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A combined stereo-photogrammetry and underwater-video system to study group composition of dolphins

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Abstract One reason for the paucity of knowledge of dolphin social structure is the difficulty of measuring individual dolphins. In Hector's dolphins, *Cephalorhynchus hectori*, total body length is a function of age, and sex can be determined by individual colouration pattern. We developed a novel system combining stereo-photogrammetry and underwater-video to record dolphin group composition. The system consists of two downward-looking single-lens-reflex (SLR) cameras and a Hi8 video camera in an underwater housing mounted on a small boat. Bow-riding Hector's dolphins were photographed and video-taped at close range in coastal waters around the South Island of New Zealand. Three-dimensional, stereoscopic measurements of the distance between the blowhole and the anterior margin of the dorsal fin (BH-DF) were calibrated by a suspended frame with reference points. Growth functions derived from measurements of 53 dead Hector's dolphins (29 female : 24 male) provided the necessary reference data. For the analysis, the measurements were synchronised with corresponding underwater-video of the genital area. A total of 27 successful measurements (8 with corresponding sex) were obtained, showing how this new system promises to be potentially useful for cetacean studies.

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Introduction

The age and sex composition of any social unit of mammals is directly relevant to studies of conservation biology, social behavior, and mating systems. Social groups are likely to fulfill a range of vital functions in acquisition and defense of resources, detection and avoidance of predators, reproduction and communal raising of progeny, and as a basis for social interactions in general (Delany 1982; Norris and Schilt 1988). Group compositions have been studied successfully for decades in terrestrial mammals such as carnivores (Macdonald 1983), ungulates (Jarman 1974), primates (Clutton-Brock and Harvey 1977) and elephants (Douglas-Hamilton 1973). For cetaceans, however, this is far more difficult because they are frequently inaccessible to the observer for extended periods.

In cetacean studies, the two general approaches used most often to describe social groups are: (1) documentation of individual co-occurrences as measured by association indices (e.g., Bejder et al. 1998), which also determine the likely composition and stability or fluidity of groups; and (2) by obtaining a sample or cross section of a group's composition. The latter can be obtained for cetacean species with an exaggerated sexual size dimorphism (e.g., killer whales, *Orcinus orca*; Bigg et al. 1990; sperm whales, *Physeter macrocephalus*; Rice 1989), from mass strandings and mass killings (e.g., pilot whales, *Globicephala* spp.; Kasuya and Marsh 1984; Martin et al. 1987; Amos et al. 1993; Bloch et al. 1993) or for species that can be caught for scientific purposes and released after sex and age determination (e.g., bottlenose dolphins, *Tursiops truncatus*; Wells et al. 1987; Odell and Asper 1990; Scott et al. 1990a, b; Wells 1991; Read et al. 1993; Würsig and Lynn 1996).

Cetaceans exhibit a close relationship of increasing body length with age for immatures and subadults, and this trait has been used for photogrammetric measurements in free-living populations of several species (Rüther and Adams 1984; Heimlich-Boran 1986; Cubbage and Calambokidis 1987; Scott and Perryman 1991; Best and Rüther 1992; Ratnaswamy and Winn 1993; Angliss et al. 1995; Dawson et al. 1995; Guinet and Bouvier 1995; Perryman and Westlake 1998). In odontocetes, body length tends to reach an asymptote at sexual maturity or some time thereafter (e.g., Gaskin and Blair 1977; Read and Gaskin 1990; Ferrero and Walker 1996; Marsili et al. 1997; Read and Tolley 1997; but see also Day and Taylor 1997). Although aerial stereo-photogrammetry has been used for decades (mainly in surveying; e.g., Wolf 1983; Karara 1989), stereo-photogrammetric measurements of whales from on-board vessels have only been undertaken recently (Rüther and Adams 1984; Dawson et al. 1995).

