A CONTRIBUTION TO THE ANATOMY OF TWO RARE CETACEAN SPECIES: THE HOURGLASS DOLPHIN (*Lagenorhynchus cruciger*) AND THE SPECTACLED PORPOISE (*Phocoena dioptrica*)

Jean-Marie Graïc[1], Tommaso Gerussi[1], Bruno Cozzi[1], Brian Chin Wing Kot[2], Rebecca M. Boys[3], Matthew R. Perrott[4], Kane Fleury[5], Emma Burns[5,6], Trudi Webster[5,7], Emma L. Betty[3], Odette Howarth[3], Carolina Loch[8], Sophie White[9], Steve Dawson[10], William Rayment[10], Stuart Hunter[4], Ros Cole[6], Derek Cox[6], Melanie Young[6], Joseph Roberts[6], Tom Waterhouse[6], Robin Smith[6] , Mike Ogle[6], Jim Fyfe[6], Hannah Hendriks[6], Anton van Helden[6], Muriel Johnstone[10], Ramari Oliphant Stewart[11,12], R. Ewan Fordyce[8], Karen A. Stockin[3].

Affiliations:

[1] Department of Comparative Biomedicine and Food Science, University of Padua, Italy

[2] Department of Infectious Diseases and Public Health, Jockey Club College of Veterinary Medicine, City University of Hong Kong, Hong Kong, China

[3] CERG, School of Natural Sciences, Massey University, Auckland, New Zealand

[4] School of Veterinary Science, Massey University, Palmerston North, New Zealand

[5] Tūhura Otago Museum, Dunedin, New Zealand

[6] Department of Conservation, Wellington, New Zealand

[7] Yellow-eyed Penguin Trust, Dunedin, New Zealand

[8] Sir John Walsh Research Institute, Faculty of Dentistry, University of Otago, New Zealand

[9] Department of Geology, University of Otago, Dunedin, New Zealand

[10] Department of Marine Science, University of Otago, Dunedin, New Zealand

[11] Ōraka-Aparima Rūnaka, Aparima (Riverton), New Zealand

[12] Te Kauika Tangaroa Charitable Trust, Westland, New Zealand

Corresponding author

Name: Tommaso Gerussi

Institution: Department of Comparative Biomedicine and Food Science, University of Padua.

Address: Viale dell'Università 16, 35020, Legnaro (PD).

Email: tommaso.gerussi@phd.unipd.it

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Ethical statement

All sampling was undertaken under the research permits 39239-MAR, RNW/22/2003/182, and RNW/HO/2008/03 (Massey University) and 39400-MAR (Tūhura Otago Museum) issued by the Department of Conservation Te Papa Atawhai. All research was done with permission from local rūnanga and rūnaka (local indigenous groups) alongside Department of Conservation Te Papa Atawhai. As no live animals were sampled, we did not require animal ethics approval for this research. The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Abstract

The anatomical description of the hourglass dolphin (*Lagenorhynchus cruciger*) and the spectacled porpoise (*Phocoena dioptrica*) remains largely unexplored, due to limited specimen availability and preservation challenges. This study employed digital imaging techniques, conventional histology and computed tomography to provide three-dimensional visualisation of anatomical structures for detailed volumetric analysis prior to necropsy. We present a comprehensive analysis of the gross macroscopical and microscopical morphology of two hourglass dolphins and four spectacled porpoises. The hourglass dolphins were characterised by their distinctive black and white pigmentation and a hooked dorsal fin, while the spectacled porpoises were distinguished for their large dorsal fin and unique eye markings. Morphometric measurements and skeletal characteristics were similar to those present in literature, while the anatomy and topography of internal organs and systems were similar to those found in other odontocetes. The respiratory systems showed an absence of lobation and a right *bronchus trachealis*. Although precise lung measurements were challenging, qualitative assessments indicate relatively large lungs for their body size, supporting the "short dive, big lung" hypothesis and suggesting that these species are not deep divers. The spectacled porpoise dorsal fin is uniquely large accompanied by a developed blood supply. This organ is hypothesised to act as a thermoregulatory window, helping to manage body heat. Overall, this study provides new data on the anatomy of the hourglass dolphin and spectacled porpoise, providing insights that may influence future research on these rare species. The findings highlighted the importance of anatomical studies in explaining in detail the evolutionary relationships within cetaceans and their ecological roles in the Southern Ocean ecosystems.

Keywords

Morphology; Computed-Tomography; osteology; histology, pelagic, polar.

Introduction

The hourglass dolphin (*Lagenorhynchus cruciger*, Quoy & Gaimard, 1824), and the spectacled porpoise (*Phocoena dioptrica*, Lahille, 1912) are two species of small (ca 2 m) cetaceans that inhabit subantarctic and Antarctic waters (Fordyce et al., 1984; Brownell and Donahue, 1999; Hammond et al., 2008; Cipriano, 2018; Goodall and Brownell et al., 2018). While aspects of their external morphology have been reported (Cipriano, 2018; Goodall and Brownell et al., 2018; refer to Table 1), internal anatomy has seldom been considered, likely because of their southern, limited geographic range and correspondingly poor access to fresh, intact specimens. The hourglass dolphins (herein hourglass dolphin) belongs to the family *Delphinidae*, with taxonomy still under debate with a recent proposal to shift to *Sagimatus* genus (Vollmer et al., 2019; see Jefferson et al., 2015 for taxonomy and general description). The most relevant external characteristics are the distinctive white and black pigmentation of the flanks and the markedly hooked dorsal fin (fig 1A). The common name arises from the hourglass shaped white marking extending from the beak to the tail flukes (Jefferson et al., 2015; Cipriano, 2018).

The spectacled porpoise (herein spectacled porpoise) belongs to the family *Phocoenidae*, and also suffers taxonomic uncertainty as to whether it's best placed within genus *Phocoena* or elsewhere (Jefferson et al., 2015). The species is characterised by a very large dorsal fin with a convex posterior margin, this feature heightened in males (Fig 1B). The eye is set within a small oval of black, with a thin dorsal semicircle of white, hence the common name "spectacled" (Jefferson et al., 2015; Goodall and Brownell, 2018).

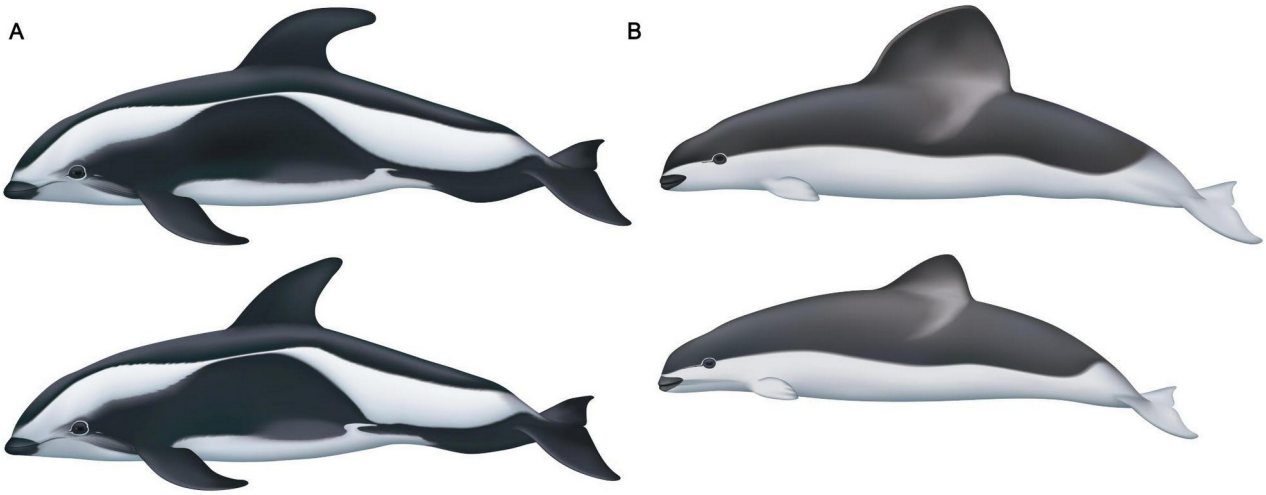

Fig. 1: (A) Typical aspect of an adult male (top) and female (bottom) hourglass dolphin (*L. cruciger*) and (B) adult male (top) and female (bottom) spectacled (*P. dioptrica*). Illustrations kindly provided by Uko Gorter (https://ukogorter.com/).

While the literature describes the external morphology and skeleton of both species (Table 1), information on their visceral anatomy is scarce, possibly due to the limited number of specimens observed and to the decomposition status of the carcasses.

Our anatomical description of these little-known species yields new data that increase our understanding and may help in resolving their taxonomic status. Specifically, our study describes the gross external morphology and the visceral macro- and micro-anatomy of six specimens (2 hourglass dolphin, 4 spectacled porpoise) examined postmortem.

Table 1 - Selected data available on hourglass dolphin and spectacled porpoise specimens available in the published literature.

Parameters	Hourglass dolphin		Spectacled porpoise		Reference
	Value	n	Value	n	
Total length (cm)	♂ 162,6 - 187 ♀ 142 - 182,9	6 7	♂ 109 - 224 ♀ 119 - 203,5 ? 94 - 101	8 13 11	Goodall et al., 1997; Brownell and Donahue, 1999; Gazitúa et al., 1999; Fernández et al., 2003; Brownell, 1999; Evans et al., 2001; Pinedo, 2002
Weight (kg)	♂ 93 - 100 ♀ 73,5 - 88	3 2	mixed sex 1.6 (foetus) - 115	7	Goodall et al., 1997; Gazitúa et al., 1999; Fernández et al., 2003; Brownell, 1999; Evans et al., 2001; Pinedo, 2002
Condylobasal length (mm)	316 – 370	11	276 – 424	54	Goodall et al. 1997 Gazitúa et al., 1999 Cipriano, 2018 Perrin et al., 2000
Visible teeth (per side)	26 – 34 top 27 – 35 bottom	6	16 – 26 top 17 – 23 bottom		Perrin et al., 2000
Vertebral column	C= 7 Th= 13 – 14 L= 18 – 19 Ca= 27+	9	C= 7 Th= 14 L= 14 – 16 Ca= 32 – 33		Marchesi et al., 2016 Perrin et al., 2000
Ribs (per side)	12 – 13	9	13 – 14		Perrin et al., 2000
Phalangeal formula	I= 2 – 3 II= 8 – 11 III= 6 – 8 IV= 2 – 4 V= 0 – 2	6	I= 2 II= 7 III= 4 IV= 3 V= 4		Perrin et al., 2000
Intestine length	18 – 19.7 m	3			Cipriano, 2018
Number of reniculi	670 (left kidney)	1			Cipriano, 2018
Other particularities	Single vena cava, absence of hepatic sinus	1			Goodall, 1997; Brownell, 1999

Materials and Methods

Here we apply conventional anatomical methods, including dissection, photography, conventional histological staining, along with *post-mortem* computed tomography (PMCT). PMCT scanning allowed for three-dimensional visualisation of organs and systems prior to dissection, allowing for volume calculations and providing comprehensive insights.

Animal data

This study examined six specimens (n = 2 hourglass dolphins; n = 4 spectacled porpoise). All specimens originated from stranding events in New Zealand between 2010 and 2020 (Table 2). Each specimen was weighed, where possible, and measured prior to CT scanning. Various elements of the spectacled porpoises from Pipikaretu, Caroline Bay and Kaitoreti Spit are stored for future research at Tūhura Otago Museum in Dunedin New Zealand.

Table 2. Specimen and strandings data of examined hourglass dolphins and spectacled porpoise examined in the study. Decomposition code according to the standards of Ijsseldijk et al., 2019.

