



Morphological Assessment of Skulls Reveals the Presence of Two Species of Bottlenose Dolphins (*Tursiops* Gervais, 1855) in Pakistan Waters, Northern Arabian Sea

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Abstract: Ten skulls of bottlenose dolphins (*Tursiops* spp.) collected from various locations along the coast of Pakistan were examined. The skulls were initially divided into two groups, Group-A ($n = 7$) and Group-B ($n = 3$), based on specific morphological characters. The data were further tested statistically using Student's t-test and violin plots. The results clustered the specimens into two morphological groups. Twelve morphological variables recommended for visual identification distinctly categorised skulls in two groups (e.g., small cranium with longer/slender rostrum (Group-A) versus stockier and wider skull (Group-B); presence of premaxillary convexity in the lateral view and premaxilla pinch in the dorsal view on the rostrum (Group-A); temporal fossa rounded (Group-A) versus small and elongated in shape (Group-B); teeth counts). The morphological variations and the supporting statistical results clearly identified the two known bottlenose dolphin species: *T. aduncus* (Group-A) and *T. truncatus* (Group-B). This study confirms the presence of these two species of *Tursiops* in Pakistani waters. It adds new information useful for developing conservation action plans required for conservation of cetacean species in this region.

Key words: Taxonomy, cranial morphology, morphometric, Pakistan

Introduction

The taxonomy of the genus *Tursiops* Gervais, 1855 (Cetacea: Delphinidae) is still unresolved, though extensive studies have been done in the past (MÖLLER & BEHEREGARAY 2001, NATOLI et al. 2004, MOURA et al. 2020, COSTA et al. 2016). Historically, about 20 putative species of bottlenose dolphins have been described based on morphological variables (HERSHKOVITZ 1966). These morphological forms are currently considered as synonyms of *T. truncatus* (Montagu, 1821) (CHARLTON-ROBB et al. 2011, WANG et al. 2000b). Only two morphotypes of *Tursiops* have been generally recognised as valid

species from the world oceans. These are *T. aduncus* (Ehrenberg, 1832) (Indo-pacific bottlenose dolphin) from the coastal waters of the Indian and Pacific Oceans and *T. truncatus* (Montagu, 1821) (common bottlenose dolphin) inhabiting both coastal and offshore waters around the world, including along the Atlantic coasts (RICE 1998, WELLS & SCOTT 2018, NGQULANA et al. 2019, HOHL et al. 2020).

Previously, PILLERI & GHIR (1972a) conducted extensive beach- and boat-based surveys along Sindh and Balochistan coasts and collected dolphin skulls. These dolphin skulls were examined based on cranial morphometry and were identified as *T. aduncus* (PILLERI & GHIR 1972a). Since then, no

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new information regarding the cranial morphology of bottlenose dolphins has been added. Recent surveys conducted along the coasts of Sindh and Balochistan provide further information on stranded bottlenose dolphins (BRAULIK 2001, GORE et al. 2012, 2017, KIANI 2014).

The most commonly encountered bottlenose species in the north-west Indian Ocean is the Indo-pacific bottlenose dolphin (PILLERI & GHIR 1972a, BALDWIN 2003). This species is also reported from the Arabian Sea (LAL MOHAN 1985a, JAYASANKAR et al. 2008, BRAULIK et al. 2010, GRAY 2016, OWFI et al. 2016, COSTA et al. 2019, MOURA et al. 2020). The *common bottlenose dolphin*, *T. truncatus*, has also been reported in offshore waters of India (JAYASANKAR et al. 2008), Oman (GRAY 2016, MINTON et al. 2010) and in the Red Sea (COSTA et al. 2019). In Pakistani waters, *T. truncatus* has also been occasionally recorded (GORE et al. 2012, KIANI 2014). However, the presence of this species is not confirmed yet. The identification of morphotypes of *Tursiops* is generally difficult in the field (AMARAL et al. 2009, PERRIN et al. 2013, GORE et al. 2017). Therefore, the present study was carried out to differentiate the two species through morphological assessment of bottlenose dolphin skulls collected along the entire coast of Pakistan.

Materials and Methods

The present study consists of data from ten skulls of bottlenose dolphins collected from the Sindh (four skulls) and Balochistan (six skulls) coasts (Fig. 1). The cranial maturity of the samples was assessed following different cranial sutures: maxilla-frontal fusion, nasal fusion, distal fusion of maxilla-premaxilla, interalveolar septa and open/closed tooth sockets (CALZADA 1997, CHEN 2011, JORDON et al. 2015). Totally, 39 cranial variables were analysed (Table 3; for definitions, see PERRIN 1975, WANG et al. 2000b, KEMPER 2004). Cranial measurements were taken using a ruler scale and Vernier calliper (up to 0.02 mm) (Fig. 2). The tooth counts were noted by enumerating tooth sockets on the rostrum. The dorsal, ventral, lateral, latero-occipital and occipital views of all skulls were photographed. For abbreviations of characters, see Table 2. All skulls are deposited in the Centre of Excellence in Marine Biology, University of Karachi (Table 1).

All skulls were visually identified based on morphometric measurements taken according to the standard protocols previously proposed for species of *Tursiops* (ROSS 1977, WANG et al. 2000b, KEMPER 2004, KURIHARA & ODA 2006, 2007, JEFFERSON



Fig 1. Map showing sampling locations along the coast of Pakistan.

Table 1. List of skulls collected from various locations and analysed in this study.

