, I., Watson, A., Chou, L.-S., 2011. Calculating total body length from rostrum-anus length in amputated bycaught dolphins. *Mar. Mam. Sci.* 27(2): E126–33. [Available at: *https://doi.org/10.1111/j.1748-7692.2010.00421.x*]

Cheney, B., Wells, R. S., Barton, T. R., Thompson, P. M., 2018. Laser photogrammetry reveals variation in growth and early survival in free-ranging bottlenose dolphins. *Anim. Conserv.* 21(3): 252–61. [Available at: *https://doi.org/10.1111/acv.12384*]

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. *Front. Mar. Sci.* 3. [Available at: *https://doi.org/10.3389/fmars.2016.00277*]

Currey, R. J. C., Rowe, L. E., Dawson, S. M., Slooten, E., 2008. Abundance and demography of bottlenose dolphins in Dusky Sound, New Zealand, inferred from dorsal fin photographs. *N. Z. J. Mar. Freshw. Res.* 42(4): 439–49. [Available at: *https://doi.org/10.1080/00288330809509972*]

Dawson, S. M., Chessum, C. J., Hunt, P. J., Slooten, E., 1995. An inexpensive, stereophotographic technique to measure sperm whales from small boats. *Rep. Int. Wha. Comm.* 45: 431-36.

Durban, J. W., Parsons, K. M., 2006. Laser-metrics of free-ranging killer whales. *Mar. Mam. Sci.* 22(3): 735–43. [Available at: *https://doi.org/10.1111/j.1748-7692.2006.00068.x*]

Durban, J. W., Fearnbach, H., Burrows, D. G., Ylitalo, G. M., 2017. Morphological and ecological evidence for two sympatric forms of Type B killer whale around the Antarctic Peninsula. *Polar Biol.* 40: 231-236. [Available at: *https://doi.org/10.1007/s00300-016-1942-x*]

Durban, J. W., Southall, B. L., Calambokidis, J., Casey, C., Fearnbach, H., Joyce, T. W., Fahlbusch, J. A., Oudejans, M. G., Fregosi, S., Friedlaender, A. S., Kellar, N. M., Visser, F., 2022. Integrating remote sensing methods during controlled exposure experiments to quantify group responses of dolphins to navy sonar. *Mar. Poll. Bull.* 174: 113194. [Available at: *https://doi.org/10.1016/j.marpolbul.2021.113194*]

Evans, P. G. H., Waggitt, J. J., 2020. Impacts of climate change on marine mammals, relevant to the coastal and marine environment around the UK. *MCCIP Science Review 2020* 421–455. [Available at: *https://doi.org/10.14465/2020.arc19.mmm*]

Fairley, J. S., 1981. *Irish Whales and Whaling*. Blackstaff Press.

Fernández-Contreras, M. M., Cardona, L., Lockyer, C. H., Aguilar, A., 2010. Incidental bycatch of short-beaked common dolphins (*Delphinus delphis*) by pairtrawlers off northwestern Spain. *ICES J. Mar. Sci.* 67(8): 1732–38. [Available at: *https://doi.org/10.1093/icesjms/fsq077*]

Fiori, L., Doshi, A., Martinez, E., Orams, M. B., Bollard-Breen, B., 2017. The use of unmanned aerial systems in marine mammal research. *Remo. Sen.* 9(6): 543. [Available at: *https://doi.org/10.3390/rs9060543*]

Giles, A. B., Butcher, P. A., Colefax, A. P., Pagendam, D. E., Mayjor, M., Kelaher, B. P., 2020. Responses of bottlenose dolphins (*Tursiops spp*.) to small drones. *Aqu Cons* 31(3): 677–84. [Available at: *https://doi.org/10.1002/aqc.3440*]

Gordon, J. C. D., 1990. A simple photographic technique for measuring the length of whales from boats at sea. *Rep. Int. Wha. Comm*. 40: 581-88.

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. *Endanger. Species Res.* 40: 183–88. [Available at: *https://doi.org/10.3354/esr00993*]

Haelters, J., Everaarts, E., Bunskoek, P., Begeman, L., Hinrichs, J. W. J., Ijsseldijk, L. L., 2016. A suspected scavenging event by red foxes (*Vulpes vulpes*) on a live stranded harbour porpoise (*Phocoena phocoena*). *Aquat. Mamm.* 42: 227–32. [Available at: *https://doi.org/10.1578/am.42.2.2016.227*]

Johnston, D. W., 2019. Unoccupied aircraft systems in marine science and conservation. *Annu. Rev. Mar. Sci.* 11: 439–436. [Available at: *https://doi.org/10.1146/annurev-marine-010318-095323*]