Species	Animal ID	Age	Sex	Stranding date	Location stranding	Dissection date	Decomposition Code
hourglass dolphin	KS10-28Lc	Adult	M	7 Sept 2010	Flea Bay (43º86' S, 173º0' E), Akaroa, NZ	10 Sept 2010	2-3
hourglass dolphin	KS20-20Lc	Adult	M	5 Aug 2020	Orepuki Beach (46º16' S, 167º43' E), Te Waewae Bay, NZ	29 Sept 2020	1-2
spectacled porpoise	KS14-45Pd/ X2020.76	Adult	M	17 Sept 2014	Pipikaretu (45º80' S ,170º7' E), Otago Peninsula, NZ	19 Sept 2014	1
spectacled porpoise	KS14-37Pd/ X2020.77	Subadult/adult	M	2 Oct 2014	Caroline Bay Beach (44º38' S, 171º24' E), Timaru, NZ	2 Oct 2014	1
spectacled porpoise	KS14-37Pd/ VT3347	Juv	F	9 Aug 2015	Bayleys Beach, (43°49′S, 172°36′E) Kaitorete Spit, Canterbury, NZ	19 Aug 2015	3
spectacled porpoise	KS20-07Pd	Adult	M	14 Jan 2020	Washdyke Lagoon, Canterbury, NZ	22 Jan 2020	2

CT scan data

CT scanning of the first hourglass dolphin (KS10-28Lc) was performed with a LightSpeed VCT CT scanner (GE Healthcare, USA), using the scan parameters: 120 kV, 100 mA, 0.63 mm slice thickness,

and sFOV of 45 cm. CT of the second hourglass (KS20-20Lc) was conducted using a CT 5000 Ingenuity CT scanner (Philips, Netherlands), with scan parameters: 120 kV, 20 mA, 0.90 mm slice thickness, and sFOV of 50 cm. Three of the spectacled porpoises underwent CT scanning: KS14-37Pd/X2020.77 and KS14-45Pd/X2020.76 were conducted using a LightSpeed Pro 16 (GE Medical Systems); scan parameters for KS14-45Pd/X2020.76 were 120 kV, 390 mA and 1.25 mm slice thickness, while for KS14-37Pd/X2020.77 were 120 kV, 270 mA and 1.25 mm slice thickness. Due to logistical difficulties, the dorsal fin of KS14-45Pd/X2020.76 was scanned separately in the LightSpeed Pro 16 with scan parameters of 120 kV, 270 mA and slice thickness of 1.25 mm, this allowed for specific imaging of the dorsal fin structure. KS20-07Pd was conducted using an Optima CT660 (GE Medical Systems), with scan parameters: 120 kV, 480 mA, and 0.63 mm slice thickness. Due to logistical difficulties the tail stock was removed and scanned separately in KS20-07Pd (scanning parameters remained the same), rendering it difficult to determine the precise number of lumbar vertebrae caudal to the dorsal fin. CT data from KS20-07Pd and KS20-20Lc cases was assessed using PMCT methodology (Kot et al., 2020; Granados-Zapata et al., 2022) and were used to guide the necropsy, thus improving findings of the conventional necropsy. Both scans were viewed using the TeraRecon iNtuition workstation (TeraRecon, San Mateo, CA, USA). Morphological and volumetric examinations were performed also using Slicer 3D (https://www.slicer.org/).

Dissection

Dissections occurred at the Cetacean Pathology Unit, Massey University Auckland (KS10-28Lc, KS20-20Lc, KS20-07Pd), AgResearch Invermay Campus, Dunedin (KS14-37Pd/X2020.77) and Tūhura Otago Museum, Dunedin (KS14-45Pd/X2020.76, KS14-37Pd/VT3347), New Zealand, following standardised sampling techniques (Geraci and Lounsbury 2007; IJisseldik et al., 2019). A more restricted examination was performed on the first hourglass dolphin (KS10-28Lc, no ingoa name assigned) in order to preserve the integrity of the cadaver for cultural display. However, a full system dissection for KS20-20Lc (ingoa name, Harua-tai-nui) and all spectacled porpoises was permitted. Standardised histological tissue samples of key organs were fixed in 10% buffered formalin solution then trimmed, paraffin embedded and subsequently sectioned (8 μm) on a rotary microtome. Sections were stained with conventional haematoxylin-eosin stain, or with Masson's trichrome and Nissl stain for specific tissues.

The pectoral fins were analysed morphometrically, following Benke (1993). The condylo-basal length was also measured following Mead and Potter (1995).

Results

Gross anatomy

Weight and morphometric measurements of each specimen are reported below in Table 3.

The hourglass dolphins had a body shape broadly resembling a very stocky *Lagenorhynchus*, with a smoothly rounded head, and no protruding rostrum. The dorsal fin had a long base, was falcate, and notably tapered caudally, ending with a bluntly pointed tip. The pectoral fins displayed a narrower base and a notch on the caudal border adjoining the body. The caudal fin, or fluke, was relatively wide and thin. The caudal peduncle had an obvious ventral keel (Fig 2B), composed of dense connective

tissue and blubber, with no additional musculature (Fig. 2B). The characteristic colour pattern was similar to that described in the literature (see Figs. 1 and 2). In common with the spectacled porpoise, the hourglass dolphins had an incomplete white line dividing the black eye spot with the black pattern of the head (Figure 2A).

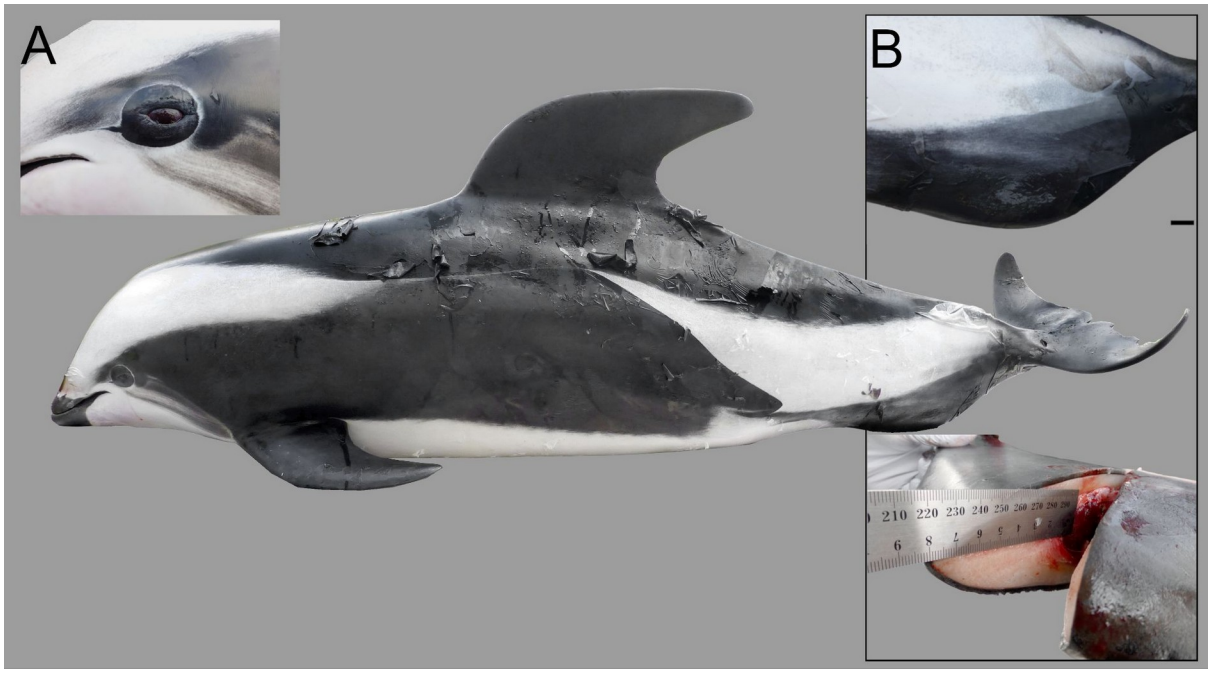

Fig. 2: Adult male specimen of hourglass dolphin KS10-28Lc. Note: Pigmentation pattern with the characteristic shape of an hourglass. Note (A) white line around the eye spot and (B), caudal keel showing presence of connective tissue and absence of any musculature.

The spectacled porpoises showed a typical porpoise-like body form, having a squat and tapered body, a clear division between dorsal black and ventral white, rounded pectoral fins and a distinctively large dorsal fin with a convex trailing edge. The white line around the eye spot was incomplete (Fig. 3).

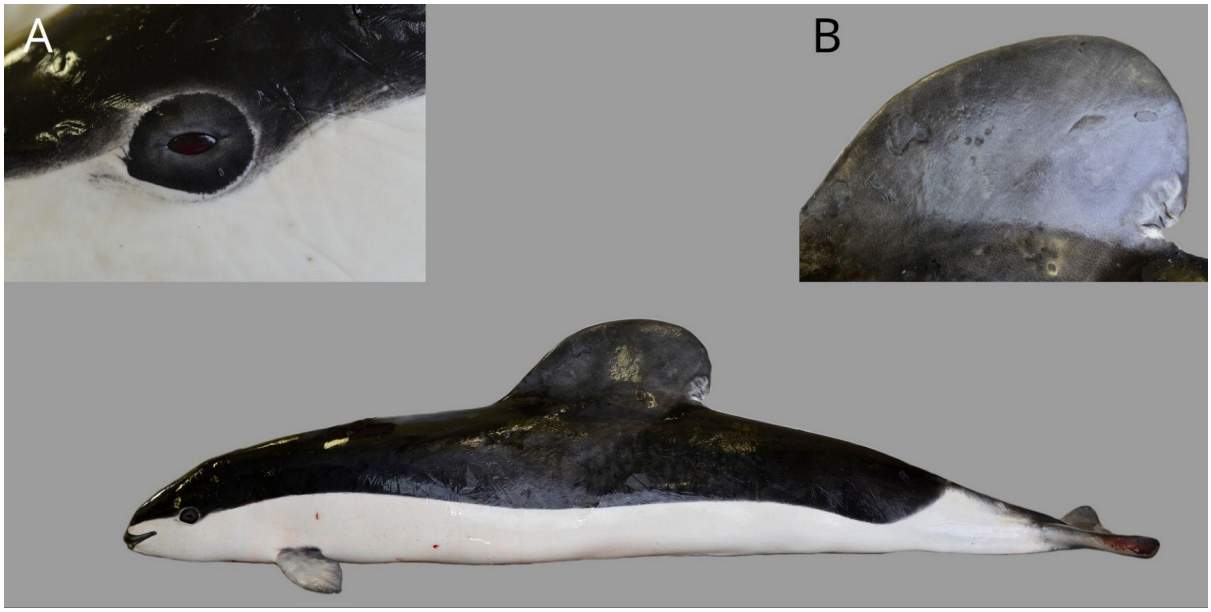

Fig. 3: Adult male spectacled porpoise KS14-45Pd/X2020.76. Note (A), distinctive white rim around the black eye patch and (B), exaggerated, wide based dorsal fin.

In both hourglass dolphins, though not observed in spectacled porpoise, we detected four small pits in the skin of the rostrum, ca 1 cm apart, likely representing remnants of the vibrissae.

Table 3 - Weight (kg) and morphometrics (cm) of examined specimens.