Hector's dolphin is the smallest marine dolphin and endemic to New Zealand. Adult females are about 10 cm longer than males and reach a total body length of up to 153 cm (Mörzer Bruyns and Baker 1973; Slooten and Dawson 1994). Males and females can be differentiated easily by the pigmentation of the genital area. In males the grey genital patch is more extensive and farther forward than in females (Slooten and Dawson 1988). So far, field observations have indicated that Hector's dolphin groups usually fall into one of three categories: (1) adult females with young calves (so-called nursery groups), (2) mixed male and female immatures and subadults, and (3) predominantly males (Stone 1992; S. Bräger, personal observations). Its general "boat-friendliness", differential pigmentation, and generally small group size make Hector's dolphin an ideal species to investigate group composition visually without having to capture individuals. This study introduces a novel combination of close-range stereo-photogrammetry combined with underwater-video to investigate dolphin group composition, and uses first results of an ongoing long-term study on Hector's dolphins around the South Island of New Zealand to show its usefulness.

Materials and methods

The stereo-photogrammetry system

Stereo-photogrammetry uses two photographs taken simultaneously from slightly different vantage points to enable stereoscopic measurements of objects that are usually impractical to measure by other means. Between November 1993 and April 1997, a 4.5-m aluminium boat with a 40-hp outboard motor was used to study Hector's dolphins in coastal waters around South Island, New Zealand. To measure the body length of bow-riding dolphins, two SLR cameras (Nikon 8008) were mounted about 1.7–1.8 m above the water surface, pointing vertically down with their optical axes parallel to each other (Fig. 1). The shutters were released electronically to guarantee simultaneous exposures. The cameras were equipped with 24-mm wide-angle lenses and positioned exactly 500 mm apart, providing an overlap area of about 2×2 m on the water surface. A frame (0.6×0.8 m) with six reference points of known relative coordinates in all three dimensions was suspended beneath the cameras so as to be included in every photograph. The reference points were needed to increase the precision of the measurements. To allow high shutter speeds (1/1000 s), fast black-and-white film (Kodak TMAX 400) was used. Negatives were developed in Ilford ID-11 developer according to standard guidelines. The negatives were analysed subsequently with an analytical stereo-digitiser (Adam MPS-2) at the Department of Surveying, University of Otago.

We calibrated the focal length of each lens, and measured its distortion, along with the principal point of autocollimation (PPA). Calibration procedures are described in detail in Bräger and Chong (1999). The cameras were set on manual focus, and the lenses were taped at 2-m focus. Repeated measurements on land and on water of four different objects of known size detected an error range of 1–6% of the expected value.

The distance chosen for measurement was between the centre of the blowhole (BH) and the anterior margin (defined by a change in angle and coloration) of the dorsal fin (DF). This part of the body is visible above the water surface during breathing and is a good predictor of total body length (TBL = 2.3096 BH-DF + 202.6, r^2=0.870, n=56; Bräger and Chong 1999). Technical details of the analysis of the stereo-photographs with the analytical ste-

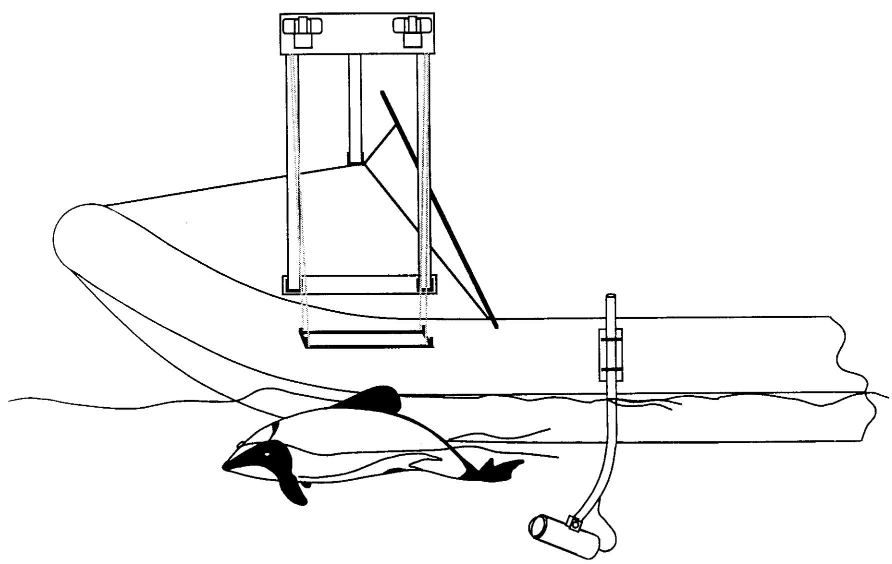

Fig. 1 Side view of the combined stereo-photogrammetry and underwater-video system

reo-digitiser are described in Bräger and Chong (1999). The three-dimensional coordinates for the two points (BH and DF) provided a straight-line measurement (as required by Norris 1961) according to the formula