Laute, A., Glarou, M., Dodds, F., Røsand, S. C. G., Grove, T. J., Stoller, A., Rasmussen, M. H., Fournet, M. E. H., 2023. Underwater sound of three unoccupied aerial vehicles at varying altitudes and horizontal distances. *J. Acoust. Soc. Am.* 153(6): 3419. [Available at: *https://doi.org/10.1121/10.0019805*]

Leander, S. G. M., Durban, J. W., Danil, K., Fearnbach, H., Joyce, T. W., Balance, L. T., 2021. 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. *Mar. Mam. Sci.* 37(4): 1507–13. [Available at: *https://doi.org/10.1111/mms.12804*]

Levesque, S., O'Donovan, J., Daly, M., Murphy, S., O'Connell, M., Jepson, P., Deaville, R., Barnett, J., Berrow, S. D., 2021. *Supply of Vertebrate Necropsy and Sample Recovery Services: Merged Final Reports*. EMFF 2014–2020 Marine Institute Report Series. Marine Institute, Ireland.

McGovern, B., Culloch, R. M., O'Connell, M., Berrow, S., 2016. Temporal and spatial trends in stranding records of cetaceans on the Irish coast, 2002–14. *J. Mar. Biol. Assoc.* 98(5): 1–13. [Available at: *https://doi.org/10.1017/S0025315416001594*]

Murphy, S., Collet, A., Rogan, E., 2005. Mating strategy in the male common dolphin (*Delphinus delphis*): what gonadal analysis tells us. *J. Mammal*. 86(6): 1247–58. [Available at: *https://doi.org/10.1644/1545-1542(2005)86[1247:MSITMC]2.0.CO;2*]

Murphy, S., Rogan, E., 2006. External morphology of the short-beaked common dolphin *Delphinus delphis*: growth, allometric relationships and sexual dimorphism. *Acta Zool. Litu.* 87(4): 315–329. [Available at: *https://doi.org/10.1111/j.1463-6395.2006.00245.x*]

Murphy, S., Winship, A., Dabin, W., Jepson, P. D., Deaville, R., Reid, R. J., Spurrier, C., Rogan, E., Lopez, A., Gonzalez, A. F., Read, F. L., Addink, M., Silva, M., Ridoux, V., Learmonth, J. A., Pierce, G. J., Northridge, S. P., 2009. Importance of biological parameters in assessing the status of *Delphinus delphis*. *Mar. Ecol. Prog. Ser.* 388: 273-91. [Available at: *https://doi.org/10.3354/meps08129*]

Murphy, S., Pinn, E. H., Jepson, P. D., 2013. The short-beaked common dolphin (*Delphinus delphis*) in the north-east Atlantic: distribution, ecology, management and conservation status. *Oceanogr. Mar. Biol.* 51: 193-280.

Murphy, S., Evans, P. G. H., Pinn, E., Pierce, G. J., 2019. Conservation management of common dolphins: Lessons learned from the North-East Atlantic. *Aquat. Conserv.: Mar. Fresw. Ecosyst.* 31(S1): 1–30. [Available at: *https://doi.org/10.1002/aqc.3212*]

O'Brien, J., Berrow, S., McGrath, D., Evans, P., 2009. Cetaceans in Irish waters: A review of recent research. *Biol. Environ.* Env 109B(2): 63–88. [Available at: *https://doi.org/10.3318/BIOE.2009.109.2.63*]

O'Callaghan, S. A., O'Connor, I., Berrow, S., 2020. Avian scavengers utilising a stranded dolphin on the west coast of Ireland. *Irish Birds* 43:106–7.

O'Connell, M., Berrow, S., 2012. *Report of the Cetacean Strandings Scheme January–December 2011*. Irish Whale and Dolphin Group.

O'Connell, M., Berrow, S., 2020. Records from the Irish Whale and Dolphin Group for 2018. *Ir. Nat. J.* 37(1): 64–72.

Peltier, H., Authier, M., Deaville, R., Dabin, W., Jepson, P. D., Canneyt, O. V., Daniel, P., Ridoux, V., 2016. Small cetacean bycatch as estimated from stranding schemes: The common dolphin case in the northeast Atlantic. *Environ. Sci. Pol.* 63: 7–18. [Available at: *https://doi.org/10.1016/j.envsci.2016.05.004*]

Perrin, W. F., 2018. Common dolphin *Delphinus delphis*. In: B. Würsig, J. G. M. Thewissen, K. M. Kovacs (Eds.), *Encyclopedia of Marine Mammals*, 3rd ed. (pp.205–9). Academic Press.