	Hourglass dolphin (*Lagenorhynchus cruciger*)		Spectacled porpoise (*Phocoena dioptrica*)			
Parameter	KS10-28Lc	KS20-20Lc	KS14-45Pd /X2020.76	KS14-37Pd/ X2020.77	KS14-37Pd/ VT3347	KS20-07Pd
Weight (kg)	78	n/a	120	96	26	n/a
Total length (cm)	170.5	183	215	200	125	210
Snout-anus	121.5	134	149	144	88	155
Snout-genital slit	102.5	113	126	117	81	137.5
Snout-navel	78	82.5	n/a	n/a	60	95.5
Snout-origin flipper	32	35.5	36	30	22	29.5
Snout-origin dorsal fin	67	73	83 (anterior insertion of fin)	78	51	83
Snout-tip dorsal fin	104.5	119	128	n/a	70	119.5
Snout-blowhole	19	22		n/a	14	18
Snout-corner mouth	18.5	20.5	12	7.8	7	9
Genital slit	13	15	11	26	9	11.5
Rostrum length	2	n/a	n/a	n/a	15	n/a
Corner mouth-eye	5	5.5	20 (snout)	7.8	8.5	11
Eye-blowhole	20.5	18.5	n/a	12	8	17.5
Dorsal fin height	16	22	27	28.5	10	26
Dorsal fin lat base	30.5	42	49	50	25	49
Fluke width	47	53.5	53	46	32	49
Fluke length	17	20	17	18	14	17
Fluke notch	2	2.5	n/a	3	2.5	3
Flipper length internal	33.5	26	n/a	16	11	11
Flipper length external	18	35	23	21.6	17	24
Flipper length width	11	13	10.5	9.6	7	10
Girth eye	73	76	n/a	64	47	72
Girth flippers (back)	98	112.5	100 *	94	65	105
Girth navel	105.5	124	116	n/a**	73	n/a
Girth anus	59.5	69	81	70	43	83
Blubber (mid dorsal) Dorsal	0.9	1.8	2	2.1	1.4	1.8
Blubber (mid dorsal) lateral	1.4	1.4	2.36	2.14	1.4	1.57
Blubber (mid dorsal) ventral	1.4	1.8	2.36	2	1.5	1.9

*with shark bite 108 based on measurements from right side; **navel is mid dorsal fin, can't accurately measure this on mature adult male spectacled porpoise.

Osteology and Arthrology

In the hourglass dolphin, the two first cervical vertebrae (C1 and C2) were fused, while in the spectacled porpoise, C1 to C6 were fused (Figure 3.1). The atlas was large and relatively flat, while the remaining six vertebrae were tightly aligned with their body joined together. For vertebral formulae and details, see Table 4.

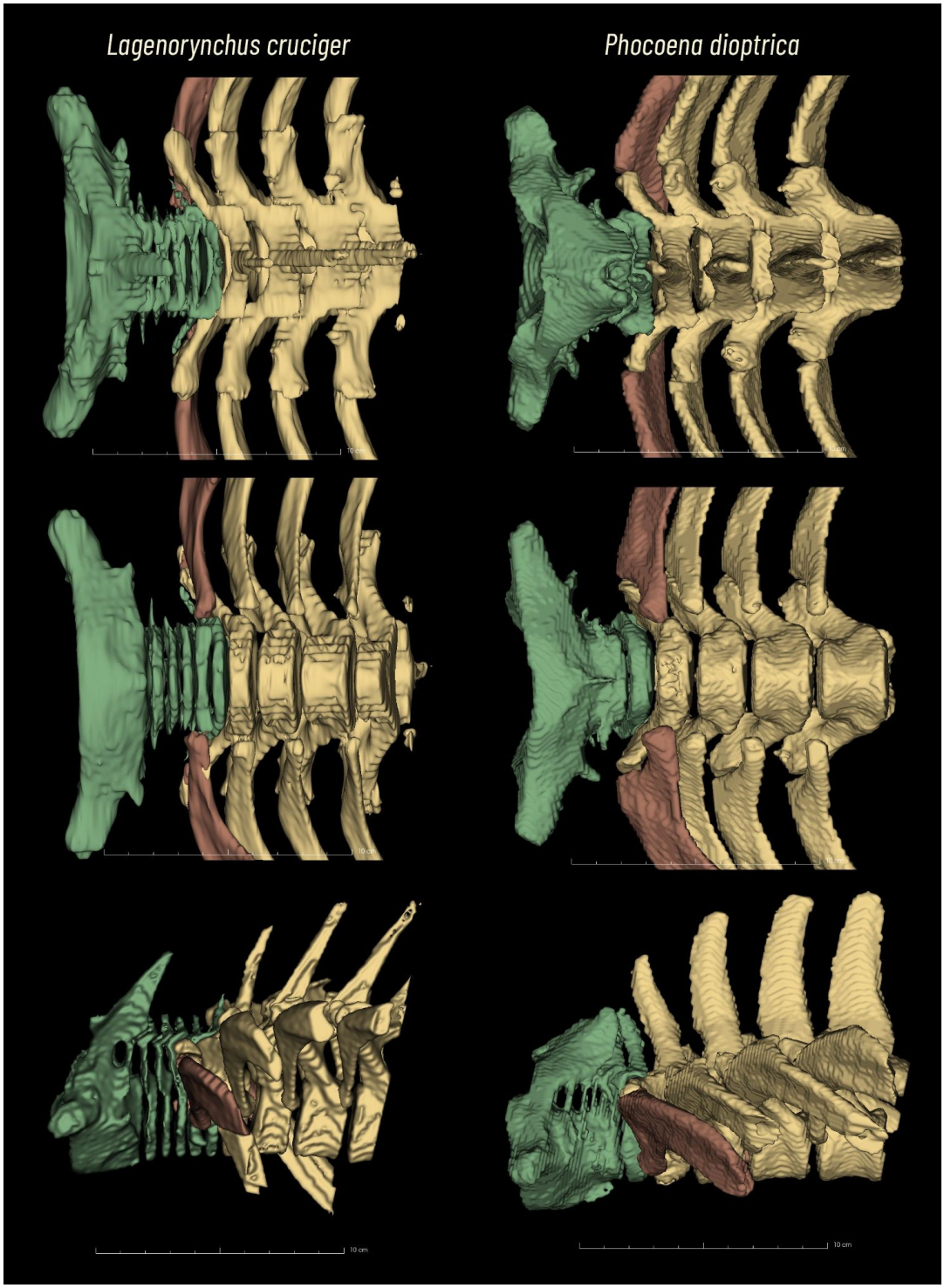

Figure 3.1. Adult hourglass dolphin KS20-20Lc and spectacled porpoise KS14-45Pd/X2020.76 cervical vertebrae segmented. In green C1-2, C3, C4, C5, C6 and C7; in yellow the first 4 thoracic vertebrae and ribs. In red, the first rib.

Both hourglass dolphin specimens had 13 thoracic vertebrae (Th), and an analogous number of ribs. Ribs 1 to 5 articulated with the sternum. The distal extremities of ribs 6 to 8 joined the distal bony aspect of the ribs rostral to them, while ribs 9 to 13 did not connect to the sternum. Ribs 1 to 6 articulated both with the transverse process of their vertebrae and the vertebral body or the vertebrae cranial to it (unlike in other mammals, in which it articulates between vertebrae), while ribs 7 to 13 articulated only with the transverse process of their vertebrae. In the spectacled porpoises, ribs 1 to 4 were connected to the sternum, ribs 5-8 were connected to the ribs rostral to them and the remaining ones were free of any relationship to the sternum (Fig. 4).

The hyoid complex in hourglass dolphin KS20-20Lc displayed a typical *Lagenorhynchus* basihyoid connected to the stylohyoids, as described by Yablokov et al. (1974). In the spectacled porpoises, the basihyoid and thyrohyoid were fused in a porpoise-like unique flat bone, articulated cranially with the two stylohyoids which in turn, run back caudally (Fig. 5).

Pectoral morphometry is detailed in Fig. 6 and Table 5.

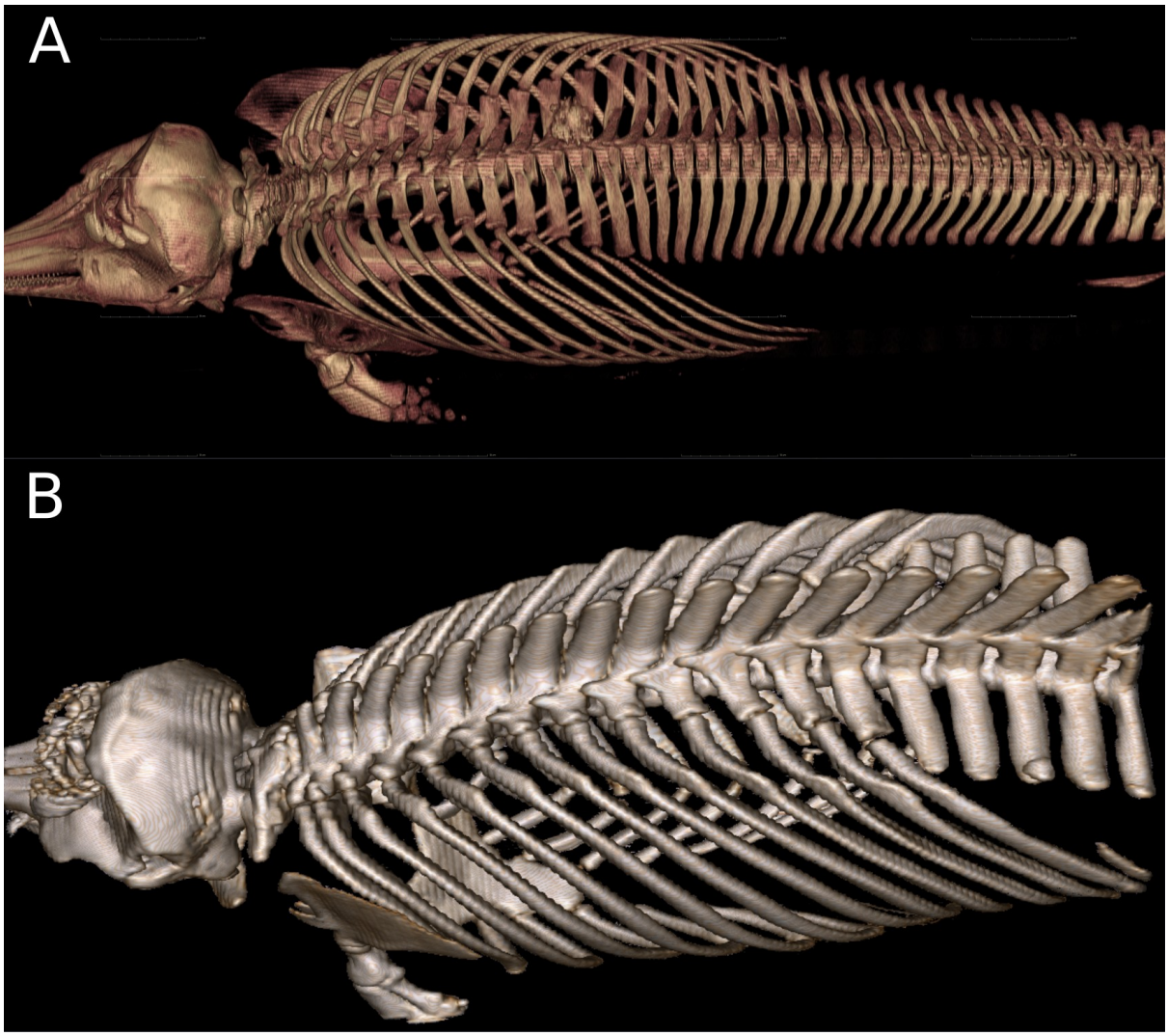

Fig. 4: Representation of the skeleton up to the lumbar vertebrae of (A) hourglass dolphin KS20-20Lc and (B) spectacled porpoise KS20-07Pd, as displayed by 3D rendering of the CT scans.

