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3D MASC: a method for estimating relative head angle and spatial distance of dolphins from underwater video footage

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The method described here, the 3D model analogous scale calculator (3D MASC), was developed to address a need for obtaining accurate measurements of dolphin head and body positional information from segments of underwater video recordings. Various methods exist for obtaining precise positional or distance measurements to/between individuals or groups from observational research on cetaceans, for example, theodolite tracking (Bailey & Lusseau 2004), hydrophone array triangulation (Lammers et al. 2006), photogrammetry (Jaquet 2006) and videogrammetry (Spitz et al. 2000). However, these methods are not applicable to all field study situations and, consequently, observational data for cetaceans are often coded or scored based on subjective observer estimates. Several studies have used methods for obtaining cetacean swimming proximity by estimating distance apart and stagger (i.e. length ahead/behind) (Connor et al. 2006) and body length (Barrett-Lennard et al. 1996) based on observer 'eyeball' estimation techniques. The 3D MASC method was developed for application to determining more precise positional and distance estimates between individual wild dolphins from underwater video data. Methods that rely on simple and cost-effective techniques for measuring distance and relative size of animals from video data using handheld sonar devices in conjunction with video have been previously developed (e.g. underwater videogrammetry described by Spitz et al. 2000); however, the 3D MASC technique has the advantage of obtaining estimates without the need for collecting additional data from supplementary devices in the field because it relies solely on analysis of video data in the laboratory.

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The 3D MASC Method

The 3D MASC method was developed as part of a research project examining echolocation behaviour by wild dolphins. Underwater video and audio data were collected from a population of wild Indo-Pacific bottlenose dolphins, *Tursiops aduncus*, inhabiting the coastal waters of Mikura Island, Japan, as part of a long-term study conducted by the Dolphin Communication Project (DCP) (see Dudzinski et al. 1995, 2003; Kogi et al. 2004). The video data were analysed to measure the changes in body and head positions of dolphin dyads with regard to echolocation activity. To determine the angle of two dolphins' heads relative to each other and the distances that the dolphins are from each other, a computer-based measurement system was established. This process involved creating an accurate 3D model of a dolphin's head and positioning the model within a 3D computer-aided design (CAD) environment, allowing the user to recreate the scene observed in the 2D video image to scale. The software package used both to create the dolphin head model and to make the measurements was Google SketchUp, a 3D modelling programme available for download from the Internet free of charge.

The dolphin head models were created based on anatomical measurements of *T. aduncus* specimens and are represented within the 3D environment using a 1:1 scale. Two measurements were used for the model: 'tip of the rostrum to the external nares' (TREN) and 'greatest

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width across zygomatic processes of squamosal' or 'zygomatic width' (ZW), which is, for the purpose of the model, analogous to the width distance between the left and the right eyes. This yields four morphological points used for the model: rostrum tip, left eye, right eye and blowhole (external nares). The end points of each of these measurements for the corresponding morphological points were mapped in the 3D environment and then joined to create a 3D polygon model, which includes a line projection extending from the rostrum tip 1 m in length ('angle indicator projection') that is used in obtaining the measurement of the relative angle. Initial measurements were obtained from an article that provided TREN and ZW for a *T. aduncus* specimen from the Mikura Island population (Shirakihara et al. 2003). Dolphin specimen MIE003 (aged 12 years) was used as the prototype for the 'mature' dolphin skull because this dolphin is well within the range of physical maturity for this species (see Shirakihara et al. 2003). Following these measurements, the mature dolphin model has a TREN of 335 mm and a ZW of 245 mm (Fig. 1).