Perryman, W. L., Lynn, M. S., 1993. Identification of geographic forms of common dolphin (*Delphinus delphis*) from aerial photogrammetry. *Mar. Mamm. Sci.* 9(2): 119–37. [Available at: *https://doi.org/10.1111/j.1748-7692.1993.tb00438.x*]

R Development Core Team, 2020. *R: A Language And Environment For Statistical Computing*. Foundation for Statistical Computing, Vienna, Austria.

Ramos, E. A., Maloney, B., Magnasco, M. O., Reiss, D., 2019. Bottlenose dolphins and Antillean manatees respond to small multi-rotor unmanned aerial systems. *Front. Mar. Sci.* 5:316. [Available at: *https://doi.org/10.3389/fmars.2018.00316*]

Rogan, E. 2016. Common dolphin (*Delphis delphis*). In: L. Lysaght and F. Marnell (Eds.), *Atlas of Mammals in Ireland 2010–2015* (1st ed., pp. 159–160). National Biodiversity Data Centre.

Rogan, E., Mackey, M., 2007. Megafauna bycatch in drift nets for albacore tuna (*Thunnus alalunga*) in the NE Atlantic. *Fish. Res.* 86(1): 6-14. [Available at: *https://doi.org/10.1016/j.fishres.2007.02.013*]

Rogan, E., Breen, P., Mackey, M., Cañadas, A., Scheidat, M., Geelhoed, S., Jessopp, M., 2018. *Aerial surveys of cetaceans and seabirds in Irish waters: Occurrence, distribution and abundance in 2015–17*. Report to the Department of Culture, Heritage and the Gaeltacht, Dublin, Ireland.

Rowe, L. E., Dawson, S. M., 2008. Laser photogrammetry to determine dorsal fin size in a population of bottlenose dolphins from Doubtful Sound, New Zealand. *Aust. J. Zool.* 56(4): 239–248. [Available at: *https://doi.org/10.1071/ZO08051*]

Rowe, L. E., Dawson, S. M., 2009. Determining the sex of bottlenose dolphins from Doubtful Sound using dorsal fin photographs. *Mar. Mamm. Sci*. 25(1): 19–34. [Available at: *https://doi.org/10.1111/j.1748-7692.2008.00235.x*]

Rowe, L. E., Currey, R. J. C., Dawson, S. M., Johnson, D., 2010. Assessment of epidermal condition and calf size of Fiordland bottlenose dolphin populations using dorsal fin photographs and photogrammetry. *Endanger. Species Res.* 11: 83–89. [Available at: *https://doi.org/10.3354/esr00256*]

Ryan, C., Berrow, S. D., McHugh, B., O'Donnell, C., Trueman, C. N., O'Connor, I., 2014. Prey preferences of sympatric (*Balaenoptera physalus*) and humpback (*Megaptera novaeangliae*) whales revealed by stable isotope mixing models. *Mar. Mamm. Sci.* 30(1): 242–258. [Available at: *https://doi.org/10.1111/mms.12034*]

Ryan, C., 2022. Insights into the biology and ecology of whales in Ireland 100 years ago from archived whaling data. *Ir. Nat. J.* 39: 24–35.

Stewart, J. D., Durban, J. W., Europe, H., Fearnbach, H., Hamilton, P. K., Knowlton, A. R., Lynn, M. S., Miller, C. A., Perryman, W. L., Tao, B. W. H., Moore, M. J., 2022. Larger females have more calves: influence of maternal body length on fecundity in North Atlantic right whales. *Mar. Ecol. Prog. Ser.* 689: 179-189. [Available at: *https://doi.org/10.3354/meps14040*]

van Aswegen, M., Christiansen, F., Symons, J., Mann, J., Nicholson, K., Sprogis, K., Bejder, L., 2019. Morphological differences between coastal bottlenose dolphin (*Tursiops aduncus*) populations identified using non-invasive stereo-laser photogrammetry. *Sci. Rep.* 9: 12235. [Available at: *https://doi.org/10.1038/s41598-019-48419-3*]

Wong, J. B., Auger-Méthé, M., 2018. Using laser photogrammetry to measure long-finned pilot whales (*Globicephala melas*). *Proceed. N. S. Inst. Sci.* 49(2): 269–291.

