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Craniometry of bottlenose dolphins (*Tursiops truncatus*) from the Adriatic Sea

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ABSTRACT

The bottlenose dolphin (*Tursiops truncatus*) is a cetacean distributed worldwide with an external morphology that varies between different populations. An endangered population of bottlenose dolphins inhabits the Adriatic Sea and is legally protected. The skulls of 95 adult bottlenose dolphins (47 females and 43 males, 5 of unknown sex) were morphometrically analyzed. They originated from bottlenose dolphins stranded dead from 1990 to 2011 in the Croatian part of the Adriatic Sea. For each animal a total of up to 53 skull measurements and meristic characters were taken using slide calipers to the nearest 0.01 cm. Sexual dimorphism within the Adriatic population was analyzed while the average morphometric values of Adriatic specimens were compared with published values for the genus Tursiops from different geographical areas. Male Adriatic bottlenose dolphins were significantly larger in terms of 19 craniometric characteristics compared to females. The male skull is wider along the rostrum, at the level of the braincase and at the orbital region. Their braincase is higher and longer and their teeth are higher. Comparison of morphometrical values between Adriatic bottlenose dolphins and populations from other seas confirms geographical polymorphism within the species *T. truncatus*. Our study showed that the skull size follows Bergmann's rule, with larger skulls found in colder waters, while smaller skulls are found in populations from temperate and tropical seas. Our results represent referent craniometrical values for the Adriatic bottlenose dolphin and should be used when implementing morphometry in population conservation.

Key words: bottlenose dolphin, *Tursiops truncatus*, Adriatic Sea, geographical polymorphism, cranial morphometry

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Introduction

The bottlenose dolphin (*Tursiops truncatus*) is a widely distributed cetacean; its range includes tropical and temperate zones of all oceans and peripheral seas. The genus Tursiops is polymorphic; at least 20 nominal species have been described in the past, based on systematic work that involved relatively small samples and restricted geographic areas (MEAD and POTTER, 1990). Only two forms are recognized today as separate species within the genus Tursiops: the widespread bottlenose dolphin (*T. truncatus*) and the distinctive indo-pacific bottlenose dolphin (*Tursiops aduncus*) found in the coastal waters of the tropical and subtropical Indian Ocean. Apparent morphological differentiation between the two forms and phylogenetic analysis of the mtDNA separated *T. aduncus* well from *T. truncatus* (ROSS, 1977; RICE, 1998; WANG et al., 1999; REEVES et al., 2002). CHARLTON-ROBB et al. (2011) proposed a new species, the burrunan dolphin (*Tursiops australis* sp. nov.) endemic to southern and south-eastern Australia. In addition, the Black Sea bottlenose dolphins are considered a separate subspecies (*Tursiops truncatus ponticus*) due to their morphological and genetic divergence (VIAUD-MARTINEZ et al., 2008). Furthermore, in some parts of the world inshore and offshore *T. truncatus* populations are differentiated although they live in close proximity. They differ in distribution, overall size, skull morphology, food habits and parasite burden (MEAD and POTTER, 1990). HOELZEL et al. (1998) also confirmed their genetic differentiation. Despite the above mentioned differences, subspecific designations are best avoided (RICE, 1998; REEVES et al., 2002). Genetic analysis, based on microsatellite DNA and mitochondrial DNA (mtDNA), revealed a significant differentiation between Atlantic and Mediterranean bottlenose dolphin populations, suggesting restricted gene flow for both males and females (NATOLI et al., 2004). Further genetic investigation identified a bottlenose dolphin population boundary between the western and eastern basins of the Mediterranean Sea and the boundary separating the Mediterranean and Black Seas. These boundaries coincide with transitions between habitat regions (NATOLI et al., 2005).

The skulls are the best represented bony remains from specimens stranded dead (LIEBIG et al., 2003), and many skull bones show variations in size and shape, depending on ontogeny, sex and geographic location (TURNER and WORTHY, 2003). Hence, skulls give valuable insights into the living fauna (LIEBIG et al., 2003), and they are used for separation of species and populations. Therefore, craniometry gives concrete values that may aid in identification of the type for each population (TURNER and WORTHY, 2003). Up to date, craniometrical data for the genus Tursiops exist for populations from the North Sea and British shores (ROSS, 1977; ROBINEAU and VELY, 1997), North Atlantic (HERSH et al., 1990; VIAUD-MARTINEZ et al., 2008), African waters (ROBINEAU and VELY, 1997; WANG et al., 2000) Australian waters (CHARLTON-ROBB et al., 2011), eastern North Pacific (WALKER, 1981), Chinese waters (WANG et al., 2000), Black Sea (VIAUD-

MARTINEZ et al., 2008) and Mediterranean Sea (VIAUD-MARTINEZ et al., 2008; SHARIR et al., 2011). Despite some differences in the methodology, the craniometric values from different studies are easily comparable, because they mostly follow the standard cranial measurements proposed by PERRIN (1975).

A population of bottlenose dolphins inhabits the Adriatic Sea. It is considered endangered and is a legally protected species in Croatia. Only one morphotype has been recognized in Croatian waters (ĐURAS GOMERČIĆ, 2006) and genetic analysis did not reveal population structuring (GALOV et al., 2011). Our study analyzes Adriatic bottlenose dolphin craniometry, in the context of world-wide bottlenose dolphin morphology. It is a study on bottlenose dolphin geographic variations that may aid regional conservation of this endangered species.