Skull Voucher	Locality	Date
MBD-001	Astola Island	February 2007
MBD-002	Khuddi Creek	May 2009
MBD-003	Dabbo Creek	May 2009
MBD-004	Astola Island	February 2007
MBD-005	Jiwani coast	-
MBD-006	Gunz beach	March 2008
MBD-007	Gunz beach	-
MBD-008	Jiwani coast	-
MBD-009	KetiBunder, Indus Delta	2017
MBD-010	KetiBunder, Indus Delta	-

et al. 2015, GRAY 2016). The following characters were used: (i) shape of the skull, (ii) length and width of rostrum, (iii) configuration of premaxilla bone on rostrum, (iv) shape and position of postorbital process, (v) orientation of pterygoid notches, (vi) broadness and narrowness of vomer bone and (vii) geometric shapes of the temporal fossa were used (Fig. 3). On their basis, the skulls were classified into two groups: Group-A of 7 specimen and Group-B of 3 specimen. Student's *t*-test was performed using the morphometric data to compare the means of the two groups. We have also used the median as a comparison base of the central tendency. Additionally, violin plots were constructed using morphometric data of cranial variables to further test that the two groups of skulls are different. We used STATA SOFTWARE (v.15.0) to perform the *t*-test for group comparison. Violin plots were constructed using R statistical software (v.4.0.2) (R CORE TEAM 2020).

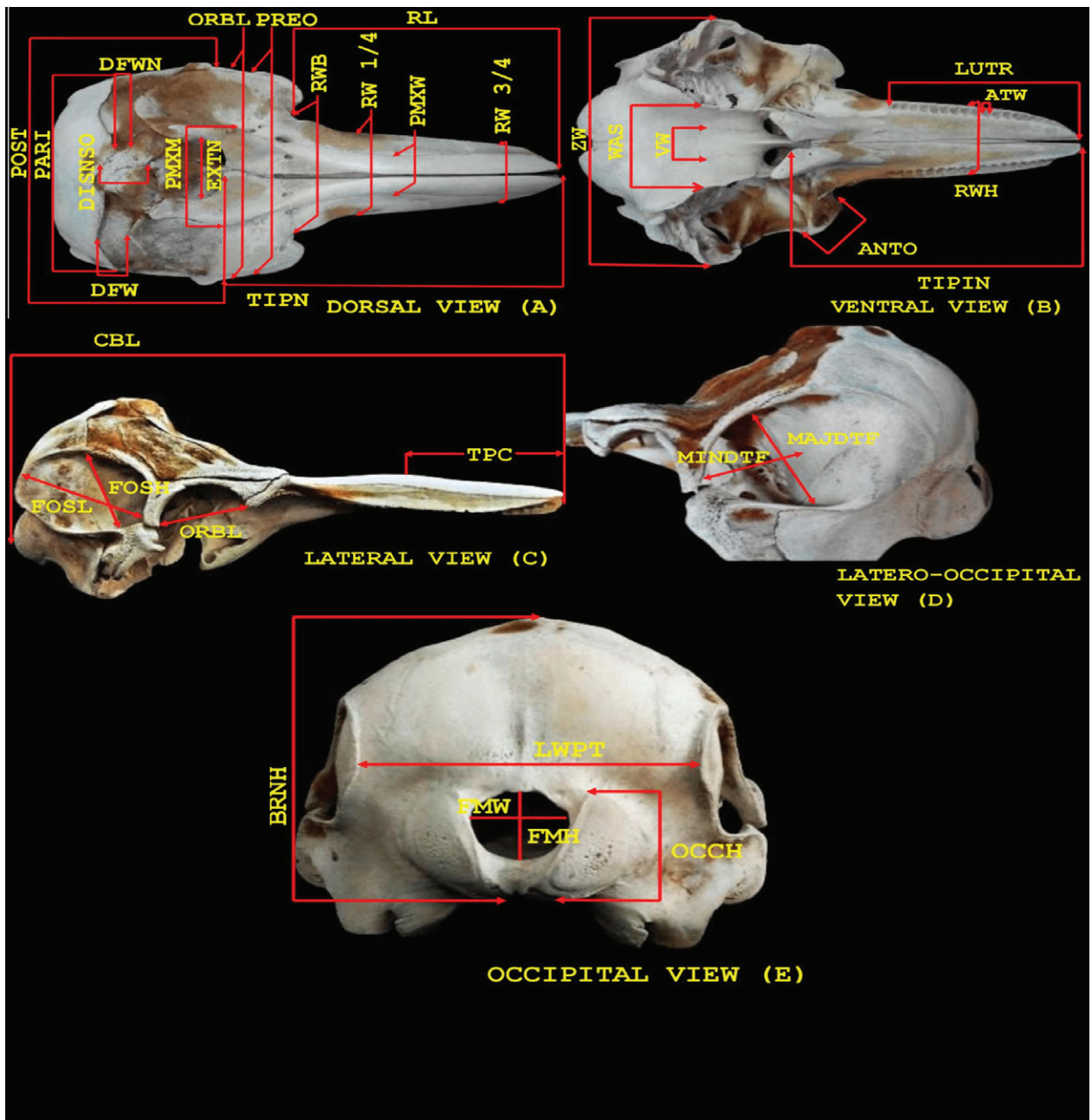


Fig 2. Dorsal (A), Ventral (B), Lateral (C), Latero-Occipital (D) and Occipital views (E) explaining skull measurements used in this study. For character abbreviations see Table 2.