It was necessary, however, to produce models that could represent the various age groups of the dolphins observed in the main research project. From the Mikura study population, the dolphins ranged in age from neonates to fully grown adults. The mature skull would not be appropriate for representing distance and angle measurements for younger dolphins included in the video data; differing skull measures would compromise TREN and ZW estimates potentially caused by inappropriate scaling. Consequently, three additional models were created as representations of varying head/skull sizes for younger age groups (Fig. 2). The four age groups represented by the four models as derived from the available skull measurements are mature (>5 years, body length 216.5–251.0 cm), juvenile (2–5 years, body length 188.0–195.0 cm), calf (0.5–2 years, body length 144.0–173.0 cm) and neonate (birth–0.5 years, body length < 144.0 cm).

These categories were derived from comparisons of body length and known ages for the mature specimen described in Shirakihara et al. (2003), two additional mature Mikura specimens described in Kakuda et al. (2002) and unpublished data provided by C. Kemper showing TREN and body length measurements of seven young *T. aduncus* specimens collected from Australian waters (C. Kemper, personal communication). The measurements for the 10 specimens, ranging in age ~2–12 years, are provided in Table 1. These four age categories are not related to the typical developmental growth curves for *T. aduncus* where maturity is often described in terms of sexual maturity (e.g. Ross 1984); rather, these categories are related to average skull sizes for the established age categories. The models for the juvenile and calf age categories were created by scaling the mature model relative to the length of the average TREN measurement for the younger dolphins (Table 1, average juvenile TREN = 282 mm, average calf TREN = 239 mm). The neonate model was scaled to a TREN length 48% that of the mature prototype TREN (neonate TREN = 161 mm). This scaling is based on the Laird–Gompertz growth model of a related species, *Tursiops truncatus*, that places asymptotic neonate body length at 119.0 cm, 48% of the asymptotic body length of a mature dolphin of the same species (250.0 cm) (Stolen et al. 2002). For these models, measurements from male and female specimens were averaged together for each age category because it was assumed that any potential differences due to sexual dimorphism were likely to be negligible. Studies involving *T. truncatus* show that skull measurements do not differ significantly between sexes (see Hersh et al. 1990; Tolley et al. 1995), with similar results obtained for *T. aduncus* (Wang et al. 2000).

To recreate the 2D scene depicting dolphin heads in a 3D environment, an image was captured from the video and imported into the 3D environment of the Google SketchUp software. Video for which both dolphins could be identified (with age known) were used to allow determination of the appropriate 3D dolphin head model to select as best representing the likely head size of the dolphins in the video. In the few cases where the dolphin ID was not known, other physical, behavioural, and anatomical features were used to estimate the age of the dolphin(s) onscreen and therefore an appropriate 3D head model could be chosen. After selecting the appropriate-sized 3D head models for each dolphin, the models were then manipulated in 3D space until the four points of each model lined up with the corresponding morphological points on the heads of each dolphin in the 2D scene (i.e. rostrum tip, left eye, right eye and blowhole; Fig. 3).

Once a match was complete, the 'camera' in the 3D environment was adjusted to show a suitable view of both

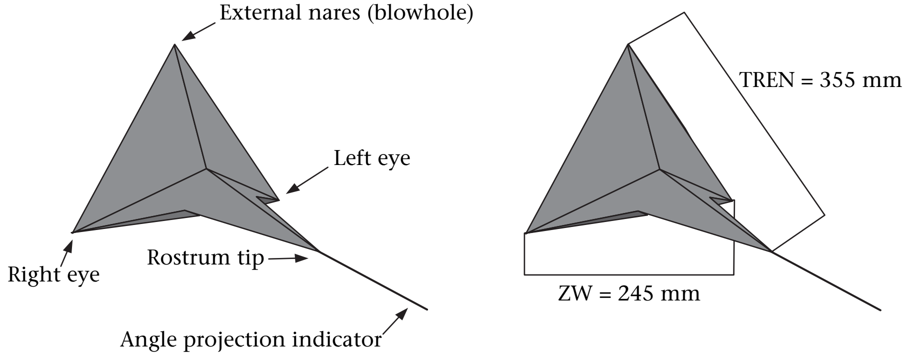

Figure 1. Example of the mature 3D dolphin head model used in the 3D MASC method. Distance between tip of rostrum to external nares (TREN) = 355 mm. Distance from left eye to right eye (ZW) = 245 mm.