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2} \quad (1)$$

The underwater-video system

A commercially available surveillance-type video camera (Panasonic WV-CL352) with a 2.8-mm super-wide angle lens (Panasonic WV-LA2.8 with a 107° angle of view) was placed inside a custom-made aluminium housing (outer dimensions: 0.3 m long and 0.15 m wide) with a dome port. The housing was attached to an aluminium pole, so that it could be lowered into the water column and rotated to change the angle towards the surface of the water as well as the horizontal orientation of the camera. The video footage was recorded and viewed onboard using a Hi8-Camcorder (Sony CCD-TR805E). This format allowed high-definition recordings which were later captured on a desktop computer with the software FusionRecorder 1.0.2. A digital clock was mounted in the field of view of the stereo-camera system, and synchronised each day with the internal clock of the video camera. This ensured that stereo-photographs and video footage could be matched in analysis.

The pole of the underwater-video camera and the frame holding the SLR cameras were made of rigid aluminium tubing. The system worked best at sea states of 0–2 Beaufort with wave height not exceeding 0.5 m, and at slow boat speeds (3.5 knots maximum). The underwater-video required water clarity of at least 1–2 m (measured with a Secchi disc) which was often problematic to achieve as Hector's dolphins are frequently found in murky water (Bräger 1998). Another restriction was the dolphins' willingness to bow-ride. Although Hector's dolphins are attracted to boats, especially those moving slowly (Mörzer Bruyns and Baker 1973), duration and intensity of bow-riding vary with the group's behaviour. Dolphins apparently engaged in social activity at the surface were much more likely to bow-ride for extended periods than those engaged in feeding or other activities. The need for bow-riding dolphins in clear, calm water can be difficult to meet along open, exposed coasts.

Age-length relationship in Hector's dolphins

Length measurements of 53 dead Hector's dolphins (29 females and 24 males, recovered between May 1985 and April 1996) were recorded. The age of each of these individuals was subsequently determined by counting the growth layer groups in stained slices of the teeth, an ageing method pioneered for cetaceans by Gaskin and Blair (1977), Perrin and Myrick (1980), Hohn et al. (1989), Hohn (1990), and Myrick (1991), and subsequently modified by Slooten (1991). The dead Hector's dolphins were 0–20 years old and the distances between blowhole and dorsal fin ranged from 380–466 mm in males (n=24) to 250–565 mm in females (n=29). Adult females were generally larger than adult males (Figs. 2 and 3), as also found by Slooten (1991). Relatively few dead individuals, however, were older than 4 years, and their lengths tended not to smoothly approach an asymptote (Figs. 2 and 3). This made it difficult to fit valid growth functions to the values, an essential factor in estimating age from stereo-photogrammetrically obtained body length. The measurements were, nevertheless, useful to assess whether an individual was immature or adult.

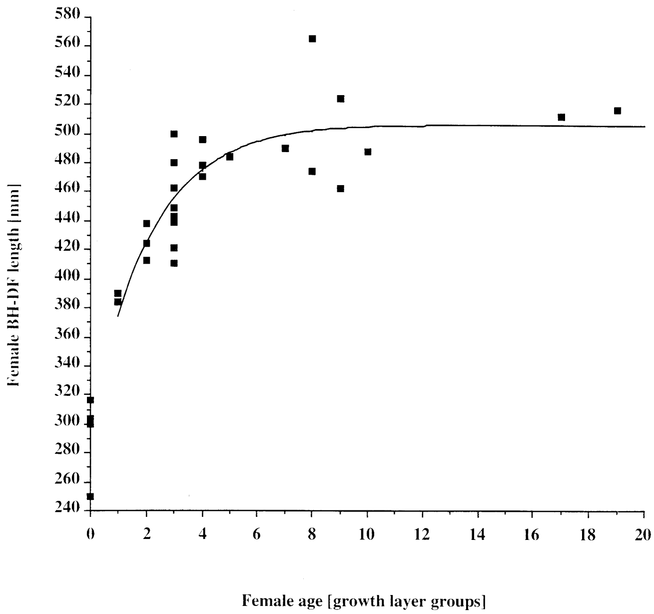

Fig. 2 Relationship of blowhole to dorsal fin distance (BH-DF) versus age in 29 dead Hector's dolphin females