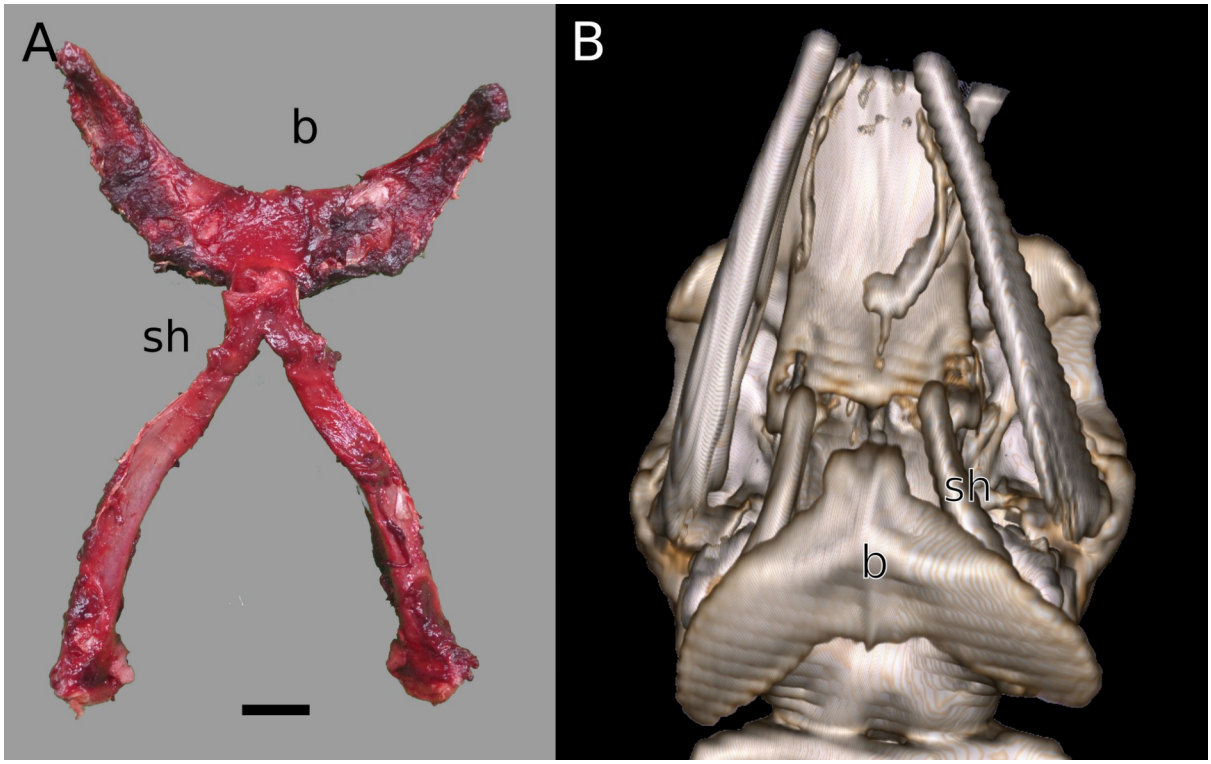

Fig. 5: (A) Visualisation of the hyoid apparatus in a dorsal view of hourglass KS20-20Lc and (B) 3D reconstruction of the skeleton in a ventral view including the hyoid bone of spectacled porpoise KS20-07Pd. Note: b, basihyoid; sh, stylohyoid.

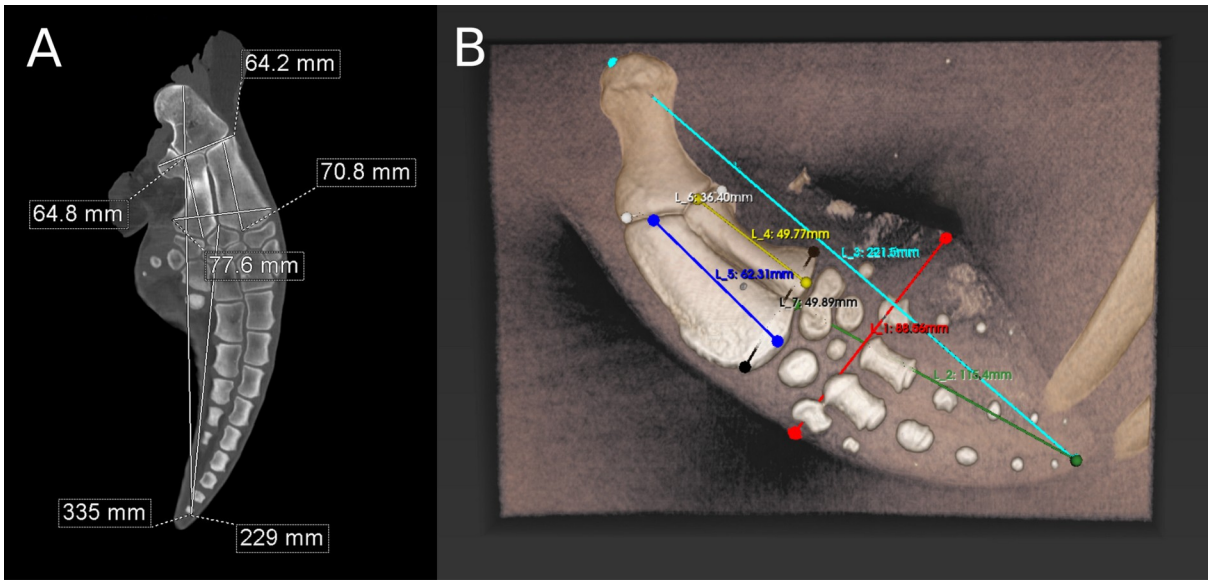

Fig. 6: Visualisation of the skeletal characteristics with measurements (A) radiograph of left flipper hourglass dolphin KS20-20Lc and (B) 3D reconstruction of the KS20-07Pd with principal measurements.

Table 4. Number of vertebrae per section, number of ribs and phalangeal formula (first number is left hand, second number is the right hand) by specimen. Note: CB = condylo-basal.

	Hourglass dolphin (*Lagenorhynchus cruciger*)		Spectacled porpoise (*Phocoena dioptrica*)			
	KS10-28Lc	KS20-20Lc	KS14-45Pd /X2020.76	KS14-37Pd/ X2020.77	KS14-37Pd/ VT3347	KS20-07Pd
CB length	319.6	362.8	307.2	293.4	239	289.6
Cervical	7	7	7	n/a	7	7
Thoracic	13	13	13	n/a	13	13
Lumbar	15	19	na	n/a	17	n.d.
Coccygeal	nd	16+20	32	n/a	37	27
Ribs	13	13	13	n/a		15?
Phalangeal formula	I= II= III= IV= V=	I= 3; 2 II= 10; 10 III= 7; 7 IV= 3; 3 V= 3; 3	I= 1; 1 II= 6 III= 5; 4 IV= 3; 3 V= 1; 1	n/a	Right only I=1 II= 6 III=5 IV=4 V=1	(only R) I= 2 II= 6 III= 5 IV= 4 V= 1

Table 5. Morphometry of the pectoral fins

Measurement (cm)	Hourglass dolphin (*Lagenorhynchus cruciger*)		Reference (*Tursiops truncatus*) (Benke, 1993)	Spectacled porpoise (*Phocoena dioptrica*)	
	KS20-20Lc			KS20-07Pd	KS14-37Pd /VT3347
Side (Right and Left)	R	L	R	R	R
FLB (flipper width)	111	111	77	88.56	70.6
FLL (flipper length)	342	335	n/a	221.5	165
ML (manus length)	233	229	70	115.4	84.6
RL (radius length)	73.1	70.8	75	62.31	48.4
RUD (radius and ulna distal width)	80.3	77.6	70	49.89	42.8
RUP (radius and ulna proximal width)	63.4	64.2	64	36.4	38.6
UL (ulna length)	65.7	64.8	66	49.77	40.2

Tympanic-periotic complex

In hourglass dolphin KS20-20Lc, the right and left TPC weighed 18 and 17 g, respectively (Fig. 7). For a full reporting of measurements, refer to Table 6.

Fig. 7: Tympano-periotic complex of hourglass dolphin KS20-20Lc. Scale bar 1 cm.

Table 6. Morphometry of the tympanic-periotic complex. TPC, tympanic-periotic complex; T, tympanic bone; P, periotic bone; L left; R, right. Measurements are shown as length x width x depth.

	Hourglass dolphin (*Lagenorhynchus cruciger*)		Spectacled porpoise (*Phocoena dioptrica*)		
Parameter	KS10-28Lc	KS20-20Lc	KS14-45Pd/ X2020.76	KS14-37Pd/ X2020.77	KS20-07Pd
T R measurements (mm)	35 x 21	35 x 19	32 x 15	32 x 18	30 x 18
T L measurements (mm)	34 x 18	34 x 19	31 x 12	31 x 15	31 x 19
P R measurements (mm)	30 x 22	29 x 15 x 8	36 x 19	31 x 15	32 x 18
P L measurements (mm)	31 x 20	29 x 18 x 12	36 x 20	32 x 20	31 x 20

Visceral anatomy

Respiratory system

In both species we found robust tracheal cartilaginous rings, visible bronchial cartilages down to the smallest distinguishable airway, a right tracheal bronchus slightly cranial to the primary bronchial division and no apparent lobation of either the left or right lung. Some parameters can be found in table 7. In hourglass dolphins, both the lungs terminated in alignment with rib 12. In spectacled porpoises, the left lung terminated approximately at the twelfth rib, with the right lung aligned with rib 10 (Figs. 8 and 9).

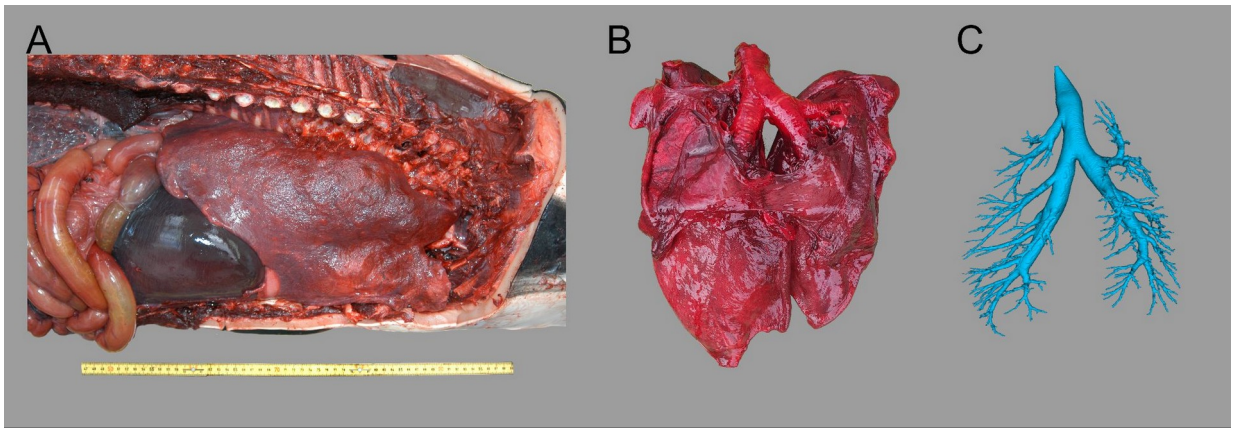

Fig. 8: Thorax with lungs in their topographical location without ribs (A), isolated dorsal and ventral aspects (B), and as a 3D reconstruction, showing the trachea and bronchial tree of hourglass dolphins KS10-28Lc. Scale on the left is common to all images.