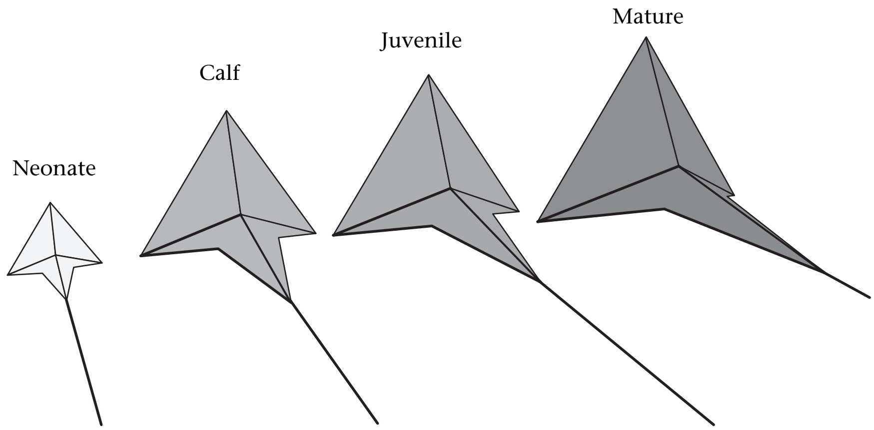

Figure 2. Head models representing the four relative dolphin age classes used in the 3D MASC method: mature, juvenile, calf and neonate. Neonate TREN = 161 mm, calf TREN = 239 mm, and juvenile TREN = 282 mm.

models for measuring distances. Using the software's 'tape measure' tool, the distance between the tips of the two rostrums was measured (Fig. 4). Given the scale model of the dolphin head created in the 3D environment, this provides an accurate estimate of the distance between the two rostrum tips in metres.

To measure the relative angles of the dolphins' heads, the two models were repositioned in 3D space without changing the relative angles of the models to the *X*, *Y* and *Z* axes. The rostrum tips were positioned so that they exactly overlapped (Fig. 5). The position of the two angle indicator projectors results in the formation of an isosceles triangle. The length of each of the angle indicator projectors extending from the rostrum tip is exactly 1 m (sides *b* and *c*; Fig. 5). By measuring the third side (*a*) using the tape measure tool (Fig. 5), the angle between the rostrums (*A*) can be calculated using the law of cosines: $a^2 = b^2 + c^2 - 2ab\ (\cos A)$. Rearranged to solve for angle *A*, the formula is

$$\cos A = \frac{b^2 + c^2 - a^2}{2bc}.$$

For the given example, side $c = 1$ m, side $b = 1$ m and side $a = 0.821$ m. Consequently, $A = 48°$. Note that the relative angle of the camera to the triangle that is formed by the three sides in Fig. 5 results in a 2D image that is not an isosceles triangle; measuring the sides of this 2D image

Table 1. Specimen measurements used to arrive at the 3D head models for the four dolphin age categories

Specimen	Body length (cm)	Known age (years)	TREN (mm)	Age category	Source
M30133	220.0	~7.5	338.5	Mature	Kakuda et al. 2002
M32733	216.5	~4.5	329	Mature	Kakuda et al. 2002
MIE003	251.0	12	335	Mature	Shirakihara et al. 2003
M16266	155.0	Unknown	250	Calf	C. Kemper unpublished data
M16608	188.0	Unknown	278	Juvenile	C. Kemper unpublished data
M17595	173.0	Unknown	253	Calf	C. Kemper unpublished data
M17597	144.0	Unknown	214	Calf	C. Kemper unpublished data
M18053	193.0	Unknown	271	Juvenile	C. Kemper unpublished data
M18057	190.0	Unknown	270	Juvenile	C. Kemper unpublished data
M19965	195.0	Unknown	308	Juvenile	C. Kemper unpublished data