Webster, T., Dawson, S., Slooten, E., 2010. A simple laser photogrammetry technique for measuring Hector's dolphins (*Cephalorhynchus hectori*) in the field. *Mar. Mamm. Sci.* 26(2): 296–308. [Available at: *https://doi.org/10.1111/j.1748-7692.2009.00326.x*]

Yahn, S. N., Baird, R. W., Mahaffy, S. D., Webster, D. L., 2019. How to tell them apart? Discriminating tropical blackfish species using fin and body measurements from photographs taken at sea. *Mar. Mamm. Sci.* 35(4): 1232–52. [Available at: *https://doi.org/10.1111/mms.12584*]

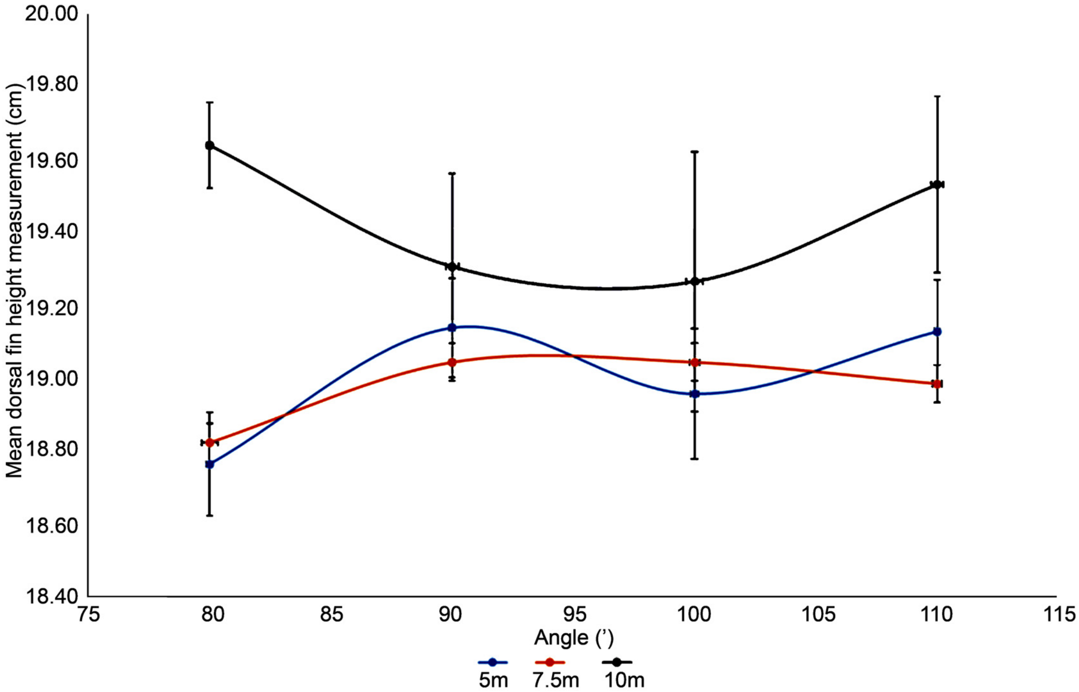
Yahn, S. N., Baird, R. W., Mahaffy, S. D., Robertson, K. M., 2023. Sexually dimorphic characteristics of short-finned pilot whales, false killer whales, pygmy killer whales, and melon-headed whales assessed using fin and body measurements from photographs taken at sea. *Mar. Mamm. Sci.* 39(1): 98–113. [Available at: *https://doi.org/10.1111/mms.12963*]

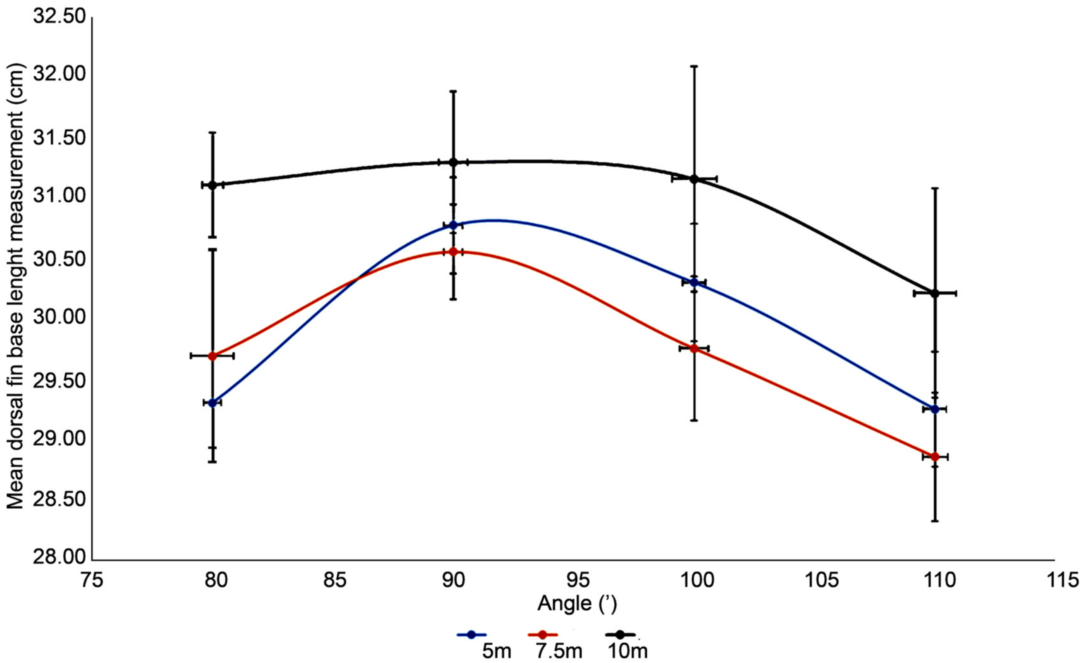
Zorn, H. E., Churnside, J. H., Oliver, C. W., 2000. Laser safety thresholds for cetaceans and pinnipeds. *Mar. Mamm. Sci.* 16(1): 186–200. [Available at: *https://doi.org/10.1111/j.1748-7692.2000.tb00912.x*]