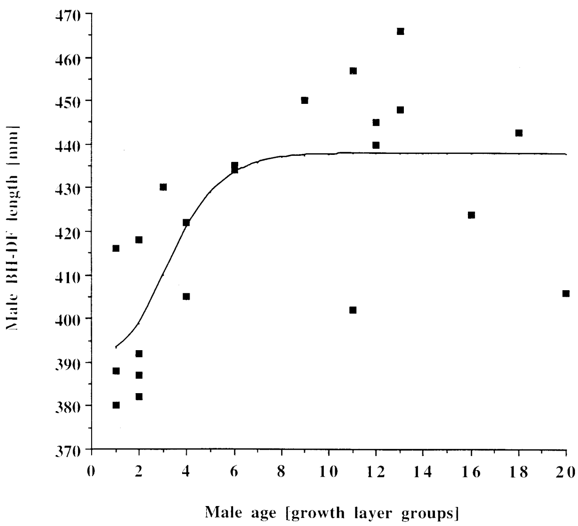

Fig. 3 Relationship of blowhole to dorsal fin distance (BH-DF) versus age in 24 dead Hector's dolphin males

Results

Efficiency of the system

Between December 1994 and February 1997, seven study areas were visited along the east, south, and west coasts of the South Island of New Zealand. Optimal conditions were encountered on only 16 days when 17 groups of 10–40 dolphins ($\bar{x}$±SE=25.8±2.78) were accompanied for 41–169 minutes ($\bar{x}$±SE=90.1±9.54). These encounters resulted in about 600 pairs of stereo-photographs, from 20 pairs of rolls of film; from Banks Peninsula and Moeraki (east coast), Porpoise Bay (south coast), and Westport, Greymouth, and Jackson Bay (west coast) (Table 1). Only in 27 (4.5%) pairs of stereo-photographs were the dolphins clearly visible near the center of both photographs, with the two points used for measurement exposed above the surface. Due to problems with back-

Table 1 Stereo-photography occasions of Hector's dolphins around the South Island of New Zealand

Stereo roll no.	Date	Study site	Group size	Time (min)
1	7 Dec 94	Banks Peninsula	30	85
2	8 Dec 94	Banks Peninsula	14	57
3	9 Feb 95	Jackson Bay	12	93
4	10 Feb 95	Jackson Bay	30	130
5–6	11 Feb 95	Jackson Bay	20	168
7–9	15 Feb 95	Greymouth	40	169
10	16 Mar 95	Banks Peninsula	16	47
11	7 Dec 95	Banks Peninsula	30	58
12	10 Jan 96	Westport	35	82
13	28 Jan 96	Greymouth	30	92
14	28 Jan 96	Greymouth	50	50
15	26 Feb 96	Porpoise Bay	12	82
16	27 Feb 96	Porpoise Bay	30	76
17	29 Jun 96	Moeraki	15	41
18	19 Dec 96	Banks Peninsula	14	64
19	16 Feb 97	Jackson Bay	20	128
20	20 Feb 97	Jackson Bay	40	110
Total	16	6	$\bar{x}$=25.8	$\bar{x}$=90.1

Table 2 Length measurements and sex determination of free-living Hector's dolphins using stereo-photogrammetry and underwater-video