C. Kemper data follow the South Australian Museum Adelaide international code for specimens.

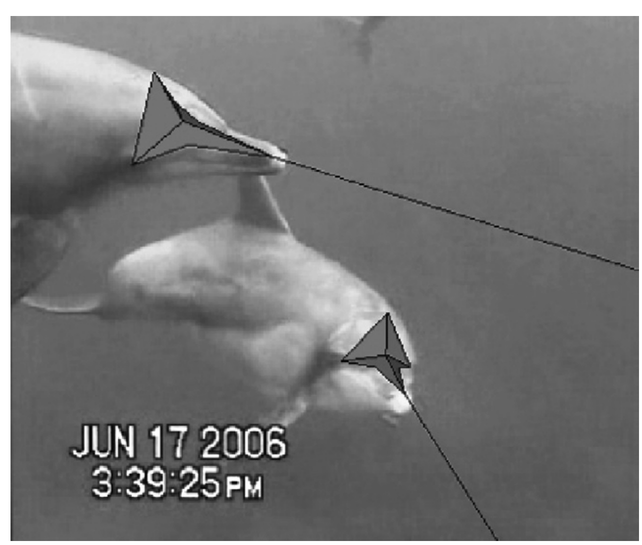

Figure 3. 2D image captured from underwater video and imported into the 3D environment of Google SketchUp. Appropriate-sized dolphin head models are mapped onto corresponding points of each dolphin head: rostrum tip, blowhole, left eye and right eye.

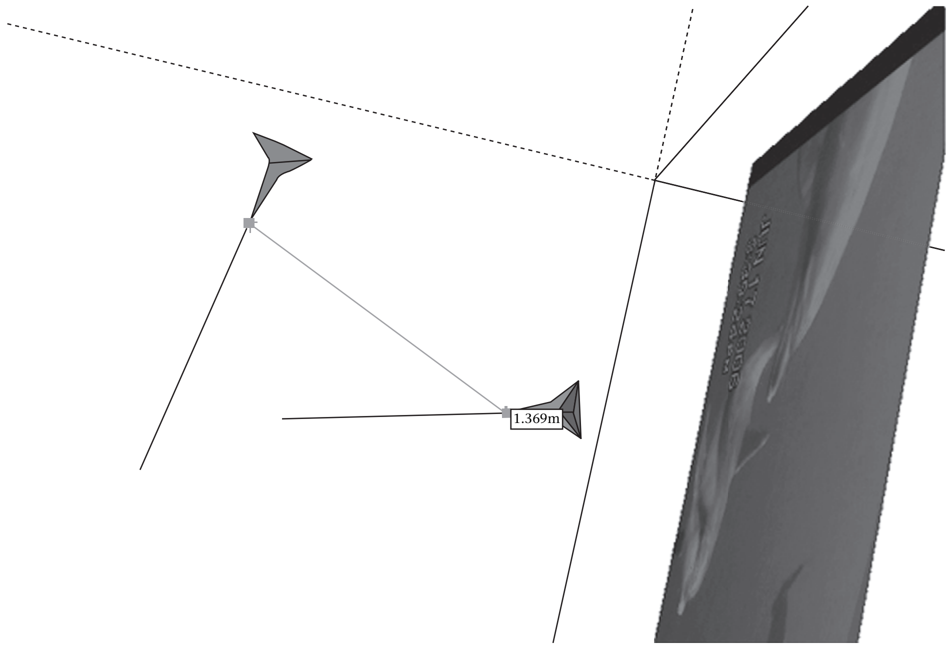

Figure 4. Models and 2D image viewed from above; the camera angle in the 3D environment has been adjusted to reveal a clear view of the models. Measurements of the spatial distance between the rostrum tips of each dolphin are taken using the software's tape measure tool within the 3D environment.

will not result in measurements of 1 m for *b* and *c*. This renders manual measurements of angles and distances using 2D tools inaccurate. Accurate measurements can be obtained only by using the known values within the 3D environment (e.g. tape measure tool, constant length of angle indicator projectors). This measurement will be constant regardless of the camera angle to the models.