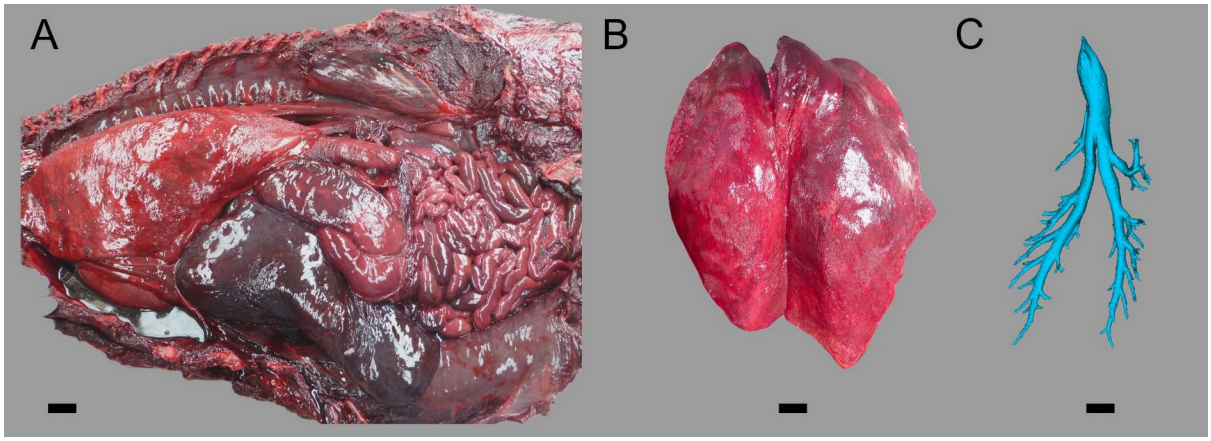

Figure 9. Representation of spectacled porpoise KS20-07Pd lungs (A) in their topographical location and (B) after removal. (C) 3D reconstruction of the trachea and bronchial tree of spectacled porpoises (KS20-07Pd). Scale bar: 2 cm.

Table 7: Lung parameters. Measurements are shown as (craniocaudal) length x (dorsoventral) height x (lateromedial) width.

Parameter	Hourglass dolphin *(Lagenorhynchus cruciger)*	Spectacled porpoise (*Phocoena dioptrica*)		
	KS20-20Lc	KS14-37Pd X2020.77	KS14-37Pd VT3347	KS14-45Pd X2020.76
Total weight (g)	3100	600,3 (L); 673 (R)	328,2 (L); 365.35 (R)	1456 (L); 1078 (R)
Total volume (L)	3,4	n/a	n/a	n/a
Right lung	440x190x98	400x120	n/a	n/a

measurements (mm)				
Left lung measurements (mm)	420x170x75	400x130	n/a	n/a

Circulatory and lymphatic systems

In both species the heart was rather flat dorsoventrally and triangular in shape, with wide and flat auricles. The left ventricle was larger, with a thicker wall compared to the right. Table 8 summarises most important measurements in some specimens.

The heart of both hourglass dolphins was located between the intercostal spaces 1 to 5, lying on the sternum with its major axis oriented laterally, so that the right and left ventricles aligned to the right sides, respectively. The paraconal groove was relatively deep with large arteries covered in fat. The diameter of the aorta was approximately 3 cm.

The hearts of spectacled porpoises KS20-07Pd and KS14-45Pd/X2020.76 were located on the sternum between intercostal space 1 and 4, and had an approximate volume of 1320 cm^3. The heart of KS20-07Pd weighed 813 g, with an aorta diameter of 3.9 cm recorded. The heart extended several vertebral arteries to the thoracic rete mirabile along its course in the thorax.

Table 8: Heart parameters. Measurements shown as width x length x diameter.

Parameter	Hourglass dolphin *(Lagenorhynchus cruciger)*	Spectacled porpoise (*Phocoena dioptrica*)		
	KS20-20Lc	KS14-37Pd X2020.77	KS14-37Pd VT3347	KS14-45Pd X2020.76
Weight (g)	296.6	562.9	269.6	1037 (approx. vol. of 1857 cm^3)
Measurements (mm)	n/a	180x220	n/a	192x210x45.6

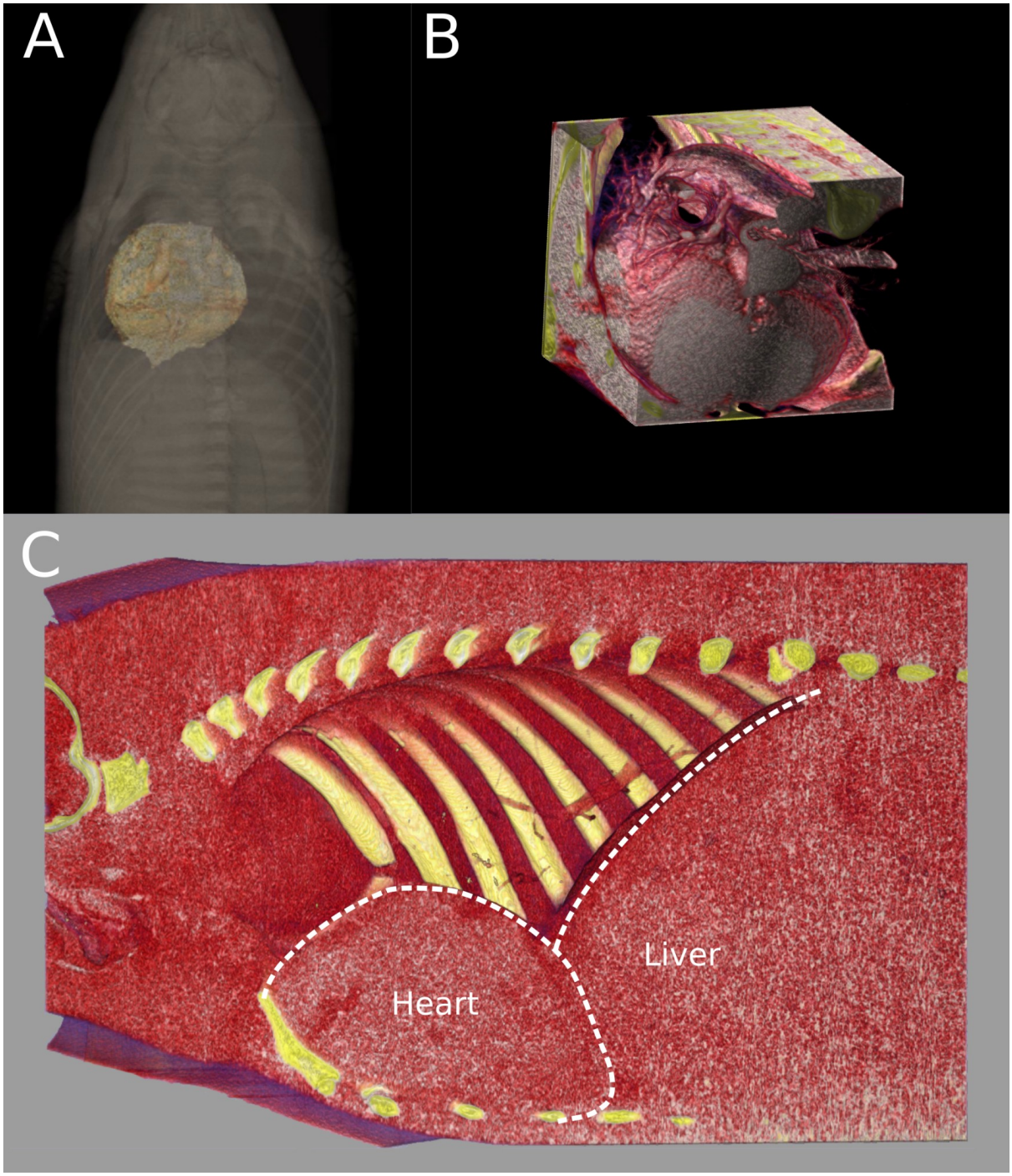

Figure 10. 3D reconstruction of the heart in hourglass dolphin KS20-20Pd (A, B) and spectacled porpoise KS20-07Pd (C). Note: (A) views the heart dorsally, showing its topography in the thoracic cavity, (B) illustrates the heart in isolation, with the aortic arch and onset of aorta shown and (C) presents a 3D model of the heart, sectioned along the sagittal plane, revealing detailed views of the right side of the heart and the liver.

In spectacled porpoise KS14-45Pd/X2020.76, it was also possible to remove the dorsal fin and scan it independently (Fig. 11). The images display the characteristic pattern of the countercurrent exchange system in cetacean appendages, featuring central arteries located along the midline of the dorsal fin

and branching dorsally, encircled by circumferential veins (Fig. 11). We hypothesised that the central arteries originating from the body were represented by the hypodense areas in the CT scan, as these structures possess rigid walls and may have lost their blood content, resulting in air-filled cavities while maintaining their structural integrity. However, instead of observing a singular line of arteries, we identified multiple lines, exhibiting an inhomogeneous distribution (Fig. 11). The 3D rendering revealed large vessels only in the central section of the dorsal fin, with scarcity in the rostral and caudal areas. Bifurcation varied, with some vessels bifurcating at the base while other vessels bifurcated more toward the tip, and others at mid-height. Cranial and caudal arteries tended to curve cranially and caudally at the tip of the fin, respectively, while central arteries ran perpendicular to the fin.

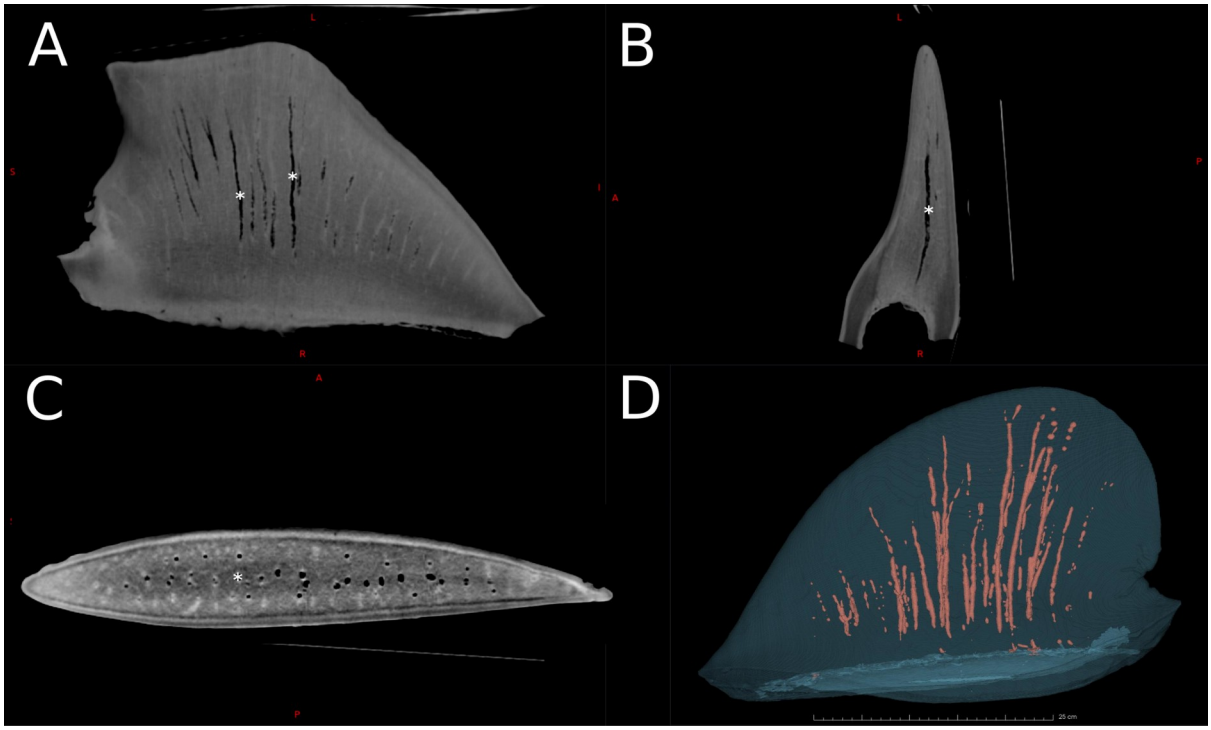

Fig 11. CT scan of the dorsal fin of spectacled porpoise KS14-45Pd/X2020.76. Note: A, B and C show the sagittal, transversal and axial planes at its base, respectively. D shows the 3D reconstruction with the render of the arteries. In A, B and C, the asterisks highlight the central arteries. These are shown as hypodense (dark) regions. The circumferential veins surrounding the arteries, due to their weaker wall and size, may have collapsed, thus appearing as small hyperdense areas. Conversely, the peripheral veins were visible as hyperdense areas.