Materials and methods

The skulls of 95 adult bottlenose dolphins (47 females and 43 males, 5 of unknown sex) were morphometrically analyzed. They originated from dissected bottlenose dolphins stranded dead from October 1990 to October 2011 in the Croatian part of the Adriatic Sea. The skulls are hosted by the Department of Anatomy, Histology and Embryology of the Faculty of Veterinary Medicine, University of Zagreb, Croatia. In order to exclude the influence of growth rate on the mean craniometric values, we only used skulls that were mature based on the criterion of rostral fusion of the premaxillae with the maxillae (PERRIN and HEYNING, 1993). For each animal a total of up to 53 skull measurements and meristic characters compiled from PERRIN (1975), WALKER (1981), WANG et al. (2000) and ĐURAS GOMERČIĆ (2006) were obtained (Fig. 1). Measurements were taken using slide calipers to the nearest 0.01 cm. The age of the animals was estimated by counting growth layer groups (GLGs) in the dentine, according to HOHN et al. (1989) on teeth sections prepared according to SLOOTEN (1991). Data on body mass, total body length (TBL) and sex were obtained from dissection protocols. Sexual dimorphism within the Adriatic population was analyzed using *t*-test ($P<0.05$, $P<0.01$) and was accentuated through the difference ratio. The difference ratio was calculated for each measurement and represents the difference between the average male (Xmale) and female (Xfemale) values divided by the average value of specimens of both sexes (Xtotal); i.e. it was calculated through the equation (Xmale-Xfemale)/Xtotal. In order to compare bottlenose dolphin morphotypes, average morphometric values of Adriatic specimens were compared with published values for the genus Tursiops from different geographical areas using the *t*-test ($P<0.05$) (ROSS, 1977; WALKER, 1981; HERSH et al., 1990; ROBINEAU and VELY, 1997; WANG et al., 2000; VIAUD-MARTINEZ et al., 2008; SHARIR et al., 2011; CHARLTON-ROBB et al., 2011).

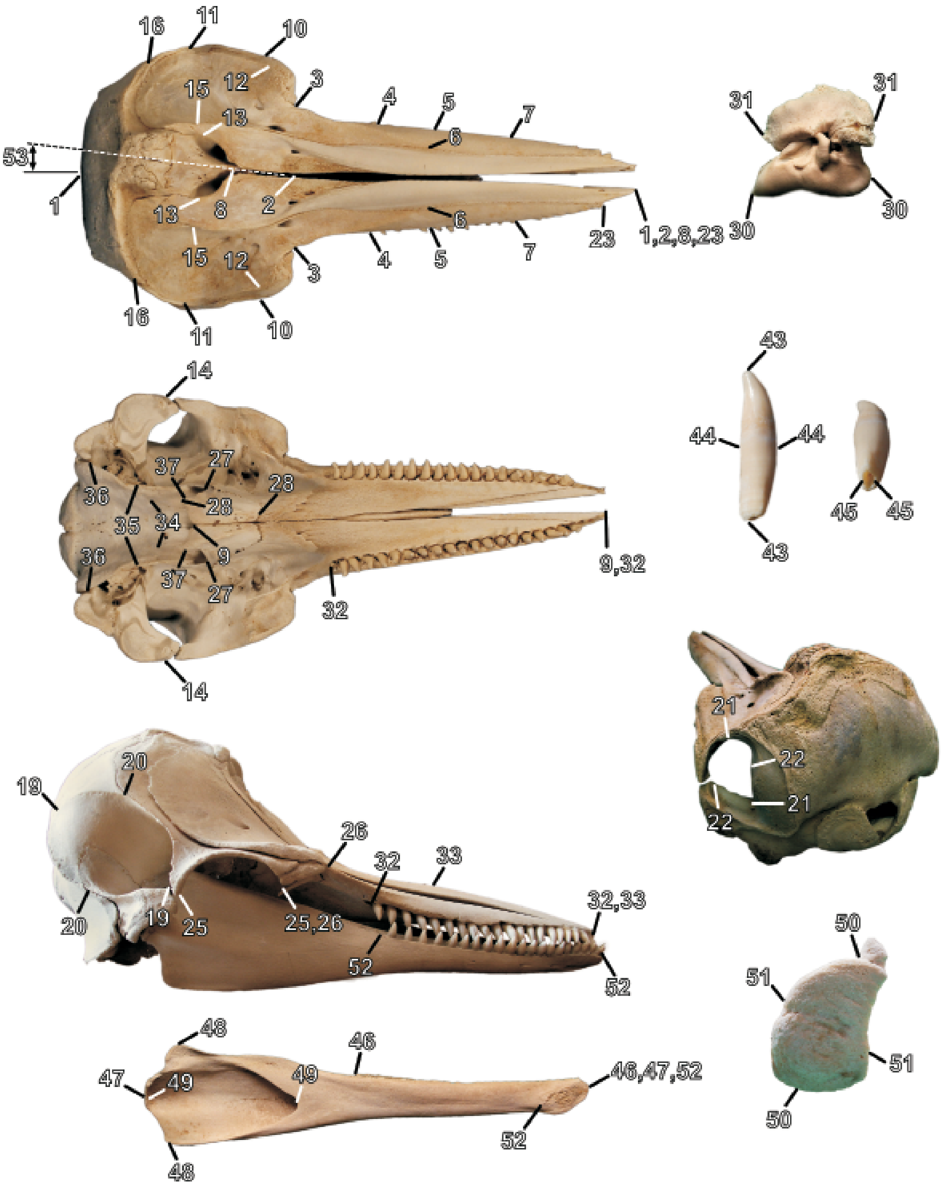

Fig. 1. Skull measurements and meristic characters of bottlenose dolphins (*Tursiops truncatus*) used in this study: condylobasal length (1), rostrum length (2), rostrum width at base (3),