APPENDIX 1

Appendix 1. The laser frame fixed onto the camera used during this studies fieldwork. [Photograph by Seán A. O'Callaghan]

APPENDIX 2





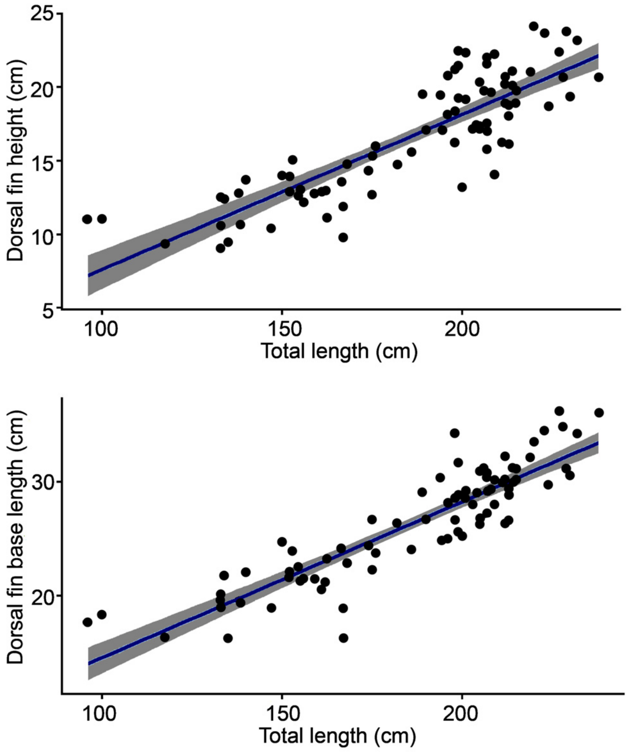
Appendix 2. (a) Dorsal fin height measurement error with increasing distance and angles varying from 90°. (b) Dorsal fin base length measurement error with increasing distance and angles varying from 90°.

APPENDIX 3

Common dolphin length estimates for line (CD) and potentially bycaught (DD) individuals using the dorsal fin base length (DBL).

Individual	Mean DBL (cm)	Total length estimate (cm)
CD 1	28.15	196.69
CD 2	25.06	178.61
CD 3	28.33	197.75
CD 4	26.55	187.33
CD 5	26.83	188.97
CD 6	27	189.96
CD 7	27.02	190.08
CD 8	26.16	185.04
CD 9	26.86	189.14
CD 10	30.64	211.27
CD 11	32.14	220.05
CD 12	25.48	181.06
CD 13	27.93	195.40
CD 14	22.25	162.16
CD 15	27.36	192.07
CD 16	28.57	199.15
CD 17	35.8	241.47
CD 18	26.65	187.91
CD 19	27.32	191.83
CD 20	24.03	172.58
CD 21	28.75	200.20
CD 22	30.79	212.14
CD 23	33.09	225.61
CD 24	31.06	213.72
CD 25	28.28	197.45
CD 26	29.07	202.08
CD 27	28.45	198.45
CD 28	27.66	193.82
CD 29	35.99	242.58
DD 1	26.18	185.16
DD 2	25.04	178.49
DD 3	19.27	144.72

APPENDIX 4



Appendix 4. (a) Stranded common dolphin total lengths and dorsal fin height measurements with a linear regression applied. (b) Stranded common dolphin total lengths and dorsal fin dorsal fin base length measurements with a linear regression applied.