In both specimens the spleen was found, with main parameters resumed in table 9. In spectacled porpoise KS20-07Pd, an accessory spleen was further recorded (Fig. 12). In hourglass dolphin KS20-20Lc, prescapular lymph nodes weights and measurements were 15 g (L) and 20 g (R) in and 51 x 40 x 11 mm (L) and 72 x 39 x 15 (R), respectively. Mesenteric lymph nodes were present at the root of the mesentery.

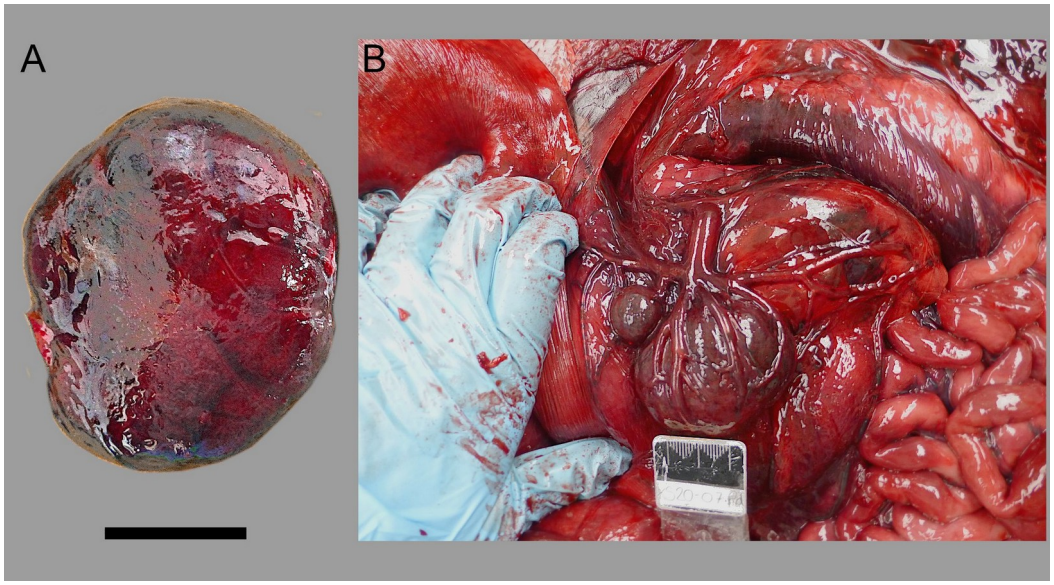

Fig. 12. Spleen of porpoise KS20-07Pd (A), with presence of accessory spleen (B) shown to the left of the primary spleen. Scale bar 2 cm.

Table 9. Spleen parameters. Measurements shown as length x width x diameter (mm).

	Hourglass dolphin (*Lagenorhynchus cruciger*)	Spectacled porpoise (*Phocoena dioptrica*)		
	KS20-20Lc	KS14-37Pd/ VT3347	KS14-45Pd/ X2020.76	KS20-07Pd
Weight (g)	20	19.93	16	27
Measurements (mm)	63x40x15	40x35	n/a	59x48x17

Digestive system

Mouth and upper digestive tract

While most teeth were intact in the hourglass dolphin KS10-28Lc, most teeth in hourglass dolphin KS20-20Lc were worn to the gum (LR: 1-11; LL: 1-13; UR: 1; UL: 1-5 and 9-24). This is reflected in ageing based on teeth GLGs assessed as >18 and 7 years, respectively. Mineralization of the pectoral limb (see above) in KS20-20Lc further supports this as an older specimen. Teeth on KS15-29 were only partially erupted and teeth of KS14-37Pd/X2020.77 were not examined. The dental formula of examined specimens can be viewed in Table 10.

Table 10. Dental formula of selective specimens examined. Note: UL, upper left; UR, upper right; LL, lower left; LR, lower right.

Parameter	Hourglass dolphin (*Lagenorhynchus cruciger*)		Spectacled porpoise (*Phocoena dioptrica*)		
	KS10-28Lc	KS20-20Lc	KS20-07Pd	KS14-45Pd/ X2020.76	KS14-37Pd/ VT3347
Teeth UR	24	19	18	21	18
Teeth LR	27	26	19	19	19
Teeth UL	25	24	19	23	18
Teeth LL	25	27	18	17	17*

The pointed tongue in KS20-20Lc measured 13.3 (L) x 6.3 cm (W), with no anterolateral papillae. Six vallate papillae were present at the root of the tongue, arranged in a V orientated towards the pharynx (Arrowhead in Fig. 13).

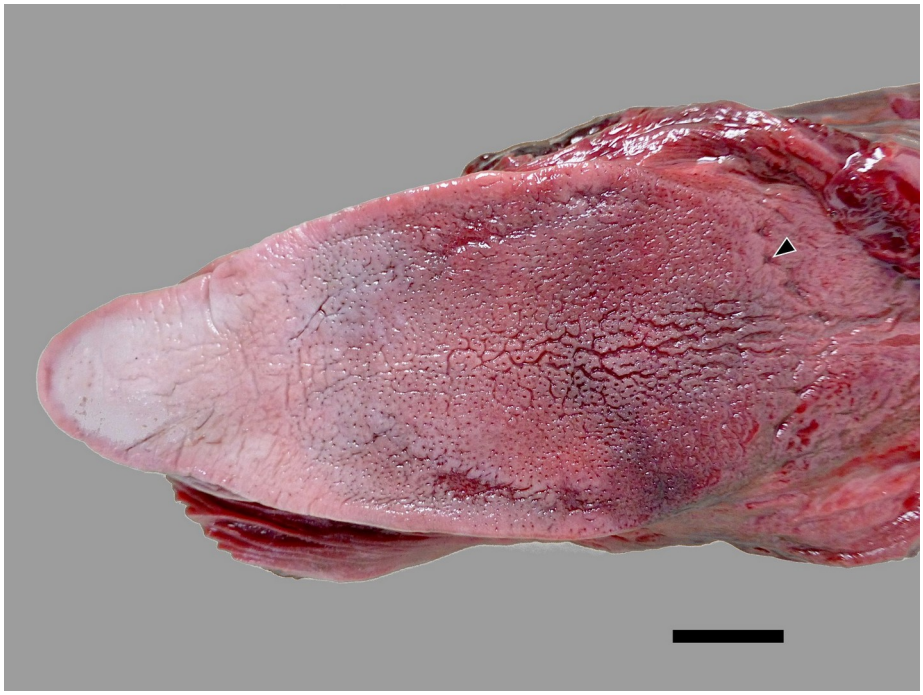

Fig. 13. Tongue of the hourglass dolphin KS20-20Lc. Scale bar 2 cm.

Stomach complex and intestine

The stomach chambers of all specimens resembled the typical delphinid pattern: one forestomach, one main stomach and one pyloric stomach. Similarly, in both species the intestine was a unique "tube" without macroscopical distinction between small and large parts, and lacking a caecum. The mesenteric lymph nodes were clearly identified.

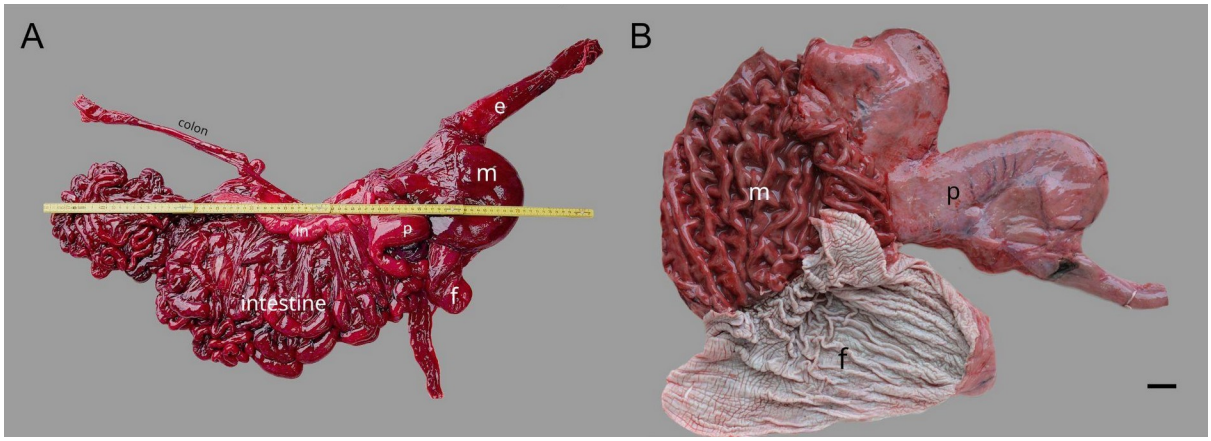

Fig. 14. Gastrointestinal components of the digestive system. (A) whole gastrointestinal system of hourglass dolphin KS20-20Lc, starting from the oesophagus and terminating at the rectum. (B) gastric chambers of the spectacled porpoise (KS14-45Pd/X2020.76). e, oesophagus; f, forestomach; i, intestine; ln, mesenteric lymph nodes; m, main stomach; p, pyloric stomach.

Liver

No lobation was apparent in the livers of both species, and no gallbladder was observed.

In the two hourglass dolphins, liver position ran from the 10th thoracic to the 2nd lumbar vertebrae, on the ventral half of the abdominal cavity. In KS10-28Lc, the right lobe extended considerably further than the left, which is consistent with its topography and the position (leftward) of the stomachs. The diaphragmatic surface of the right lobe was expanded cranially and contained most of the mass of the organ. The right lobe was separated from the left by a thin falciform ligament, which was thin and terminated in a sheet covering the cranial portion of the stomachs. This was considerably less evident in the KS20-20Lc, where the liver appeared almost divided in even halves, although the right half was thicker than its left counterpart.

In the spectacled porpoises, the liver was positioned approximately between thoracic rib 8 to lumbar vertebra 4. A highly developed right compared to more inferior left lobe was noted, without the diaphragmatic expansion described prior for the two hourglass dolphin specimens. The falciform ligament still clearly divided the main left and right lobes of the liver (Fig. 15 C, D).

In both species we also could not find any venous sinus.

Details on the dimensions and weight of the liver for three specimens (KS10-28Lc, KS20-20Lc and KS20-07Pd) are reported in Table 11.