Date	Study area	BH-DF (mm)	Estimate total body length (mm)	Gender
7 Dec 94	Banks Peninsula	435	1207	
7 Dec 94	Banks Peninsula	348	1006	
7 Dec 94	Banks Peninsula	403	1133	
7 Dec 94	Banks Peninsula	418	1168	
7 Dec 94	Banks Peninsula	309	916	
8 Dec 94	Banks Peninsula	566	1510	
8 Dec 94	Banks Peninsula	404	1135	
8 Dec 94	Banks Peninsula	317	934	
10 Feb 95	Jackson Bay	390	1103	Female
15 Feb 95	Greymouth	445	1230	
15 Feb 95	Greymouth	387	1096	Female
15 Feb 95	Greymouth	438	1214	Female
7 Dec 95	Banks Peninsula	420	1173	Female
7 Dec 95	Banks Peninsula	360	1034	Female
7 Dec 95	Banks Peninsula	354	1020	Female
7 Dec 95	Banks Peninsula	383	1087	Female
28 Jan 96	Greymouth	427	1189	
28 Jan 96	Greymouth	390	1103	
28 Jan 96	Greymouth	396	1117	
26 Feb 96	Porpoise Bay	417	1166	Male
29 Jun 96	Moeraki	429	1193	
29 Jun 96	Moeraki	480	1311	
29 Jun 96	Moeraki	416	1163	
29 Jun 96	Moeraki	452	1247	
19 Dec 96	Banks Peninsula	365	1046	
16 Feb 97	Jackson Bay	398	1122	
16 Feb 97	Jackson Bay	407	1143	

lighting and lack of underwater visibility, determining the gender of dolphins with the underwater-video setup was only possible in 8 of the 27 cases.

Growth function for male and female Hector's dolphin

Age and length (BH-DF) data from 53 dead Hector's dolphins were used to calculate growth functions for 24 males and 29 females. The resulting functions have the following form:

For males:

$$\text{Length}=392.5+45.49 \times\exp\{\exp[-0.73221\times(\text{age}-2.94655)]\} \quad (2)$$

For females:

$$\text{Length}=-8512.8+9019.5 \times\exp\{\exp[-0.47461\times(\text{age}-7.8805)]\} \quad (3)$$

Due to the high variability in measurements of dead dolphins, the sample size needs to be increased to im-

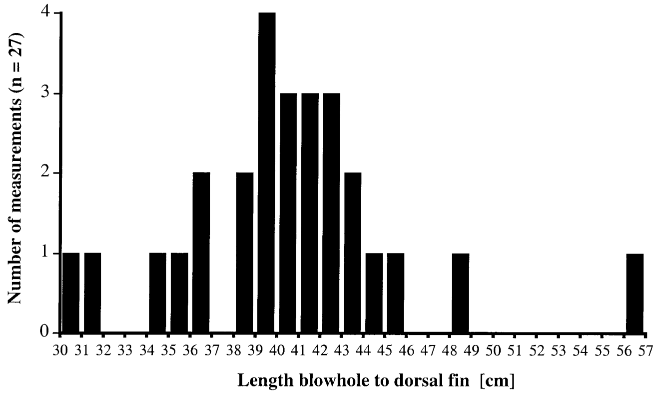

Fig. 4 Distribution of blowhole to dorsal fin (BH-DF) distances for 27 stereo-measurements

prove the predictive power of the Gompertz growth functions.

Length measurements and sex determination

The 27 successful BH-DF measurements are from ten different dates and five different study areas (Table 2). They range from 309 mm to 566 mm ($\bar{x}$±SE=405.7±9.76 mm). All but four individuals (85%), however, had BH-DF distances of 348–452 mm (Fig. 4). Of the eight individuals that could be sexed, seven were females and one was a male. The BH-DF distances were in the range 354–438 mm for females and 417 mm for males (Table 2). None of the dead females older than 3 years had a BH-DF distance of less than 462 mm (Fig. 2), which indicates that all seven females were likely to have been 1–3 years old. Among the dead males, individuals with BH-DF distances of 406–418 mm were anywhere between 2 and 20 years old (Fig. 3). Due to small sample sizes and high intrasexual variation, it was not possible to accurately estimate age from measured length.

Discussion

Analytical photogrammetry has reached a rather sophisticated stage in its ability to describe aspects of animal ecology and behaviour (Osborn 1997), and video techniques are greatly enhancing its efficiency (for example, Wardle and Hall 1994; Wratten 1994). Given this, it is surprising that photogrammetric techniques are not more widely used in biological studies. The combined stereo-photogrammetry and underwater-video system measures length and documents sex of Hector's and other bow-riding dolphins without having to catch or restrain them.