rostrum width at 60 mm of the base (4), rostrum width at half length (5), premaxillaries width at half length (6), rostrum width at ¾ length of the base (7), rostrum tip to external nares (8), rostrum tip to internal nares (9), greatest preorbital width (10), greatest postorbital width (11), least supraorbital width (12), external nares width (13), greatest width across zygomatic process of squamosal (14), greatest width of premaxillaries (15), greatest parietal width (16), vertical external height of braincase from midline of basispheniod to summit of supraoccipital, without supraoccipital crest (17), internal length of braincase from hindmost part of occipital condyles to foremost part of cranial cavity (18), greatest length of posttemporal fossa (19), greatest width of posttemporal fossa (20), major diameter of left temporal fossa (21), minor diameter of left temporal fossa (22), projection of premaxillaries beyond maxillaries (23), distance from foremost end of nasals to hindmost part of margin of supraoccipital crest (24), length of orbit (25), length of antorbital process of left lacrimal (26), greatest width of internal nares (27), greatest length of left pterygoid (28), greatest width of anterior overhang of supraoccipital crest (29), greatest length of bulla of tympanoperiotic (30), greatest length of periotic of tympanoperiotic (31), length of upper left tooth row (32), tip of rostrum to the apex of the premaxillary convexity (33), width of the caudoventral edge of vomer (34), width of alisphenoid at the suture with the basisphenoid (35), greatest width of basisphenoid at articular facetes for hyoid (36), greatest width of pterygoids (37), alveolar tooth width measured at middle of the rostrum (38), upper left number of teeth counted as number of teeth alveoli (39), upper right number of teeth counted as number of teeth alveoli (40), lower left number of teeth counted as number of teeth alveoli (41), lower right number of teeth counted as number of teeth alveoli (42), greatest tooth height (43), greatest tooth width (44), greatest width of biggest tooth pulp cavity (45), lower left tooth row length (46), greatest length or ramus (47), greatest height of ramus (48), length of mandibular fossa (49), greatest height of mandibular condyle (50), greatest width of mandibular condyle (51), length of mandibular symphysis (52), skull asymmetry (53).

Results

Sexual differences in cranial morphometry of Adriatic bottlenose dolphins. Skulls determined as cranially mature, based on the criterion of rostral fusion, originated from 5 to 26 year old females and from 6 to 28 year old males. Significant differences between the sexes ($P<0.05$, $P<0.01$) were found in body mass, total body length, and 19 cranial measurements (Table 1). Cranially mature, male Adriatic bottlenose dolphins are on average 3.3% longer and up to 11.8% heavier than females. The most noticeable craniometrical differences between males and females concern the rostrum. Along its length the rostrum is significantly wider in males (measurements 4, 5 and 7). The male premaxillae appear wider in their rostral part (6), with an average of 4.91 ± 0.40 cm in males and 4.64 ± 0.35 cm in females; but also caudally at the level of the braincase (15). The premaxillaries project beyond the maxillaries (23) by an immense 20.8% more in males (1.77 ± 0.43 cm) than in females (1.44 ± 0.57 cm). The width of the male skull is greater at the orbital region (10, 11 and 12) and ventrally across zygomatic processes of the squamosals (14). The braincase of males is higher (17) and longer (18). The temporal fossa proper (22) is 5.7% wider in males (5.40 ± 0.48 cm) than females (5.11 ± 0.54 cm). Another extensive difference is at the junction between the nasals (24), which is 10.7% longer in males (5.22 ± 0.81 cm), while the average length in females is 4.69 ± 0.83 cm. The antorbital process of the lacrimal (26) is 5.60 ± 0.42 cm long in males and 5.16 ± 0.58 cm in females. Males have a longer pteryoid (28). The alveoli are 7.7% wider (38) in males (1.18 ± 0.15 cm), compared to alveolar width in females (1.09 ± 0.12 cm). The teeth (43) in males (3.43 ± 0.28 cm) are higher as well. The mandibular condyles (51) are by 7.5% wider in males (3.00 ± 0.31 cm).

Table 1. Body mass, age, total body length (TBL) and 53 craniometric measurements (in cm) of adult bottlenose dolphins from the Adriatic Sea.