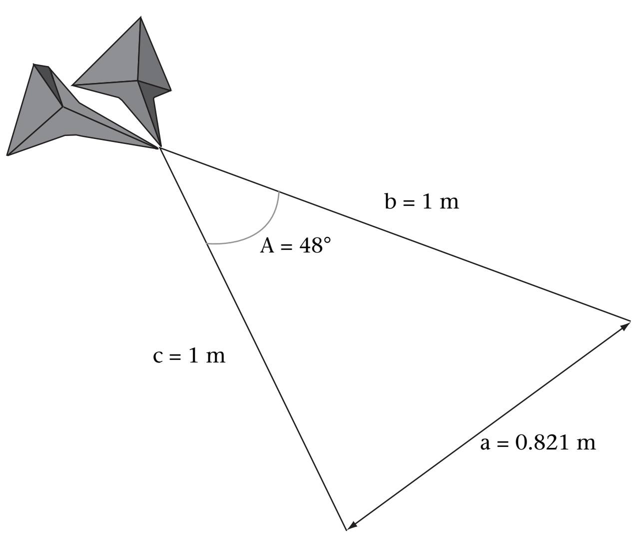

Figure 5. Models are repositioned so that the rostrum tips are aligned in the 3D environment, creating an isosceles triangle. Angle indicator projections for each model become sides *c* and *b* of the triangle with a constant measurement of 1 m for each projection. Side *a* is then measured using the software's tape measure tool and is composed of the distance between the tips of the angle indicator projections for each model ($a = 0.821$ m). Angle *A* can then be calculated using the law of cosines ($A = 48°$).

Validity

A test was performed to determine (1) how closely measurements obtained using the 3D MASC method match real-world measurements and (2) whether the 3D MASC method yields measurements that are more accurate than those yielded by traditional methods. Two dummy dolphin heads with the same size and shape as the model created in the CAD environment were constructed out of boxboard. The dummy heads were placed on supporting rods and manipulated into random positions at random distances in a clutter-free environment. Seventy images of the two dummy heads were taken from random vantage points using a digital still camera, with the position of the dummy heads altered between images. For each image, the distance between the rostrum tips of the dummy heads was recorded using a tape measure. The still image for each of the dummy head positions was imported into Google SketchUp, and the 3D MASC method was used to obtain the distance between rostrum tips. The two sets of 70 measurements were significantly and highly positively correlated ($r_{68} = 0.910$, $P < 0.001$), suggesting that the measurements obtained with the 3D MASC method closely match the real-world measurements. All correlation analyses were conducted using SPSS v12 (SPSS Inc., Chicago, IL, U.S.A.).

To test whether the 3D MASC method is superior to traditional distance estimation methods, a naïve experimenter (i.e. unaffiliated with this study) was given the opportunity to become familiar with the size and shape of the dummy dolphin heads and was then asked to view each of the 70 still images and to estimate the distance between rostrums using the eyeball method (i.e. using the depth and size cues present in the 2D image). The naïve experimenter's estimates were significantly positively correlated with the real-world measurements ($r_{68} = 0.789$, $P < 0.001$), although the correlation was lower than that between the 3D MASC and the real-world measurements. There was also a significant positive correlation between the 3D MASC and the eyeball methods ($r_{68} = 0.754$, $P < 0.001$).