First experiences with Hector's dolphins indicate that the system requires calm sea conditions and clear water. Depending on the species, some patience may be required in waiting for the animals to be sufficiently approachable. The system is best used in conjunction with other (e.g., photo-identification) work. This gives the necessary contact with the animals and flexibility to be able to change to stereo-photography when the conditions are suitable.

Dolphins tended to surface in front of the zone of overlap of the stereo cameras. For this reason, the cameras should be mounted as far forwards on the bow as possible. Alternatively, a more flexible approach could be to mount the system in different places on the vessel. Ideally, it should be mounted as high above the water as possible. This would allow use of narrower lenses which are usually less prone to lens distortion. Length measurements of aged individuals are necessary to fit growth functions. When beginning a stereo-photogrammetric study, these growth functions should be calculated first to assess the accuracy needed in the stereo-photogrammetric measurements.

Another important issue is the need to gather data from a representative cross section of the group and, by studying many groups, of the entire population. During this study, it soon became obvious that usually only a few individuals bow-ride. These individuals have a higher chance of being photographed than others. In Hector's dolphins, these individuals appeared to be predominantly immatures (about 1–4 years old) of both sexes. It is also necessary to identify individuals to avoid measuring the same dolphins repeatedly. This could be done by photographing identifying marks such as scratches and rake marks on the dolphins' backs while the stereo-photography and video system is in use. The present technique will be especially useful for obtaining data on group and subgroup composition when dolphins ride the bows of vessels in clear, calm waters, such as spinner (*Stenella longirostris*), common (*Delphinus capensis* and *D. delphis*), bottlenose (*Tursiops truncatus*), and spotted dolphins (*Stenella attenuata* and *Stenella frontalis*) in tropical or near-tropical coastal waters. It could also be used from larger vessels in deep oceanic waters, with a much wider range of target species.

A yet untapped potential of this system could be the measurement of various proportions on an individual, which may give an indication of its health status, nourishment, or pregnancy. Subgroup spacing could be correlated with composition, for a more detailed description of inter-animal relationships and communication modalities (Schilt and Norris 1997). Sayigh et al.'s (1993) system for recording underwater sounds while underway in a small boat could be an extremely useful adjunct to our combined stereo-photogrammetry/underwater-video system. Combining both would allow continuous underwater video and sound recording, coupled with photogrammetry of individuals with groups.

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References

Amos B, Schlötterer C, Tautz D (1993) Social structure of pilot whales revealed by analytical DNA profiling. Science 260: 670–672

Angliss RP, Rugh DJ, Withrow DE, Hobbs RC (1995) Evaluations of aerial photogrammetric length measurements of the Bering-Chukchi-Beaufort Seas stock of bowhead whales (*Balaena mysticetus*). Rep Int Whal Comm 45:313–324

Bejder L, Fletcher D, Bräger S (1998) A method for testing association patterns of social animals. Anim Behav 56:719–725

Best PB, Rüther H (1992) Aerial photogrammetry of southern right whales *Eubalaena australis*. J Zool 228:595–614

Bigg MA, Olesiuk PF, Ellis GM, Ford JKB, Balcomb KC (1990) Social organization and genealogy of resident killer whales (*Orcinus orca*) in the coastal waters of British Columbia and Washington State. Rep Int Whal Comm (Spec Issue) 12:383–405

Bloch D, Lockyer C, Zachariassen M (1993) Age and growth parameters of long-finned pilot whales off the Faroe Islands. Rep Int Whal Comm (Spec Issue) 14:163–208

Bräger S (1998) Behavioural ecology and population structure of Hector's dolphin (*Cephalorhynchus hectori*). PhD thesis, University of Otago, Dunedin, New Zealand

Bräger S, Chong A (1999) An application of close range photogrammetry in dolphin studies. Photogramm Rec 16:503–517

Clutton-Brock TH, Harvey PH (1977) Primate ecology and social organization. J Zool 183:1–39

Cubbage JC, Calambokidis J (1987) Size-class segregation of bowhead whales discerned through aerial stereo-photogrammetry. Mar Mamm Sci 3:179–185