Results

Visual assessment of cranial traits

All skulls identified in this study belonged to mature specimen of *Tursiops*. The visual differences in many cranial characters suggested that possibly two species of *Tursiops* are present in Pakistani waters. Apparent visual differences noted between Group-A (MBD-005) and Group-B (MBD-007) are shown in Fig. 3. The morphological features (Fig. 3) generally revealed that skulls in Group-A were small and robust, rostrum narrower and elongated, tapering abruptly at

proximal 60 mm. On the other hand, Group-B skulls were stockier with broad and long rostrum and taper gradually. The orbital plates were less antero-mesially inclined in lateral view in Group-A as compared to Group-B where the plate margins were slightly parallel and more antero-mesially inclined. Premaxillary ‘pinch’ was observed in Group-A at $\sim 1/3$ rostral length (dorsal view) with a prominent premaxillary convexity (lateral view) (Fig. 3, A-1 & A-3). Premaxillary ‘pinch’ and premaxillary convexity were not obvious in Group-B (Fig. 3, B-1 & B-3). The vomer bone was compressed (narrower) in Group-A, as op-

Table 2. Panel A – comparison of group mean values for cranial meristic characters of bottlenose dolphin skulls based on *t*-test. Panel B – comparison of group values based on medians. **Note:** *** and ** show significant differences at the 1% and 5%, respectively.

Panel A: Comparison of group mean values						
List of cranial and meristic characters		Group mean comparison based on t-Test				
Cranial traits	Abbreviations	Group B (Mean)	Group A (Mean)	Mean Difference (B-A)	t-Stat:	P-Value
Condylbasal length	CBL	522.66	468.07	54.59***	4.31	0.003
Length of rostrum	LR	298.67	267.89	30.78**	3.03	0.016
Width of rostrum at base	RWB	127.07	109.24	17.82***	3.48	0.008
Width of rostrum at 60 mm	RWQ	97.43	76.73	20.70***	4.22	0.003
Width of rostrum at mid length	RWH	84.2	62.74	21.46***	6.04	0
Width of premaxillaries at midlength of rostrum	PMXWH	45.73	35.8	9.93***	3.15	0.014
Width of rostrum at 3/4 length	RWT	63.67	46.6	17.07***	4.24	0.003
Distance from tip of rostrum to external nares	TIPN	342.33	309.17	33.16**	2.98	0.017
Distance from tip of rostrum to internal nares	TIPIN	337	295.43	41.57**	2.96	0.018
Greatest preorbital width	PREO	210	192.14	17.86	1.65	0.138
Greatest postorbital width	POST	227.33	201.93	25.40***	3.73	0.006
Least supraorbital width	ORBLW	218	193.67	24.33***	3.74	0.006
Greatest width of external nares	EXTN	56.26	54.77	1.49	0.83	0.431
Greatest width across zygomatic process of squamosal	ZW	253.33	217.93	35.40***	4.53	0.002
Greatest width of premaxillaries	PMXM	91.9	87.49	4.41	1.63	0.141
Greatest parietal width	PARI	198.67	172.14	26.52***	3.87	0.005
Height of braincase	BRNH	176.67	167.29	9.38	0.65	0.531
Internal length of braincase	BRNL	141	125.64	15.36***	3.13	0.014
Greatest length of left posttemporal fossa	FOSL	108.83	96.91	11.92**	2.64	0.03
Greatest width of left posttemporal fossa	FOSH	74.67	66.93	7.74***	3.91	0.004
Major diameter of left temporal fossa proper	MAJDTF	70.67	66.07	4.59	1.5	0.171
Minor diameter of left temporal fossa proper	MINDTF	54.67	48.93	5.74	1.9	0.094
Distance between nasals to hindmost point of margin of supraoccipital crest	DISNSOC	43.47	32.24	11.22	2.21	0.058
Length of left orbit	ORBL	64.83	63.93	0.9	0.29	0.779
Length of antorbital process	ANTO	58.27	43.07	15.19***	5.07	0.001
Length of upper left tooth row	LUTR	255	231.07	23.93**	3.07	0.015
Number of teeth-upper left	TEEUL	22.67	24.29	-1.62	1.77	0.115
Number of teeth-upper right	TEEUR	22.67	24.29	-1.62	1.77	0.115
Greatest width of basisphenoid	VW	50.93	26.97	23.96***	5.69	0
Width of alisphenoid	WAS	92.37	71.74	20.62***	4.06	0.004
Alveolar tooth width measured at mid rostrum	ATW	9.67	8.68	0.98	1.4	0.198
Tip of rostrum to apex of premaxillary convexity	TPC	184.67	178	6.67	0.5	0.629
Least width between posterior borders of temporal fossa	LWPTF	146.33	143.04	3.29	0.54	0.607
Dorsal frontal width at maxilla	DFWM	12.93	16.29	-3.35	0.95	0.368
Dorsal frontal width at nasals	DFWN	24.57	17.13	7.44	1.58	0.153
Greatest width of Occipital condyles	OCCW	105.8	103.23	2.57	0.58	0.578
Greatest height of Occipital condyles	OCCH	65.5	59.8	5.7	1.54	0.161
Greatest width of foramen magnum	FMW	41.67	41.56	0.11	0.07	0.944
Greatest height of foramen magnum	FMH	40.17	36.13	4.04	1.23	0.254
Panel B: Comparison based on Median						
Group-A		Group-B				
Average Mean	Average Median	Average Mean	Average Median			
116.75	73.26	129.28	88.63			