	Total (males, females and unknown sex)		Males		Females		
	N	Measurement (cm)	N	Measurement (cm)	N	Measurement (cm)	Difference (%)
Body mass (kg)	75	204.56 ± 52.39 (110.0 - 324.0)	40	215.86 ± 59.32 (110.0 - 324.0)	35	191.64 ± 40.19 (119.0 - 298.0)	11.8*
Age (year)	84	16.58 ± 5.95 (5.0 - 28.0)	39	16.62 ± 6.07 (6.0 - 28.0)	44	16.57 ± 5.97 (5.0 - 26.0)	0.3
TBL	88	274.82 ± 21.19 (200.0 - 322.0)	42	280.40 ± 22.07 (215.0 - 322.0)	45	271.27 ± 16.25 (210.0 - 299.0)	3.3*
1/TBL		0.1867 ± 0.0246	38	0.1865 ± 0.0136 (0.164 - 0.219)	42	0.1901 ± 0.0103 (0.176-0.223)	-1.9
1	84	51.54 ± 2.04 (45.3 - 56.0)	39	51.90 ± 2.09 (45.7 - 55.2)	42	51.35 ± 1.86 (45.3 - 56.0)	1.1
2	86	29.00 ± 1.48 (24.1 - 31.8)	40	29.11 ± 1.65 (24.1 - 31.8)	43	29.03 ± 1.21 (25.5 - 31.5)	0.3
3	94	13.13 ± 0.82 (10.5 - 15.2)	43	13.29 ± 0.75 (11.4 - 14.5)	46	13.07 ± 0.80 (10.5 - 15.2)	1.6
4	91	10.13 ± 0.68 (8.0 - 11.7)	41	10.42 ± 0.62 (8.6 - 11.7)	45	9.94 ± 0.51 (8.2 - 10.8)	4.8**
5	84	8.62 ± 0.62 (7.1-10.9)	40	8.84 ± 0.58 (7.6 - 10.9)	41	8.45 ± 0.57 (7.1 - 9.6)	4.5**
6	86	4.77 ± 0.41 (3.9 - 5.6)	40	4.91 ± 0.40 (3.9 - 5.6)	43	4.64 ± 0.35 (4.0 - 5.5)	5.7**
7	83	6.75 ± 0.56 (5.5 - 8.0)	40	6.94 ± 0.47 (5.8 - 7.9)	41	6.58 ± 0.60 (5.5 - 8.0)	5.3**

For each measurement mean, standard deviation, minimal and maximal values are presented. Significant difference (P) between the sexes is marked * (P<0.05) and ** (P<0.01) in the difference ratio (%) column. Greater average values in females are marked -.

Table 1. (continued)

	Total (males, females and unknown sex)		Males		Females		
	N	Measurement (cm)	N	Measurement (cm)	N	Measurement (cm)	Difference (%)
8	86	34.47 ± 1.68 (29.2 - 37.5)	40	34.56 ± 1.87 (29.2 - 37.5)	43	34.51 ± 1.36 (30.5 - 37.0)	0.1
9	78	34.94 ± 1.65 (29.5 - 38.0)	39	35.09 ± 1.75 (29.5 - 37.7)	36	34.94 ± 1.40 (31.2 - 38.0)	0.4
10	93	22.91 ± 1.16 (19.0 - 25.4)	43	23.44 ± 1.09 (20.4 - 25.4)	45	22.50 ± 0.92 (19.0 - 25.0)	4.1**
11	92	25.75 ± 1.24 (21.4 - 28.7)	43	26.27 ± 1.14 (22.8 - 28.7)	44	25.37 ± 1.02 (21.4 - 28.0)	3.5**
12	94	22.99 ± 1.14 (19.2 - 25.5)	43	23.47 ± 1.05 (20.3 - 25.5)	46	22.68 ± 0.92 (19.3 - 25.0)	3.4**
13	94	5.74 ± 0.29 (5.0 - 6.4)	43	5.77 ± 0.30 (5.0 - 6.4)	46	5.73 ± 0.28 (5.2 - 6.4)	0.8
14	89	25.57 ± 1.42 (20.7 - 28.8)	43	26.07 ± 1.35 (23.0 - 28.8)	41	25.25 ± 1.15 (20.7 - 27.0)	3.2**
15	94	9.63 ± 0.53 (8.6 - 11.0)	43	9.77 ± 0.57 (8.6 - 11.0)	46	9.53 ± 0.44 (8.6 - 10.6)	2.6*
16	92	21.00 ± 1.00 (18.8 - 25.0)	43	21.13 ± 1.04 (19.6 - 25.0)	44	20.90 ± 0.99 (18.8 - 24.0)	1.1
17	91	15.04 ± 0.71 (13.5 - 17.2)	43	15.25 ± 0.72 (13.8 - 17.2)	43	14.87 ± 0.62 (13.6 - 16.5)	2.6**
18	88	15.16 ± 0.89 (13.5 - 17.1)	40	15.44 ± 0.98 (13.9 - 17.1)	43	14.94 ± 0.76 (13.5 - 16.5)	3.3*
19	91	11.46 ± 0.79 (9.7 - 13.9)	42	11.67 ± 0.91 (10.2 - 13.9)	44	11.34 ± 0.60 (9.7 - 12.3)	2.8
20	91	8.52 ± 0.66 (7.1 - 10.0)	42	8.66 ± 0.66 (7.2 - 10.0)	44	8.44 ± 0.62 (7.2 - 9.7)	2.6
21	92	6.76 ± 0.56 (5.1 - 7.9)	42	6.86 ± 0.51 (5.8 - 7.9)	45	6.67 ± 0.55 (5.1 - 7.8)	2.8
22	92	5.23 ± 0.56 (3.5 - 6.5)	42	5.40 ± 0.48 (4.2 - 6.5)	45	5.11 ± 0.54 (3.5 - 6.2)	5.7**
23	75	1.60 ± 0.53 (0.2 - 2.8)	37	1.77 ± 0.43 (0.9 - 2.8)	37	1.44 ± 0.57 (0.2 - 2.6)	20.8**
24	92	4.98 ± 0.84 (3.4 - 7.9)	43	5.22 ± 0.81 (3.8 - 7.4)	44	4.69 ± 0.83 (3.4 - 7.9)	10.7**
25	92	6.45 ± 0.30 (5.4 - 7.2)	43	6.50 ± 0.30 (5.8 - 7.2)	44	6.41 ± 0.31 (5.4 - 7.0)	1.3