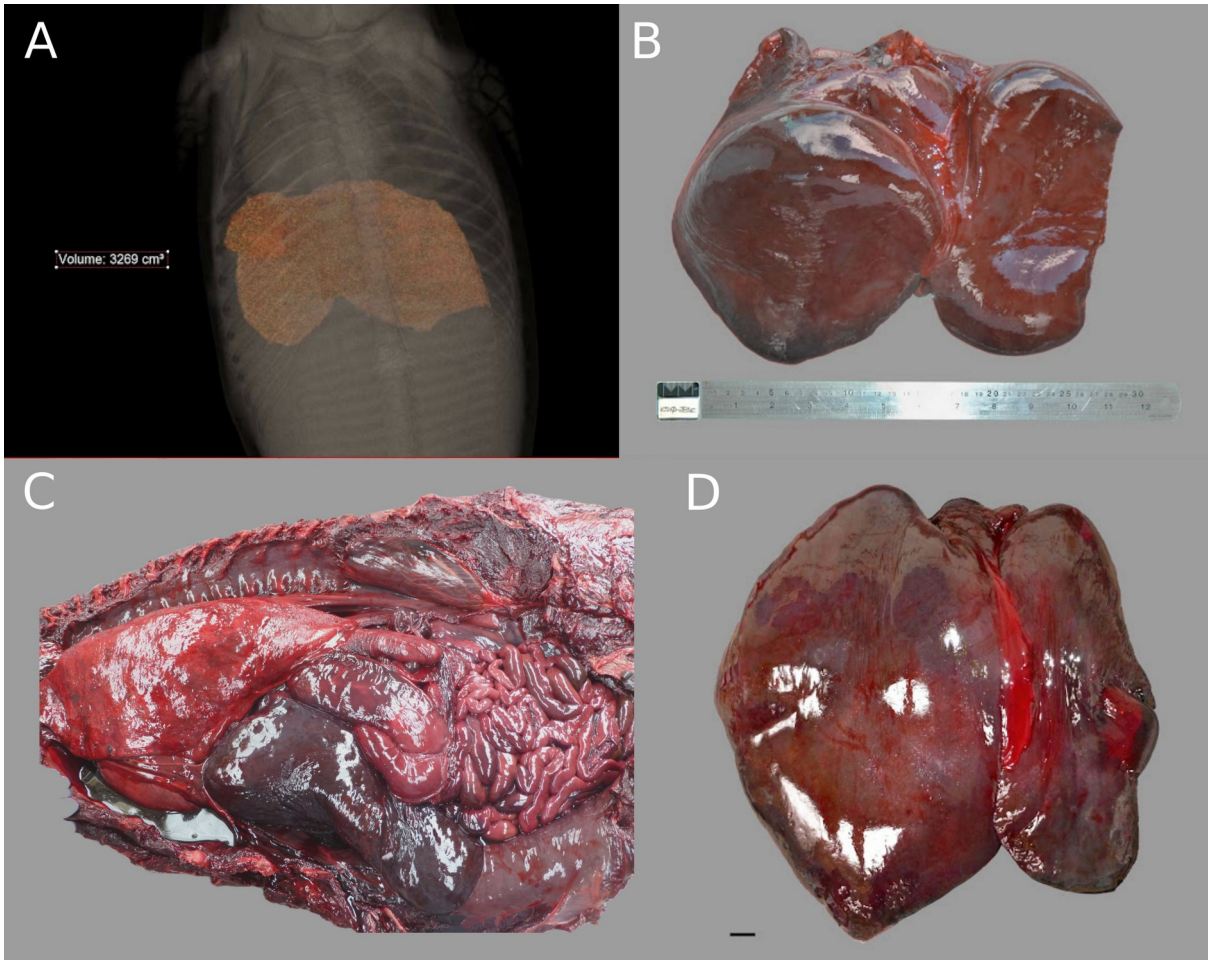

Fig. 13 Representation of the liver in the hourglass dolphin KS20-20Lc (A, B) and spectacled porpoise KS20-07Pd (C, D). Images (A) and (C) showed the liver in its topographical location within the abdominal cavity while (B) and (D) show the extracted and isolated organ. Note the difference between the large right compared to smaller left lobe. Note: Scale bar of (D) = 1 cm.

Table 11. Liver morphometry in hourglass dolphin and spectacled porpoise. Measurements shown as width x length x height.

	Hourglass dolphin (*Lagenorhynchus cruciger*)		Spectacled porpoise (*Phocoena dioptrica*)			
Parameter	KS10-28Lc	KS20-20Lc	KS20-07Pd	KS14-45Pd/ X2020.76	KS14-37Pd/ X2020.77	KS14-37Pd/ VT3347
Weight (g)	1865	1964	3855	4143	2368	861
Measurements (mm)	n/a	272 x 309 x 42	n/a	n/a	n/a	n/a

Endocrine system

<u>Adrenal glands</u>

In both species, the adrenal glands were composed of a thick cortex (divided into *zona glomerulosa*,

fasciculata and reticularis), and a thin medulla. The adrenal glands of hourglass dolphins demonstrated a more ovoidal shape compared to the spectacled porpoises, which were more pyramidal in shape. Microscopically, there were more septa in the spectacled porpoise compared to the hourglass dolphin, with the zona *fasciculata* comprising the thickest component (Fig.16). Details on size and weight of the adrenal glands are reported in Table 12.

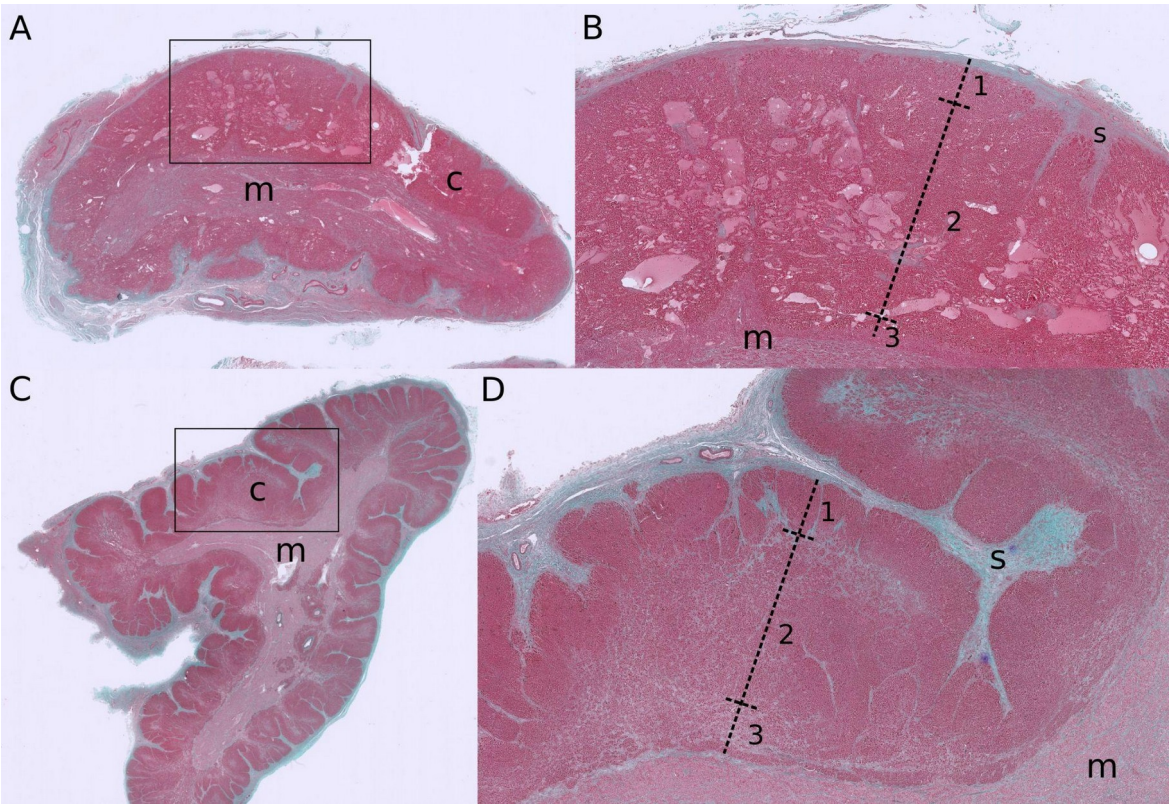

Fig. 16. Adrenal glands of hourglass dolphin KS20-20Lc (A, B) and spectacled porpoise KS20-07Pd (C, D) stained with Masson's trichrome. A and C display the whole gland. B and D offer a subdivision of the cortex into zona *glomerulosa* (1), *fasciculata* (2) and *reticularis* (3) at 20x magnification. Note: c, cortex; m, medulla; s, septa.

Table 12. Adrenal gland morphometry. Measurements shown as length x width x diameter. Note: L = left; R = right.

Parameter	Hourglass dolphin (*Lagenorhynchus cruciger*)		Spectacled porpoise (*Phocoena dioptrica*)		
	KS10-28Lc	KS20-20Lc	KS20-07Pd	KS14-37Pd /X2020.77	KS14-45Pd/ X2020.76
Adrenal R weight (g)	n/a	8	7	19.2	15
Adrenal R measurements (mm)	n/a	78 x 28 x 9	55 x 30 x17	67 x 35 x n/a	n/a
Adrenal L weight (g)	n/a	7	8	18.4	11
Adrenal L measurements (mm)	n/a	52 x 23 x 7	51 x 34 x 10	55 x 26 x n/a	n/a

Urinary system

Each kidney in the hourglass dolphins had ca 300 reniculi, similar to that of bottlenose dolphin *Tursiops truncatus* (Cozzi et al., 2017). Renal structure was typical of cetaceans, with the muscular basked (*sporta perimedullaris*) and renicular arterioles dividing the cortex and medulla (Fig.17). Details on the morphometry of the kidneys are further summarised in Table 13.

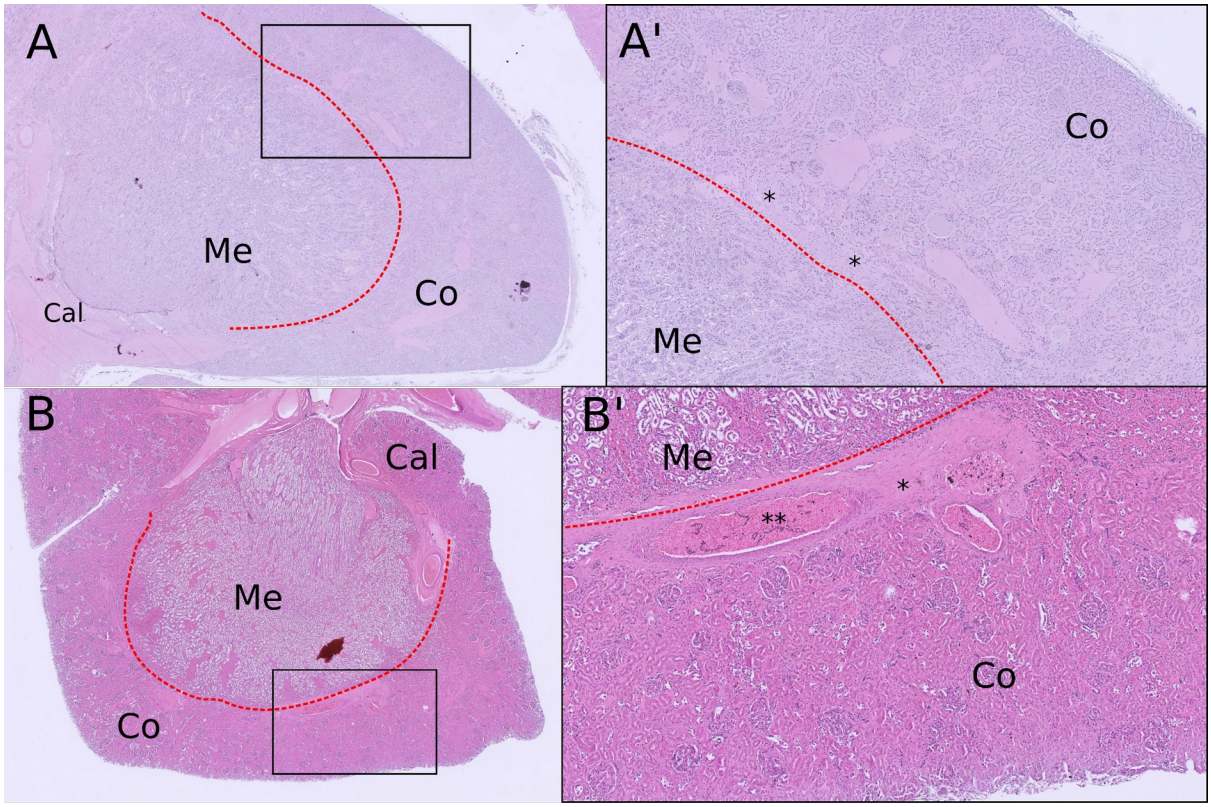

Fig. 17. Histological assessment of reniculus of hourglass dolphin KS20-20Lc (A, A') and spectacled porpoise KS20-07Pd (B, B') stained with hematoxylin-eosin. A and B show the whole structure with the red dotted line dividing the cortex (Co) from the medulla (Me), which in turn collects the urine in the calyx (cal). A' and B' show the muscular basket (*) and renicular arterioles (**) at 20 magnification

Table 13. Morphometry of the kidneys of the specimens. K, kidney; L, left; R, right. Measurements: length x width x diameter.