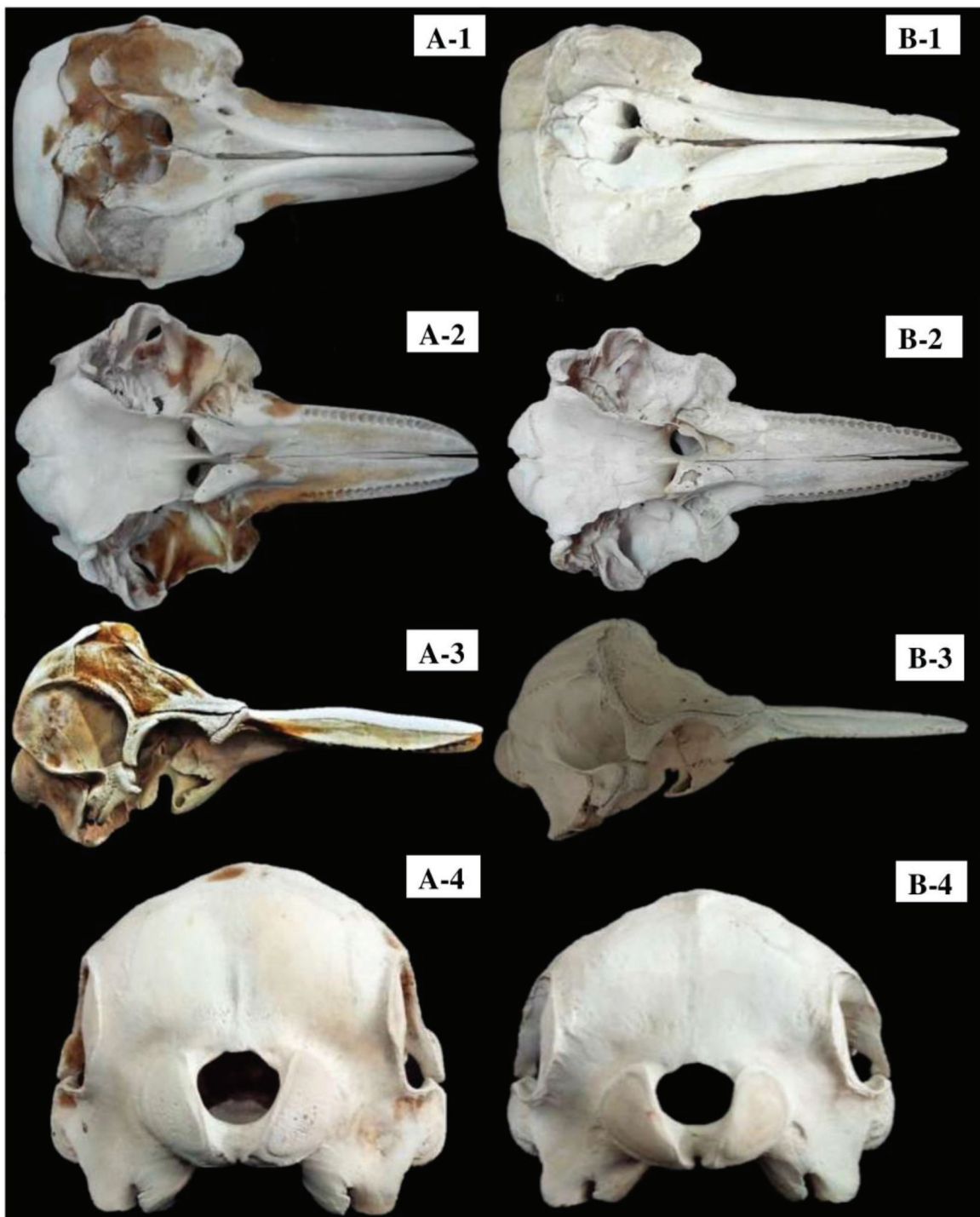


Fig 3. Dorsal (1), ventral (2), lateral (3) and occipital (4) views of bottlenose dolphins of Group A (MBD-005, A1-4) and B (MBD-007, B1-4) from Pakistan coast.

posed to Group-B skulls, which had wider vomer bone. The temporal fossa was large and rounded with no temporal crests flaring backward towards the occipital region in Group-A and a small and less elliptical or D-shape feature with temporal crests flaring backward in Group-B. The pterygoid notch was subacute with elongated palatines near pterygoids on the ventral side (Fig. 3, A-2) in Group-A. The pterygoid

notch in Group-B was broad and had an obtuse apex with short palatines (Fig. 3, B-2). Group-A skulls had a distinguishing feature: the postorbital process of the frontal bone was narrow with a backward inclination towards the temporal fossa and the postorbital process was long and slender (Fig. 4, A-a) and the maxillary bone was sharply sloping downward (Fig. 4, A-b). In Group-B, the postorbital process was broad