Table 1. (continued)

	Total (males, females and unknown sex)		Males		Females		
	N	Measurement (cm)	N	Measurement (cm)	N	Measurement (cm)	Difference (%)
26	93	5.33 ± 0.59 (3.2 - 6.3)	43	5.60 ± 0.42 (4.5 - 6.3)	45	5.16 ± 0.58 (3.7 - 6.2)	8.2**
27	93	7.56 ± 0.52 (6.3 - 8.9)	43	7.63 ± 0.53 (6.4 - 8.9)	45	7.50 ± 0.48 (6.3 - 8.5)	1.8
28	78	7.60 ± 0.60 (6.4 - 9.1)	41	7.75 ± 0.65 (6.4 - 9.1)	32	7.46 ± 0.45 (6.7 - 8.4)	3.8*
29	92	2.55 ± 1.13 (0.6 - 5.0)	43	2.73 ± 1.13 (1.1 - 5.0)	44	2.30 ± 1.07 (0.6 - 4.7)	16.8
30	90	3.85 ± 0.14 (3.4 - 4.2)	43	3.88 ± 0.13 (3.6 - 4.1)	43	3.83 ± 0.15 (3.4 - 4.2)	1.3
31	90	3.43 ± 0.17 (2.9 - 3.9)	43	3.46 ± 0.20 (2.9 - 3.9)	43	3.41 ± 0.14 (3.2 - 3.7)	1.5
32	86	24.22 ± 1.33 (20.1 - 27.0)	40	24.32 ± 1.45 (20.1 - 26.8)	43	24.27 ± 1.11 (21.5 - 27.0)	0.2
33	85	16.69 ± 1.64 (12.8 - 22.0)	39	17.08 ± 1.72 (12.8 - 20.3)	43	16.47 ± 1.45 (13.3 - 22.0)	3.7
34	92	4.24 ± 0.70 (2.1 - 6.3)	42	4.25 ± 0.74 (2.1 - 6.3)	45	4.30 ± 0.64 (2.5 - 5.7)	-1.1
35	92	8.04 ± 0.59 (6.5 - 9.6)	42	8.16 ± 0.57 (6.9 - 9.4)	45	8.00 ± 0.53 (6.7 - 9.6)	2.0
36	92	12.78 ± 0.66 (10.4 - 14.4)	42	12.85 ± 0.62 (11.5 - 14.4)	45	12.79 ± 0.62 (11.0 - 14.1)	0.5
37	64	6.03 ± 0.52 (4.2 - 7.3)	35	6.08 ± 0.58 (4.2 - 7.3)	25	6.00 ± 0.41 (5.1 - 6.6)	1.3
38	92	1.13 ± 0.14 (0.8 - 1.7)	42	1.18 ± 0.15 (0.9 - 1.7)	45	1.09 ± 0.12 (0.8 - 1.4)	7.7**
39	83	22.55 ± 1.38 (17.0 - 26.0)	38	22.55 ± 1.55 (17.0 - 26.0)	43	22.56 ± 1.22 (19.0 - 25.0)	0.0
40	81	22.65 ± 1.29 (20.0 - 25.0)	38	22.66 ± 1.30 (20.0 - 25.0)	41	22.61 ± 1.26 (20.0 - 25.0)	0.2
41	84	22.05 ± 1.42 (19.0 - 26.0)	39	22.15 ± 1.53 (19.0 - 26.0)	44	21.98 ± 1.34 (19.0 - 25.0)	0.8
42	84	22.02 ± 1.54 (18.0 - 27.0)	39	22.18 ± 1.71 (18.0 - 27.0)	44	21.91 ± 1.38 (19.0 - 25.0)	1.2
43	83	3.35 ± 0.33 (2.3 - 4.1)	38	3.43 ± 0.28 (2.8 - 4.1)	44	3.28 ± 0.35 (2.3 - 3.8)	4.5*

Table 1. (continued)