	Hourglass dolphin (*Lagenorhynchus cruciger*)		Spectacled porpoise (*Phocoena dioptrica*)			
Parameter	KS10-28Lc	KS20-20Lc	KS20-07Pd	KS14-45Pd/ X2020.76	KS14-37Pd/ X2020.77	KS14-37Pd/ VT3347
R K weight (g)	300	455	378	414	324	112.26
R K measurements (mm)	200 x 90 x 25	251 x 104 x 27	238 x 99 x 25	250 x 90 x 30	198 x 79 x 41.6	n/a

L K weight (g)	335	458	372	431	260.6	105.5
L K measurements (mm)	220 x 90 x 30	243 x 123 x 21	233 x 98 x 25	240 x 90 x 33	210 x 80 x 31.4	n/a
Bladder weight (g)	n/a	47	n/a	n/a	n/a	n/a
Bladder measurements (mm)	na	103 x 34 x 20	na			na

Genital system

In KS14-37Pd/VT3347, the left ovary weighed 1.9g, was 15 mm in length, 10 mm in width and 5 mm in diameter. The uterus was 30 mm in length and 15 mm in width, belonging to an immature female.

In males of both species, the penis was S-shaped and displayed the retractor muscles characteristic of several artiodactyls. The apex was thin and the prostate gland clear (Figure 18).

In the five males, the testicles were large as usual in adult cetaceans, with a white-pearl colour, and an epididymis running on the dorsal border of the testicle for most of its length. However, the testicles were more elongated in the hourglass dolphins compared to the spectacled porpoise. The size of the testicles in both species indicated that all males were sexually mature.

Details on the morphometry of the genital apparatus are reported in Table 14.

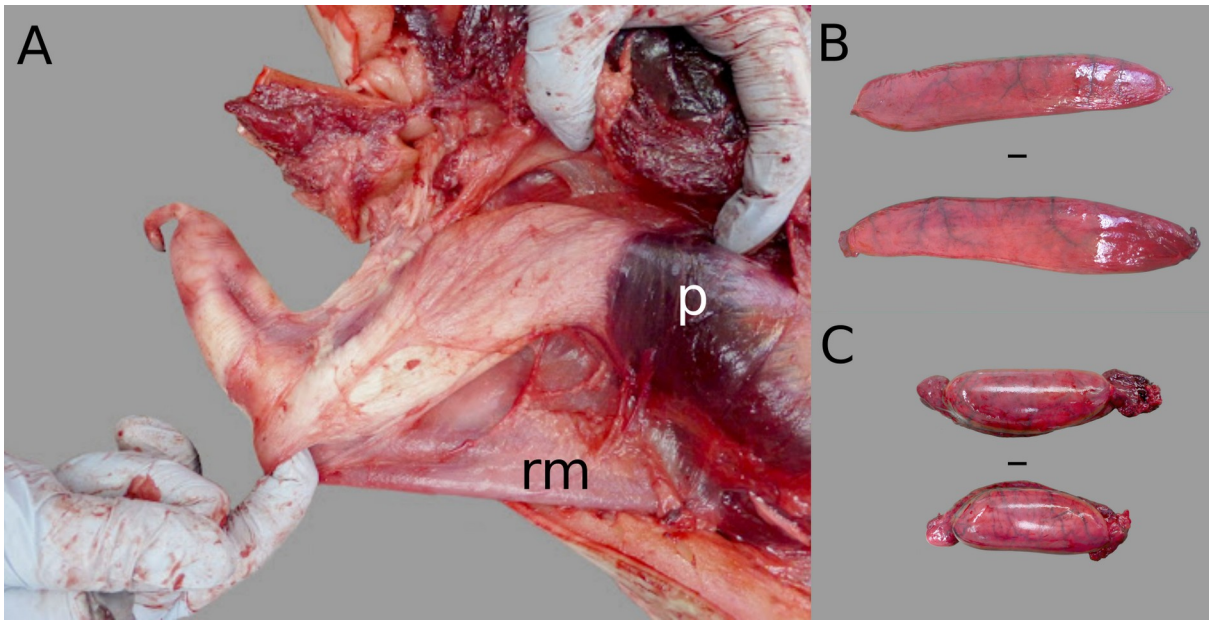

Fig.18. Male reproductive system: (A) Penis of hourglass dolphin KS20-20Lc with retractor muscle (rm) and prostate (p) covered by the muscles ischiocavernosus and bulbo-urethralis; (B) testicles of hourglass dolphin KS20-20Lc; (C) testicles of spectacled porpoise KS20-07Pd.

Table 14. Morphometry of the male genital apparatus. Note: (T) testis, (E) epididymis; L, left; R, right. Note: Measurements are reported as length x width x diameter (mm).

Parameter	Hourglass dolphin (*Lagenorhynchus cruciger*)	Spectacled porpoise (*Phocoena dioptrica*)

	KS10-28Lc	KS20-20Lc	KS20-07Pd	KS14-45Pd /X2020.76	KS14-37Pd /X2020.77
R T + E weight (g)	315	434	323	n/a	119.9
R T - E weight (g)	267	369	276	n/a	n/a
R T measurements - length x width x depth (mm)	305 x 59	350 x 72 x 21	161 x 68 x 39	131 x 51 x n/a	150 x 50 x n/a
L T + E weight (g)	360	466	285	n/a	124.5
L T - E weight (g)	270	383	249	n/a	82.2
L T measurements - length x width x depth (mm)	285 x 55	375 x 74 x 19	152 x 61 x 39	138 x 50 x n/a	150 x 50 x n/a
Postanal hump measurements (cm)	4.3 x 28	6.5 x 5.2 x 28	n/a	n/a	n/a
Penis length (mm)	n/a	300	n/a	~190	n/a

Discussion

The anatomical description of little known or endemic species is rarely for the sole purpose of describing a new species, but rather to offer insight on where the species fits taxonomically. Here we provided an anatomical overview and description of two seldom reported species, the hourglass dolphin and the spectacled porpoise, using not only photography and conventional histology but also computed tomography including three-dimensional reconstructions. This work was only possible thanks to the collaborative efforts of many individuals spanning multiple teams within and beyond New Zealand.

In terms of size, both species were within similar ranges of total body length, although male hourglass dolphins weighed marginally less than what was reported for adult males (~90kg). Skeletal features, including condylo-basal length and dental characteristics, aligned with previously reported ranges for these species (Goodall et al., 1997; Brownell, 1999; Brownell and Donahue, 1999; Gazitúa et al., 1999; Evans et al., 2001; Pinedo, 2002; Fernández et al., 2003). The anatomical features of other organs and systems, such as the spleen, gastrointestinal tract, liver, adrenal glands, kidneys, and male reproductive systems, were similar to those of other odontocetes. This similarity reinforces the idea of a shared evolutionary lineage and common functional adaptations among marine mammals (Cozzi et al., 2017). This included the characteristic ‘keel’ of the hourglass dolphin, which, as in other delphinids, is composed of blubber and dense connective tissue.

The respiratory anatomy revealed a lack of lobation and the presence of a right bronchus trachealis, consistent with findings in other cetaceans (Fanning and Harrison, 1974; Cozzi et al., 2017). Although systematic measurement of lung weight and total lung capacity was challenging, qualitative evaluation indicated that both species possess relatively large lungs for their body size. This observation aligns with the "short dive, big lung" relationship observed by Piscitelli et al. (2010, 2013), suggesting that their lung size is adapted for this diving behaviour. Meanwhile, observation of the cardiocirculatory system revealed that in terms of topography and anatomy, the heart in both species aligns with that of other cetaceans (Cozzi et al., 2017).

The dorsal fin of the spectacled porpoise presented unique characteristics, including its size and blood supply. The dorsal fin of other cetaceans studied in captivity has been demonstrated to be a

heterogeneous thermoregulatory window, together with the fluke and flippers (Meagher et al., 2002; Cozzi et al., 2017; Plön et al., 2018; Favilla et al., 2023), allowing these animals to conserve or dissipate body heat as required. In particular, vascularisation of the dorsal fin is hypothesised to cool down the male gonads (Plön et al., 2018). Our observations revealed large vessels branching extensively throughout the dorsal fin, reaching up to the tip. These findings were consistent with those reported by Plön and colleagues (2018) in their studies of the Indo-Pacific humpback dolphin (*Sousa plumbea*) and the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*). However, we noted an inexplicable paucity of vessels in the cranial and caudal regions of the fin. This inconsistency may be due to technical limitations in detecting these vessels or a true absence, which would require further investigation, including differences between sexes and potentially utilising MRI with contrast agents to enhance the quality of results. Interestingly, it is worth noting that the Dall's porpoise (*Phocoenoides dalli*), a relative of the spectacled porpoise that also inhabits cold waters, possesses both a small dorsal fin and fluke, in addition to having a relatively thin blubber layer (Jefferson, 2018). This comparison highlights the variability in thermoregulatory strategies among cetaceans, indicating thermoregulatory mechanisms need further investigation. The large size of the dorsal fin of the spectacled porpoise could therefore serve multiple functions. A large dorsal fin could minimises lateral torsion during swimming, enhancing propulsive efficiency, while also maximising exposure to sunlight, which can aid in thermoregulation by warming the blood flowing through its extensive vascular network. To a lesser degree, the dorsal fin of the hourglass dolphin was also large with a wide surface area. However, no large vessels similar were observed in the available CT images, unlike the spectacled porpoise. An alternative hypothesis is that the enlarged dorsal fins of males would serve as a marker of sexual maturity. Collectively, these characteristics highlight the roles in which dorsal fins may affect the ecology and survival of the spectacled porpoise.

Regardless of insights provided, our study faced several limitations regarding the opportunistic methodologies employed. For example, not all specimens were assessed in the same manner postmortem or imaged uniformly. Variation in CT scan quality arose from access to different machines, and the advance of technology across the ten years of specimen acquisition. More recent scans showed improved resolution compared to the old ones. The unattached large dorsal fin of spectacled porpoise KS14-45Pd/X2020.76 hindered complete scans of the entire animal, making it difficult to count the lumbar vertebrae. Additionally, histological analyses were limited to only a selection of specimens, highlighting the need for greater consistency in future examinations of these rare and elusive species. Despite such challenges, the findings presented here support existing literature, while documenting for the first time the vascular pattern of the dorsal fin of the spectacled porpoise.

In conclusion, this anatomical study of the hourglass dolphin and spectacled porpoise underscores their adaptations to marine environments, reflecting evolutionary pressures that shaped their morphology and physiology. The ecology of these species is essentially a blank canvas. Further research is encouraged on their ecological roles and the potential impacts of environmental changes on their populations.

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