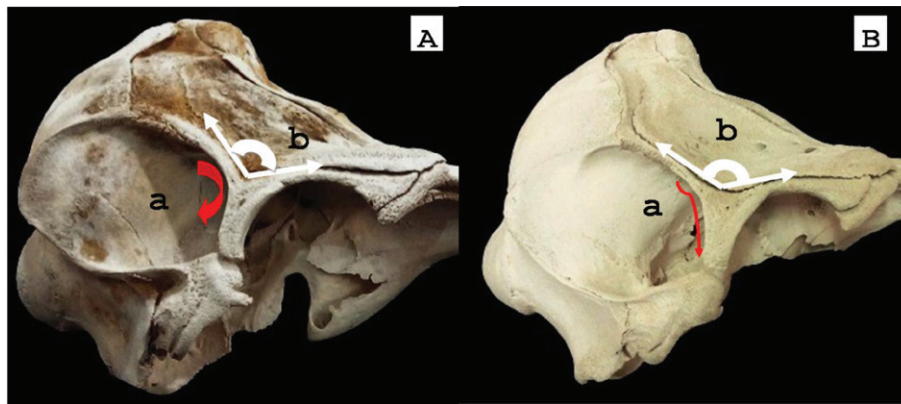


Fig 4. Lateral views of skulls of MBD-005 (Group A) versus MBD-006 (Group B); **a.** Postorbital process of the frontal bone is long, narrow, and inclined/angular towards temporal fossa (Group A) vs. Postorbital process small, broad, and straight not inclined towards temporal fossa (Group B); **b.** The angle of maxillary bone is sharp (Group A) vs. gradual sloping downward (Group B).

and smaller in length. The postorbital process was straight with no backward inclination (Fig. 4, B-a) and maxillary bone were gradually sloping downward (Fig. 4, B-b).

Statistical analyses

For cranial measurements, see Tables 2 and 3. Skull characters of Groups A and B demonstrated significant differences in the distribution of numeric data (Fig. 5, Table 2). Out of 39 cranial variables studied, 20 variables showed significant morphometric differences. However, 16 variable (CBL, LR, RWB, RWQ, RWH, RWT, PMXWH, POST, ORBLW, ZW, PARI, BRNL, FOSH, ANTO, VW and WAS) having high significant differences in their mean values recorded for skulls in two groups were selected for further analysis.

The morphological parameters recorded for Group A and B, such as CBL, POST, ORBLW, ZW, PARI, BRNL, FOSH, ANTO, VW and WAS, were significantly smaller in Group-A skulls (Table 2). The rostral width characters RWB, RWQ, RWH and RWT also differed significantly in study groups of skulls. Rostral widths were broader in Group-B and the morphometric ranges are not overlapping in Group-A and Group-B. LR and PMXWH were significantly smaller in Group-A compared to Group-B but with minimal overlapping in morphometric ranges. Density distribution analysis of the significant mean values of cranial variables is shown as violin plots (Fig. 5). In order to know the central tendency of two Groups (A and B), median was used as this is appropriate for data that has extreme values or outliers. In Table 2 panel B depicts comparison of average mean value, which suggests that the average mean value is greater than average median

values for both species. This comparison of median values clearly showed that the distribution of data was positively skewed. The skewed data and outliers have a lesser effect on the median and, hence, the comparison median of morphometric parameters of two groups of skulls clearly indicated that the characteristics of the skulls in the two groups were different and appeared to represent two species.

Our results evidently confirm that all specimens (three skulls) collected from around the Ji-wani Bay, Balochistan are confirmed as *T. truncatus* (Group-B) and the seven other specimens, collected from both Sindh (four skulls) and Balochistan (three skulls) as *T. aduncus* (Group-A).

Discussion

The present study confirmed two species of *Tursiops* from Pakistani waters: *T. aduncus* (Group-A) from both Sindh and Balochistan and *T. truncatus* (Group-B) from the Balochistan coast only. In our study, the bottlenose dolphin species were identified based on morphological characteristics of skulls: small skull and elongated rostrum in *T. aduncus* and (stockier skull with broad and longer rostrum in *T. truncatus*). Our observations are in agreement with previous studies (ROSS 1977, WANG et al. 2000b, KEMPER 2004, KURIHARA & ODA 2006, 2007, GRAY 2016, JEDENSJÖ et al. 2020). Cranial features in bottlenose dolphins may vary within the same species due to ecological differences, such as feeding, echolocation and variation in feeding habits and temperature (WALKER 1981, HERSH & DUFFIELD 1990, GRAY 2016, NGQULANA 2019, JEDENSJÖ et al. 2020). This may be possible because bottlenose dolphin species can be both sympatric and parapatric,

Table 3. Comparison of cranial measurements (mm) and tooth counts of bottlenose dolphins (present study) from Pakistan and other geographical forms recorded previously. Basic measurement protocol followed PERRIN (1975). Abbreviations: n = sample size; SD = standard deviation; % CBL = percent of condylobasal length.