	Total (males, females and unknown sex)		Males		Females		
	N	Measurement (cm)	N	Measurement (cm)	N	Measurement (cm)	Difference (%)
44	83	0.82 ± 0.08 (0.6 - 1.1)	38	0.83 ± 0.07 (0.6 - 0.9)	44	0.82 ± 0.09 (0.7 - 1.1)	0.8
45	83	0.20 ± 0.15 (0.1 - 0.7)	38	0.21 ± 0.13 (0.1 - 0.6)	44	0.18 ± 0.16 (0.1 - 0.7)	16.4
46	88	24.29 ± 1.40 (18.7 - 27.2)	40	24.56 ± 1.31 (20.6 - 27.2)	45	24.28 ± 1.13 (21.8 - 26.7)	1.2
47	88	44.36 ± 1.89 (37.0 - 48.0)	40	44.70 ± 1.82 (39.9 - 48.0)	45	44.34 ± 1.43 (40.0 - 47.0)	0.8
48	85	9.78 ± 0.45 (8.5 - 10.9)	40	9.86 ± 0.42 (8.6 - 10.8)	42	9.68 ± 0.44 (8.5 - 10.5)	1.8
49	89	14.67 ± 0.83 (12.5 - 17.0)	41	14.71 ± 0.85 (12.5 - 17.0)	45	14.70 ± 0.82 (13.0 - 16.7)	0.1
50	89	4.12 ± 3.44 (2.9 - 36.0)	40	3.85 ± 0.34 (3.2 - 4.8)	45	4.41 ± 4.83 (3.1 - 36.0)	-13.6
51	89	2.87 ± 0.33 (2.0 - 3.7)	40	3.00 ± 0.31 (2.5 - 3.7)	45	2.78 ± 0.28 (2.2 - 3.4)	7.5**
52	87	6.57 ± 0.90 (3.4 - 8.0)	39	6.64 ± 0.79 (4.1 - 8.0)	45	6.69 ± 0.74 (4.6 - 7.9)	-0.8
53	93	4.62 ± 1.60 (2.0 - 9.0)	42	4.79 ± 1.69 (2.0 - 9.0)	46	4.42 ± 1.50 (2.0 - 8.0)	7.8

Comparison of craniometric values of the bottlenose dolphin (Tursiops truncatus) from the Adriatic Sea with the genus Tursiops species from other seas. Craniometric values of the Adriatic bottlenose dolphins were compared with published values of the seven most frequently used cranial measurements for the genus Tursiops. Table 2 shows the published cranial measurements of 21 Tursiops populations, with the values from the Adriatic animals placed in the center of the table. The upper part of the table contains populations whose measurements are in general lower than those of Adriatic bottlenose dolphins, while the lower part of the table represents populations with mostly higher values compared to the results from the Adriatic Sea.

Table 2. Craniometric measurements (in cm) of bottlenose dolphins

Measurement		Condylobasal length	Length of rostrum	Width of rostrum at base	Greatest preorbital width	Greatest parietal width	Length of upper left tooth row	Number of teeth-upper left
East Australia (*T. a.*) (1.)		44.1 N = 5 (42.4-45.5)	25.43 N = 5 (24.3-26.4)	10.34 N = 5 (9.38-10.78)	19.39 N = 5 (18.0-20.05)		20.91 N = 5 (20.0-21.6)	23.20 N = 5 (21.0-25.0)
Indian/ Banana River on the east coast of Florida (*T. t.*) (2.)	male	44.71 ± 1.73 N = 36	24.51 ± 1.16 N = 36	10.7 ± 0.83 N = 36	19.68 ± 1.19 N = 36	18.05 ± 0.58 N = 35	21.33 ± 1.05 N = 36	24.7 ± 1.1 N = 32
	female	45.16 ± 2.13 N = 33	24.75 ± 1.34 N = 33	10.81 ± 0.67 N = 33	19.69 ± 1.1 N = 33	17.77 ± 0.59 N = 33	21.54 ± 1.21 N = 33	23.8 ± 1.0 N = 33
Black Sea (*T. t.*) (3.)		45.23 N = 27						
South Africa (*T. a.*) (4.)		47.27 ± 1.62 N = 33 (43.3-50.7)	27.19 ± 1.2 N = 33 (25.0-29.7)	11.23 ± 0.61 N = 33 (10.09-12.5)	20.34 ± 0.82 N = 32 (18.0-21.98)		22.48 ± 0.97 N = 31 (20.8-24.5)	25.8 ± 1.09 N = 33 (24.0-28.0)
Eastern tropical Pacific offshore form (*T.* sp.) (5.)		47.34 N = 20 (44.8-49.2)	26.27 N = 20 (24.8-27.8)	11.92 N = 20 (11.1-12.8)	21.27 N = 20 (19.5-23.0)	18.15 N = 20 (17.1-19.8)	22.62 N = 20 (21.0-24.3)	22.7 ± 1.2 N = 28 (20.0-25.0)
Chinese waters (*T. a.*) (4.)		48.51 ± 2.22 N = 18 (45.1-52.9)	28.2 ± 1.5 N = 18 (25.8-31.7)	11.58 ± 0.78 N = 19 (10.3-13.4)	20.19 ± 1.42 N = 18 (17.7-23.0)		23.69 ± 1.35 N = 19 (20.9-26.6)	25.2 ± 1.1 N = 20 (23.0-27.0)
South Australia (*T. aus.* sp. nov.) (1.)		49.36 N = 27 (47.0-51.3)	28.04 N = 27 (26.55-29.5)	13.26 N = 27 (12.35-14.53)	21,34 N = 27 (19.8-23.15)	18.55 N = 27 (17.46-19.48)	23.66 N = 27 (22.3-25.0)	23.88 N = 25 (22.0-27.0)

(*T.* sp. = genus *Tursiops*; *T. t.* = *Tursiops tuncatus*; *T. a.* = *Tursiops aduncus; T. aus.* sp. nov. = *Tursiops australis* sp. nov.) from different world seas. Mean, sample size, standard deviation, minimal and maximal value is presented. Average values in light gray are significantly lower, while average values in dark gray are significantly higher than those in Adriatic bottlenose dolphins.