A test was performed to determine whether there was a significant difference between the two correlation coefficients (i.e. the correlation between the 3D MASC method's measurements and the real-world measurements compared with that between the eyeball estimates and the real-world measurements). This test, Steiger's test for the difference between two nonindependent correlations (Steiger 1980), revealed that the 3D MASC method correlated significantly more highly with real-world measurements than did the eyeball method ($t_{67} = 3.54$, $P < 0.001$). Steiger's test was conducted using Microsoft Excel 2002. In light of the results of this test, it can be concluded that the 3D MASC method is superior to the traditional method when attempting to measure the distance between dolphin heads from video images.

Interobserver Reliability

A test was performed to calculate interobserver reliability for measurements obtained using the 3D MASC method. A naïve observer (i.e. unaffiliated with this study, but familiar with dolphin anatomy) was given oral instructions and shown a demonstration on how to use the 3D MASC method to obtain measurements for the dolphins recorded in the 2D images. After one supervised training trial, the naïve observer was given 15 randomly chosen 2D images/episodes and asked to record both distance and head angle using the 3D MASC method. The correlation was then calculated between these scores and those recorded independently by the first author for the same sample of images. The two sets of scores were significantly and highly correlated in the case of both distance (Pearson correlation: $r_{13} = 0.910$, $P < 0.001$) and head angle (Pearson correlation: $r_{13} = 0.921$, $P < 0.001$). These results indicate that the 3D MASC method is highly reliable. Inexperienced observers seem able to quickly and easily learn this measurement technique and have it yield consistent results.

Conclusion

The 3D MASC method of determining distance between rostrums and head angle measurements between two dolphins captured on video relies on scale models manipulated in a 3D environment and produces values that mirror the real-life situation. It is likely that using an eyeball estimation technique may result in a significant degree of error that may produce unreliable values for distance and head angles. The absence of stereoscopic depth and perspective cues in a 2D still or video image as well as the unknown factor of the size scale of the objects in the scene can produce extremely unreliable distance and angle estimates (Cutting & Vishton 1995). The new 3D MASC method aims to reduce these errors by introducing mathematical techniques in combination with true anatomical measurements of dolphin skulls rendered in a scale 3D environment to produce true-to-life distance and head angle estimates.

Errors in estimates are likely to come in two forms: inappropriate scale and user error. For the 3D MASC method to work properly, the 3D scale model of a dolphin head must be as close as possible to the real size of the dolphin head being measured from the video screen. Differences between the model and the actual dolphin head size will bias measurements. This is a particular problem for younger dolphin head models (neonate and calf) that were derived from highly variable measurements of young *T. aduncus* specimens that were subsequently placed into arbitrary age categories. It is also important to note that the scaled 3D head models for the younger dolphins are based on estimated average head sizes and, consequently, an appreciable margin of error exists which could confound measurements from video data of younger individuals. It should also be noted that average *T. aduncus* anatomical measurements vary somewhat between populations (e.g. South Africa, Japan, Taiwan, Australia, etc.), and the inclusion of Australian *T. aduncus* measurements as the basis for scaling of the younger dolphin models may have skewed the scale somewhat by providing nonanalogous TREN measurements for the Mikura population. Actual measurements of calf and neonate *T. aduncus* skulls from dolphins in Japan would facilitate confirmation of the precision of the 3D MASC methods as applied to younger dolphins. In terms of user error, this method requires the observer to accurately align the four morphological points in the 3D environment. If the user is unable to line up these points accurately, an analogous head position for the model will not be obtained, consequently biasing the resulting measurements. Still, interobserver reliability was high, suggesting that this method is relatively straightforward to learn and apply.

Aside from the advantages of relying on scale models and trigonometric techniques to provide better estimates, the 3D MASC method is valuable because it can be accomplished using CAD software that is available for free download (Google SketchUp). The 3D MASC is a cost-effective method that can be implemented with a minimum of complicated programming, intimate knowledge of CAD software or monetary investment. It is hoped that other research groups requiring similar measurements obtained from either underwater or surface video of other animal species can provide feedback as to the effectiveness/usefulness of this method.

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