Cranial traits	Present study						South African waters (Ross 1977, 1984)						Chinese waters (WANG et al. 2000b)							
	Group A			Group B			T. aduncus			T. truncatus			T. aduncus			T. truncatus				
	n	SD	%CBL	Mean (Range)	n	SD	%CBL	Mean (Range)	n	SD	Mean (Range)	n	SD	Mean (Range)	n	SD	Mean (Range)	n	SD	Mean (Range)
CBL	7	20.5	100	468.1 (442-505.5)	3	9.5	100	522.6 (513-532)	33	16.1	472.7 (433.0-507.0)	9	26.2	545.8 (504.0-578.0)	18	22.2	485.1 (450.7-529.1)	50	33.4	506.2 (394.4-561.1)
LR	7	16.2	57.2	267.8 (243-294)	3	8.74	57.2	298.6 (289-306)	33	12	271.9 (250.0-97.0)	9	18	309.1 (283.2-334.6)	18	15	281 (258.0-317.4)	49	23.4	283.8 (203.5-319.6)
RWB	7	6.67	23.4	109.2 (100.9-119)	3	9.33	24.3	127.0 (118.5-137)	33	6.13	112.3 (100.9-125.0)	9	10.8	142.8 (127.0-157.8)	19	7.84	115.8 (103.4-134.0)	49	11.2	134.5 (98.1-154.1)
RWQ	7	8.01	16.4	76.7 (68.4-87.7)	3	3.17	18.7	97.4 (94.5-100.8)	-	-	-	-	-	-	-	-	-	-	-	-
RWH	7	5.91	13.4	62.7 (57.5-74)	3	1.08	16.1	84.2 (83-85.1)	32	3.97	64.9 (56.0-74.9)	9	10.5	88.6 (73.1-105.8)	18	5.03	64.2 (56.3-71.3)	46	8.92	83 (54.5-101.5)
PMXWH	7	4.75	7.7	35.8 (30.8-45.5)	3	3.97	8.8	45.7 (42-49.9)	33	3.46	83.4 (76.8-90.1)	9	5.83	101.2 (88.2-108.1)	18	5.35	86.2 (77.1-100.0)	50	6.93	93.5 (76.5-107.4)
RWT	7	6.04	10	46.6 (39-55.5)	3	5.13	12.2	63.6 (58-68)	33	5.37	48.8 (34.0-59.8)	9	9.74	66.9 (55.9-85.0)	17	6.4	50.3 (41.0-60.6)	47	7.75	64.3 (44.7-80.4)
TIPN	7	16.7	66	309.1 (288-335)	3	14.19	65.5	342.3 (327-355)	33	12.8	316.9 (294.0-343.0)	9	18.2	364.5 (337.2-386.9)	14	17.6	328.5 (298.4-366.1)	49	26.7	335.2 (243.5-375.2)
TIPIN	7	22.7	63.1	295.4 (265-333)	3	10.58	64.5	337 (325-345)	-	-	-	-	-	-	-	-	-	-	-	-
PREO	7	10.8	41.1	192.1 (183-215)	3	25.24	40.1	210 (182-231)	32	8.16	203.4 (180.1-219.8)	9	15.5	253.4 (229.8-276.9)	18	14.2	201.9 (177.0-230.1)	49	18.6	231.8 (171.5-262.5)
POST	7	10.4	43.2	201.9 (189.5-220)	3	8.08	43.5	227.3 (220-236)	32	9.15	230.2 (202.2-251.0)	9	17.1	277.3 (253.9-301.1)	14	14.5	223.4 (200.0-245.3)	50	19.5	254.6 (187.2-286.6)
ORBLW	7	9.96	41.4	193.6 (180-209.7)	3	7.55	41.7	218 (211-226)	33	7.53	207.3 (187.1-225.0)	6	16.7	250.4 (228.8-269.8)	18	13.8	199.5 (175.3-226.3)	50	18.2	224.5 (163.2-254.1)
EXTN	7	2.9	11.7	54.7 (49-57.8)	3	1.42	10.8	56.2 (55-57.8)	33	2.6	54.4 (50.0-61.0)	6	4.95	62.2 (54.9-68.2)	18	4.26	58.7 (54.0-70.3)	50	3.75	57.7 (49.5-67.6)
ZW	7	11.9	46.6	217.9 (207.5-242)	3	9.5	48.5	253.3 (244-263)	30	10.7	229.6 (197.9-251.0)	9	19.5	282.3 (257.0-313.0)	13	13.5	230.6 (209.0-251.3)	50	20.5	257.3 (188.6-290.0)