Israeli coast (*T. t.*) (6.)	49.7 ± 1.88 N = 40 (46.8-54.0)	27.62 ± 1.2 N = 29 (25.5-30.3)	12.7 ± 0.68 N = 30 (11.38-14.5)	21.54 ± 1.03 N = 29 (20.1-24.1)	19.53 ± 1.12 N = 30 (18.0-22.83)	23.64 ± 1.06 N = 28 (21.7.25.9)	22.82 ± 1.02 N = 28 (21.0-25.0)
Chinese waters (*T. t.*) (4.)	50.62 ± 3.33 N = 50 (39.4-56.1)	28.38 ± 2.34 N = 49 (20.4-32.0)	13.45 ± 1.12 N = 49 (9.8-15.4)	23.18 ± 1.86 N = 49 (17.2-26.3)		24.36 ± 2.05 N = 49 (17.2-27.8)	23.9 ± 1.4 N = 54 (21.0-27.0)
Northern temperate Pacific offshore form (*T.* sp.) (5.)	50.72 N = 12 (47.6-57.0)	27.48 N = 12 (25.1-29.7)	12.81 N = 12 (11.7-14.5)	23.02 N = 12 (21.6-27.2)	18.29 N = 12 (16.8-19.4)	24.05 N = 11 (21.8-27.3)	23.6 N = 12 (22.0-25.0)
Croatian Adriatic coast (*T. t.*)	51.54 ± 2.04 N = 84 (45.3-56.0)	29.00 ± 1.48 N = 86 (24.1-31.8)	13.13 ± 0.82 N = 94 (10.5-15.2)	22.91 ± 1.16 N = 93 (19.0-25.4)	21.0 ± 1.0 N = 92 (18.8-25)	24.22 ± 1.33 N = 86 (20.1-27)	22.55 ± 1.38 N = 83 (17.0-26.0)
Western Mediterranean (*T. t.*) (3.)	52.03 N = 18						
Eastern Italy (*T. t.*) (6.)	52.08 ± 1.57 N = 19 (50.1-55.5)	29.23 ± 1.21 N = 19 (27.1-32.5)	13.82 ± 0.7 N = 19 (12.4-14-9)	23.46 ± 1.29 N = 19 (21.8-25.9)	21.24 ± 0.89 N = 19 (19.9-22.8)	24.58 ± 0.97 N = 19 (22.9-27.0)	21.94 ± 1.26 N = 18 (20.0-25.0)
Eastern Pacific coastal form (*T.* sp.) (5.)	52.09 ± 1.53 N = 28 (49.7-55.6)	28.31 ± 1.22 N = 28 (26.6-30.9)	13.66 ± 0.60 N = 28 (12.6-15.1)	23.64 ± 1.01 N = 28 (22.0-26.2)	19.02 ± 0.64 N = 28 (19.2-21.1)	24.95 ± 1.11 N = 28 (23.0-27.5)	22.0 ± 1.4 N = 32 (19.0-25.0)
Western Italy (*T. t.*) (6.)	52.21 ± 1.55 N = 14 (50.5-50.4)	29.19 ± 1.04 N = 14 (27.3-31.5)	13.44 ± 0.71 N = 14 (12.3-15-0)	21.52 ± 3.86 N = 14 (8.6-24.6)	19.66 ± 3.26 N = 14 (8.6-21.5)	24.9 ± 0.91 N = 13 (23.5-26.7)	22.08 ± 1.19 N = 13 (21.0-25.0)
Spanish Mediterranean (*T. t.*) (6.)	52.52 ± 1.12 N = 5 (51.0-54.0)	29.78 ± 1.02 N = 5 (28.2-30.9)	14.22 ± 0.42 N = 6 (13.5-14.8)	23.45 ± 0.73 N = 6 (22.4-24.4)	21.6 ± 0.75 N = 6 (20.5-22.3)	25.08 ± 0.85 N = 5 (23.7-25.9)	21.2 ± 1.3 N = 5 (20.0-23.0)

Table 2. (continued)

Measurement	Condylobasal length	Length of rostrum	Width of rostrum at base	Greatest preorbital width	Greatest parietal width	Length of upper left tooth row	Number of teeth-upper left
South Australia (*T. t.*) (1.)	52.79 N = 13 (50.55-54.7)	30.37 N = 13 (29.15-32.6)	14.31 N = 13 (13.63-15.89)	23.76 N = 13 (22.4-25.1)	19.02 N = 13 (18.16-19.63)	25.31 N = 13 (24.0-26.7)	23.36 N = 11 (20.0-26.0)
Eastern North Atlantic (*T. t.*) (3.)	53.74 N = 18						
British shores (*T. t.*) (7.)	54.1 ± 1.94 N = 17 (50.0-57.5)						
South Africa (*T. t.*) (4.)	54.58 ± 2.62 N = 9 (50.4-57.8)	30.91 ± 1.8 N = 9 (28.32-33.46)	14.28 ± 1.08 N = 9 (12.7-15.78)	25.34 ± 1.56 N = 9 (22.98-27.69)		24.24 ± 4.58 N = 6 (15.40-27.69)	24.2 ± 0.67 N = 9 (23.0-25.0)
North Sea (*T. t.*) (8.)	55.4 ± 1.0 N = 34 (54.0-57.3)	30.9 ± 0.8 N = 34 (29.7-32.4)	15.5 ± 0.6 N = 34 (14.0-16.5)		22.0 ± 0.8 N = 34 (20.4-23.7)		24.0 ± 1.6 N = 50 (19.0-28.0)
North-west Africa (*T. t.*) (8.)	56.9 ± 1.7 N = 53 (54.0-61.0)	33.2 ± 1.2 N = 53 (30.8-36.2)	13.7 ± 0.7 N = 52 (12.4-15.4)		19.0 ± 0.8 N = 52 (17.3-20.8)		23.0 ± 1.2 N = 52 (20.0-27.0)