Dawson SM, Chessum CJ, Hunt PJ, Slooten E (1995) An inexpensive, stereo-photographic technique to measure sperm whales from small boats. Rep Int Whal Comm 45:431–436

Day T, Taylor PD (1997) Von Bertalanffy's growth equation should not be used to model age and size at maturity. Am Nat 149:381–393

Delany MJ (1982) Mammal ecology. Blackie, Glasgow

Douglas-Hamilton I (1973) On the ecology and behaviour of the Lake Manyara elephants. PhD Thesis, Oxford University, Oxford

Ferrero RC, Walker WA (1996) Age, growth, and reproductive patterns of the Pacific white-sided dolphin (*Lagenrhynchus obliquidens*) taken in high seas drift nets in the central north Pacific Ocean. Can J Zool 74:1673–1687

Gaskin DE, Blair BA (1977) Age determination of harbour porpoise, *Phocoena phocoena* (L.), in the western North Atlantic. Can J Zool 55:18–30

Guinet C, Bouvier J (1995) Development of intentional stranding hunting techniques in killer whale (*Orcinus orca*) calves at Crozet Archipelago. Can J Zool 73:27–33

Heimlich-Boran SL (1986) Cohesive relationships among Puget Sound killer whales. In:Kirkevold BC, Lockard JS (eds) Behavioral biology of killer whales. Alan R Liss, New York, pp 261–284

Hohn AA (1990) Reading between the lines, analysis of age estimation in dolphins. In: Leatherwood S, Reeves RR (eds) The bottlenose dolphin. Academic Press, San Diego, pp 575–585

Hohn AA, Scott MD, Wells RS, Sweeney JC, Irvine AB (1989) Growth layers in teeth from known-age, free-ranging bottlenose dolphins. Mar Mamm Sci 5:315–342

Jarman PJ (1974) The social organisation of antelope in relation to their ecology. Behaviour 48:215–267

Karara HM (1989) Non-topographic photogrammetry, 2nd edn. American Society of Photogrammetry and Remote Sensing, Falls Church, Virginia

Kasuya T, Marsh H (1984) Life history and reproductive biology of the short-finned pilot whale, *Globicephala macrorhynchus*, off the Pacific coast of Japan. Rep Int Whal Comm (Spec Issue) 6:259–310

Macdonald DW (1983) The ecology of carnivore social behaviour. Nature 301:379–384

Marsili L, Casini C, Marini L, Regoli A, Focardi S (1997) Age, growth and organochlorines (HCB, DDTs and PCBs) in Mediterranean striped dolphins *Stenella coeruleoalba* stranded in 1988–1994 on the coasts of Italy. Mar Ecol Prog Ser 151:273–282

Martin AR, Reynolds P, Richardson MG (1987) Aspects of the biology of pilot whales (*Globicephala melaena*) in recent mass strandings on the British coast. J Zool 211:11–23

Mörzer Bruyns WFJ, Baker AN (1973) Notes on Hector's dolphin, *Cephalorhynchus hectori* (van Beneden) from New Zealand. Rec Dom Mus 8:125–137

Myrick AC (1991) Some new and potential uses of dental layers in studying delphinid populations. In: Pryor K, Norris KS (eds) Dolphin societies: discoveries and puzzles. University of California Press, Berkeley, pp 251–279

Norris KS (1961) Standardized methods for measuring and recording data on the smaller cetaceans. J Mamm 42:471–476

Norris KS, Schilt CR (1988) Cooperative societies in three-dimensional space, on the origins of aggregations, flocks, and schools, with special reference to dolphins and fish. Ethol Sociobiol 9:149–179

Odell DK, Asper ED (1990) Distribution and movements of freeze-branded bottlenose dolphins in the Indian and Banana Rivers, Florida. In: Leatherwood S, Reeves RR (eds) The bottlenose dolphin. Academic Press, San Diego, pp 515–540

Osborn J (1997) Analytical and digital photogrammetry. In: Parrish JK, Hamner WM (eds) Animal groups in three dimensions. Cambridge University Press, Cambridge, pp 36–60