PMXM	7	4.41	18.7	87.4 (81.8-94.6)	3	1.73	17.6	91.9 (89.9-93)	33	3.46	83.4 (76.8-90.1)	9	5.83	101.2 (88.2-108.1)	13	13.5	230.6 (209.0-251.3)	50	20.5	257.3 (188.6-290.0)
PARI	7	9.67	36.9	172.1 (162-191)	3	10.69	38	198.6 (192-211)	-	-	-	-	-	-	-	-	-	-	-	-
BRNH	7	12.2	35.8	167.2 (148-185)	3	35.7	33.8	176.6 (139-210)	-	-	-	-	-	-	-	-	-	-	-	-
BRNL	7	7.93	26.9	125.6 (109-135)	3	3.61	27	141 (137-144)	-	-	-	-	-	-	-	-	-	-	-	-
FOSL	7	5.83	20.7	96.9 (90.4-108.4)	3	8.31	20.8	108.8 (101.8-118)	-	-	-	-	-	-	-	-	-	-	-	-
FOSH	7	3.24	14.3	66.9 (60.8-70)	3	1.17	14.3	74.6 (73.8-76)	-	-	-	-	-	-	-	-	-	-	-	-
MAJDTF	7	5.04	14.1	66.0 (56.5-72)	3	1.53	13.5	70.6 (69-72)	-	-	-	-	-	-	-	-	-	-	-	-
MINDTF	7	4.76	10.4	48.9 (41-54)	3	2.89	10.5	54.6 (53-58)	-	-	-	-	-	-	-	-	-	-	-	-
DISNSOC	7	6.36	6.9	32.2 (23-42)	3	9.74	8.3	43.4 (32.8-51.9)	-	-	-	-	-	-	-	-	-	-	-	-
ORBL	7	4.77	13.7	63.9 (59.9-73.5)	3	3.62	12.4	64.8 (62.5-69)	-	-	-	-	-	-	-	-	-	-	-	-
ANTO	7	4.93	9.2	43.0 (37.9-52.7)	3	1.55	11.2	58.2 (57-60)	21	3.97	44.8 (38.1-52.8)	8	6.42	63.7 (52.9-71.0)	14	3.15	46.1 (40.1-51.2)	49	6.43	60 (40.8-71.9)
LUTR	7	12.56	49.4	231.0 (216.5-247)	3	6	48.8	255 (249-261)	31	9.64	224.8 (208.0-245.0)	6	45.8	242.4 (154.0-276.9)	19	13.5	(209.4-65.9)	49	20.5	243.6 (172.0-277.7)
TEEUL	7	0.41	51.6	24.8 (24-25)	3	0.58	46.5	22.6 (22-23)	33	1.09	25.8 (24-28)	9	0.67	24.2 (23-25)	20	1.11	25.2 (23-27)	54	1.39	23.9 (21-27)
TEEUR	7	0.41	51.6	24.8 (24-25)	3	0.58	45.9	22.6 (22-23)	33	1.04	25.3 (24-28)	9	0.83	23.8 (22-25)	20	1.23	25.4 (24-28)	54	1.42	23.8 (20-27)
VW	7	6.08	5.7	26.9 (20-39)	3	6.19	9.7	50.9 (44-55.9)	-	-	-	-	-	-	-	-	-	-	-	-
VAS	7	6.04	15.3	71.7 (64.8-79.7)	3	10.37	17.7	92.3 (84.1-104)	-	-	-	-	-	-	-	-	-	-	-	-
ATW	7	0.77	1.9	8.6 (7.9-10)	3	1.53	1.9	9.6 (8-11)	-	-	-	-	-	-	-	-	-	-	-	-
TPC	7	15.11	38	178 (152-200)	3	28.22	35.3	184.6 (165-217)	-	-	-	-	-	-	-	-	-	-	-	-
LW/PTF	7	3.87	30.6	143.0 (138-148)	3	16.5	28	146.3 (130-163)	-	-	-	-	-	-	-	-	-	-	-	-
DFWM	7	4.14	3.7	16.2 (13-25)	3	7.24	2.4	12.9 (7-21)	-	-	-	-	-	-	-	-	-	-	-	-
DFWN	7	5.14	3.7	17.1 (10-24)	3	10.36	4.7	24.5 (14-34.7)	-	-	-	-	-	-	-	-	-	-	-	-
OCCW	7	6.9	22.1	103.2 (95-114)	3	4.75	20.2	105.8 (101-110.5)	-	-	-	-	-	-	-	-	-	-	-	-
OCCH	7	5.01	12.8	59.8 (53.1-65)	3	6.24	12.5	65.5 (60.5-72.5)	-	-	-	-	-	-	-	-	-	-	-	-
FMW	7	2.28	8.9	41.5 (38-43.7)	3	1.94	8	41.6 (40-43.8)	-	-	-	-	-	-	-	-	-	-	-	-
FMH	7	4.47	7.7	36.1 (29.5-42)	3	5.56	7.7	40.1 (34-44.8)	-	-	-	-	-	-	-	-	-	-	-	-

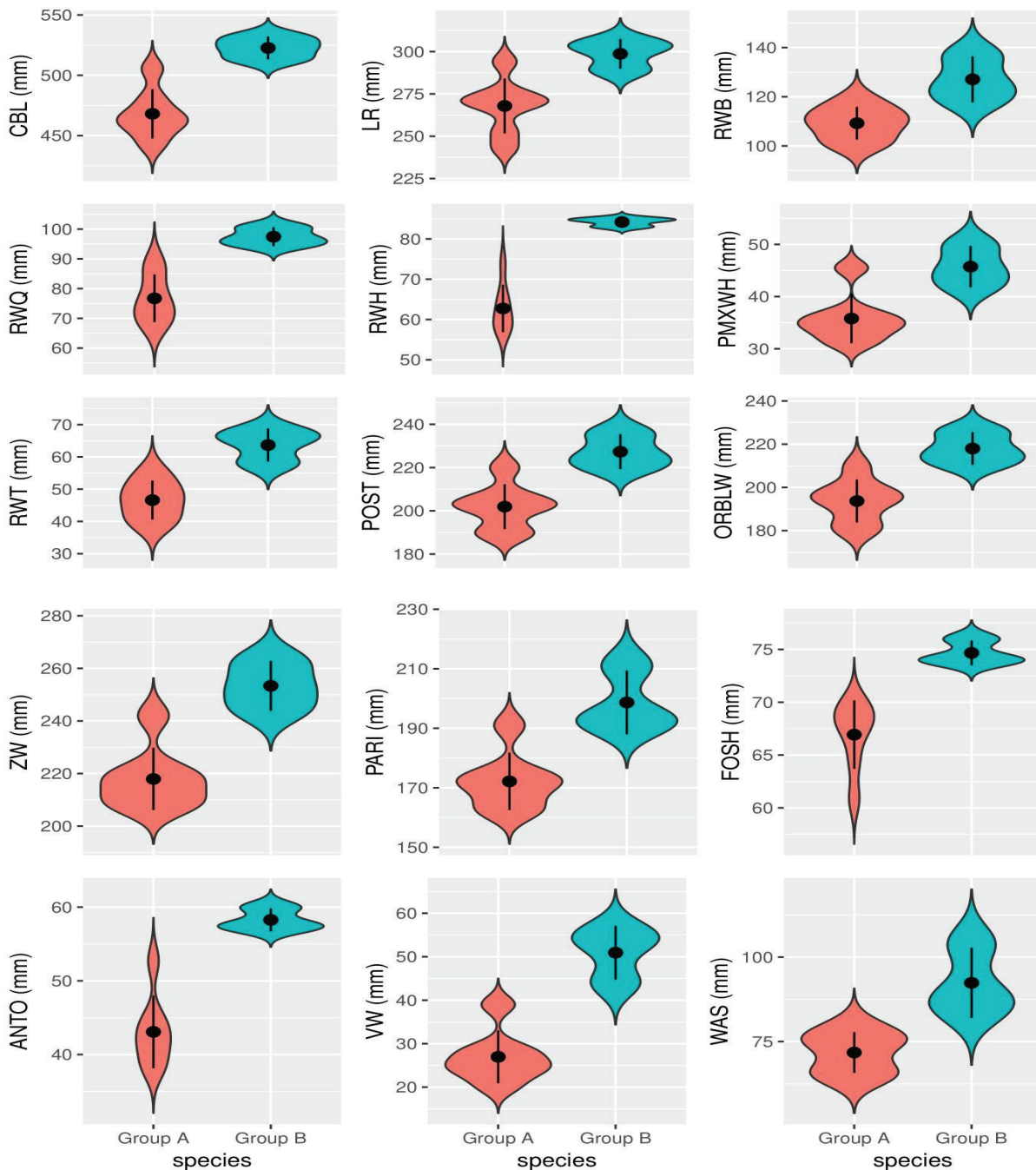


Fig 5. Violin plots showing the comparison of significant mean differences of different cranial characteristics between groups A and B based on *t*-test. The black dot shows the mean value and the line in violin plots represents the range. Abbreviations: **CBL**: condylobasal length, **LR**: length of rostrum, **RWB**: rostrum width at base, **RWQ**: rostrum width at 60 mm, **RWH**: rostrum width at midlength, **PMXWH**: width of premaxillaries at midlength of rostrum, **RWT**: rostrum width at $\frac{3}{4}$, **POST**: post orbital width, **ORBLW**: orbital width, **ZW**: zygomatic width, **PARI**: parietal width, **FOSH**: temporal fossa width, **ANTO**: length of antorbital process, **VW**: vomer width, **WAS**: width of alisphenoid.

depending on the region they inhabit (HALE et al. 2000, WANG et al. 2000b). *Tursiops aduncus* generally inhabits shallow water near the continental shelf, whereas *T. truncatus* is found in both inshore and offshore waters (RICE 1998, REEVES et al. 2002). In the present study, similar ecological characteris-

tics of cranial morphometry were observed in two putative species of bottlenose dolphin. We focused on the characteristics important for differentiating *T. aduncus* from *T. truncatus*. Such characteristics are CBL, LR, the configuration of premaxillae, the antero-medial ridge on the rostrum, number of teeth

sockets and variation in shape and size of temporal fossa (FOSH) (ROSS 1977, LAL MOHAN 1985a, WANG et al. 2000b, KEMPER 2004, KURIHARA & ODA 2006, 2007, GRAY 2016, JEDENSJÖ et al. 2020).

In the recent past, the Centre of Excellence in Marine Biology under Darwin Initiative Program collected data on cetaceans from 2004 to 2009 through beach and boat-based surveys along the coast of Pakistan (GORE et al. 2012, 2017, KIANI 2014). These studies improved the knowledge on cetacean diversity and distribution. They recorded bottlenose dolphins sighted in the Karachi harbour, coastal, near-shore and continental shelf waters of Sindh and Balochistan. The present study on bottlenose dolphins through cranial morphometry is an important addition to the data pool of cetacean diversity in Pakistani waters and provides valuable information required for conservation of marine mammals in the region. Studies based on molecular tools and landmark-based geomorphometry may be utilised to strengthen the outcome of present study. The Indopacific bottlenose dolphin is listed as 'Data Deficient' and the common bottlenose dolphin as 'Least Concern' in the IUCN Red List of Threatened Species; both are also listed in Appendix II of CITES (HAMMOND et al. 2012a, b). Bottlenose species are exposed to many threats in Pakistani waters, such as culling for bait, capture as bycatch, occasional boat strikes and pollution (RIZVI et al. 1988, ALI & JILANI 1995, GORE et al. 2012, KIANI 2014, KIANI & WAEREBEEK 2015). Therefore, conservation action plans are required to safeguard this species and all other cetacean species occurring in this region.

Acknowledgments: We thank Ana P. B. Costa (Department of Biology, University of Glasgow, Scotland, UK) and Catherine M. Kemper (South Australian Museum, Adelaide, Australia) for specimen identification, helpful comments and useful discussions during manuscript preparation. We also thankfully acknowledge the enthusiastic support received from Dr Seema Shafique and Dr Zaibun Nisa Burhan and students and staff members (Ariba Hasan, Saedul Bibi, Naveed Ahmad, Mohammad Ibrahim, Farhan Ghauri, Naveed Naseer, and Rashid Baloch) of Centre of Excellence in Marine Biology (CEMB) in the laboratory and field collection. ML was supported through Senior Research Fellowship from CEMB.

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Received: 19.04.2021

Accepted: 02.08.2022