Perrin WF, Myrick AC (1980) Growth of odontocetes and sirenians: problems in age determination. Rep Int Whal Comm (Spec Issue) 3:1–50

Perryman WL, Westlake RL (1998) A new geographic form of the spinner dolphin, *Stenella longirostris*, detected with aerial photogrammetry. Mar Mamm Sci 14:38–50

Ratnaswamy M, Winn HE (1993) Photogrammetric estimates of allometry and calf production in fin whales, *Balaenoptera physalus*. J Mamm 74:323–330

Read AJ, Gaskin DE (1990) Changes in growth and reproduction of harbour porpoises, *Phocoena phocoena*, from the Bay of Fundy. Can J Fish Aquat Sci 47:2158–2163

Read AJ, Tolley KA (1997) Postnatal growth and allometry of harbour porpoises from the Bay of Fundy. Can J Zool 75:122–130

Read AJ, Wells RS, Hohn AA, Scott MD (1993) Patterns of growth in wild bottlenose dolphins, *Tursiops truncatus*. J Zool 231:107–123

Rice DW (1989) Sperm whale *Physeter macrocephalus* Linnaeus, 1758. In: Ridgway SH, Harrison R (eds) Handbook of marine mammals, vol 4. Academic Press, San Diego, pp 177–233

Rüther H, Adams LP (1984) Two-phase photogrammetry with displaced contol. S Afr J Photogramm Remote Sensing Cartogr 14:107–117

Sayigh LS, Tyack PL, Wells RS (1993) Recording underwater sounds of free-ranging dolphins while underway in a small boat. Mar Mamm Sci 9:209–213

Schilt CR, Norris KS (1997) Perspectives on sensory integration systems, problems, opportunities, and predictions. In: Parrish JK, Hamner WM (eds) Animal groups in three dimensions. Cambridge University Press, Cambridge, pp 225–244

Scott MD, Wells RS, Irvine AB (1990a) A long-term study of bottlenose dolphins on the west coast of Florida. In: Leatherwood

S, Reeves RR (eds) The bottlenose dolphin. Academic Press, San Diego, pp 235–244

Scott MD, Wells RS, Irvine AB, Mate BM (1990b) Tagging and marking studies on small cetaceans. In: Leatherwood S, Reeves RR (eds) The bottlenose dolphin. Academic Press, San Diego, pp 489–514

Scott MD, Perryman WL (1991) Using aerial photogrammetry to study dolphin school structure. In: Pryor K, Norris KS (eds) Dolphin societies: discoveries and puzzles. University of California Press, Berkeley, pp 226–241

Slooten E (1991) Age, growth and reproduction in Hector's dolphin. Can J Zool 69:1689–1700

Slooten E, Dawson SM (1988) Studies on Hector's dolphin, *Cephalorhynchus hectori*: a progress report. Rep Int Whal Comm (Spec Issue) 9:325–338

Slooten E, Dawson SM (1994) Hector's dolphin *Cephalorhynchus hectori* (van Beneden, 1881). In: Ridgway SH, Harrison R (eds) Handbook of marine mammals, vol 5. Academic Press, San Diego, pp 311–333

Stone G (1992) Hector's dolphin research program, 1990–92. Canterbury Cons Tech Rep Ser 4:1–56

Wardle CS, Hall CD (1994) Marine video. In: Wratten SD (ed) Video techniques in animal ecology and behaviour. Chapman and Hall, London, pp 89–111

Wells RS (1991) The role of long-term study in understanding the social structure of a bottlenose dolphin community. In: Pryor K, Norris KS (eds) Dolphin societies: discoveries and puzzles. University of California Press, Berkeley, pp 199–225

Wells RS, Scott MD, Irvine AB (1987) The social structure of free-ranging bottlenose dolphins. In: Genoways HH (ed) Current mammalogy. Plenum Press, New York, pp 247–305

Wolf PR (1983) Elements of photogrammetry. McGraw-Hill, Singapore

Wratten SD (1994) Video techniques in animal ecology and behaviour. Chapman and Hall, London

Würsig B, Lynn SK (1996) Movements, site fidelity, and respiration patterns of bottlenose dolphins on the central Texas coast. NOAA Tech Mem NMSF-SEFSC-383:1–111

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