Source of data: (1.) CHARLTON-ROBB et al. (2011), (2.) HERSH et al. (1990), (3.) VIAUD-MARTINEZ et al. (2008), (4.) WANG et al. (2000), (5.) WALKER (1981), (6.) SHARIR et al. (2011), (7.) ROSS (1977), (8.) ROBINEAU and VELY (1997)

A clear distinction between the Adriatic bottlenose dolphin and *T. aduncus* is observed. The skull of *T. aduncus* is shorter and has a shorter rostrum, although the number of teeth is higher. Expectedly, the newly proposed burrunan dolphins (*T. australis* sp. nov.) and the Adriatic population differ in all measurements, except in the width of the rostrum at base. Burrunan dolphins have a smaller and narrower skull and shorter rostrum with a higher number of teeth. Black Sea bottlenose dolphins have a significantly smaller condylobasal length than Adriatic bottlenose dolphins. Smaller skulls (in length and width) appear in bottlenose dolphins from the Israeli coast, Florida, and in offshore animals from the Pacific. Although their skull appears smaller, the number of teeth is significantly higher than in Adriatic bottlenose dolphins. The bottlenose dolphin population from Chinese waters shows a smaller condylobasal length, but the values of skull widths do not differ significantly from Adriatic specimens.

Similar craniometric values to those observed in Adriatic specimens can be found in populations from Italian waters and the Spanish Mediterranean. Higher craniometric values than those identified in Adriatic bottlenose dolphins appear in more distinct populations from higher latitudes. Namely, bottlenose dolphin populations from Australian waters, the eastern North Atlantic, British shores and the North Sea, and south and north-west African waters have significantly longer and wider skulls with a higher number of teeth.

Discussion

Despite the cosmopolitan distribution of the bottlenose dolphin and intensive research concerning this species, there are still gaps in the knowledge of its morphotypes, sexual dimorphism and overall geographical variations. Systematic morphometrical studies have only been conducted only on a few populations. Frequently, only the main morphometric measurements, i.e. the total body length, condylobasal length, the parietal width of the skull and teeth count are published. Beside this, sexual dimorphism analyzes are underrepresented.

Although the bottlenose dolphin does not bear distinct morphological characters for differentiation between the sexes, many authors agree that the male bottlenose dolphin is larger in size than the female (NISHIWAKI, 1972; LEATHERWOOD and REEVES, 1983; LEATHERWOOD et al., 1988; COCKCROFT and ROSS, 1990; JEFFERSON et al., 1993; READ et al., 1993; TOLLEY et al., 1995; REEVES et al., 2002; STOLEN et al., 2002). Our results support these findings. The mean total body length of cranially mature Adriatic bottlenose dolphin males is 3.3% (9.14 cm) longer than that of females. Additionally, their mean body mass is 11.8% (24.22 kg) greater than that of females. Contrary, HERSH et al. (1990) did not found any significant difference in the total body length of female and male bottlenose dolphins from eastern Florida. Detailed external body morphometry showed some further differences between the sexes of the bottlenose dolphin. Namely, TOLLEY et al. (1995) examined external sexual dimorphism of the bottlenose dolphin and concluded that males are significantly larger in 20 external body measurements. Concerning the skull, our study showed that out of 53 measurements, 19 were significantly larger in males than females. HERSH et al. (1990) determined that male bottlenose dolphins from the Atlantic coast of Florida have on average more teeth than females in all four jaws, but other cranial measurements were not significantly different between the sexes. Another study on Florida bottlenose dolphins (TURNER and WORTHY, 2003) again failed to identify significant sexual dimorphism in this population, in contrast to the adjoining Texas population, where sexual dimorphism was well pronounced (TURNER and WORTHY, 2003).

During the last decades a revision of the genus Tursiops clarified the long-lasting presence of numerous species and subspecies. A clear distinction was proven, at different levels, only between two groups of Tursiops specimens and grouped them into two species, *T. truncatus* and *T. aduncus*. In general, *T. aduncus* is smaller and less robust, with a longer, more slender beak, usually has more teeth, a less convex melon and proportionally larger dorsal fin and flippers (PERRIN et al., 2007). In contrast, *T. truncatus* is generally larger, has a wide head and body, a short stubby beak, long flippers and a moderately tall, falcate dorsal fin. It has a marked crease between the melon and the beak (REEVES et al., 2002). Interestingly, morphotype diversity found by craniometry is to a certain extent supported by genetics. The new proposed species *T. australis* sp. nov. significantly differs from *T. truncatus* in two mtDNA gene regions, the cytochrome b region and the control region, suggesting complete reproductive isolation (CHARLTON-ROBB et al., 2011). Comparison of nuclear and mtDNA markers reveal diversity between *T. truncatus* and *T. aduncus* from many geographic regions (HOELZEL et al., 1998; WANG et al., 1999; NATOLI et al., 2004). Craniometric differences between Adriatic bottlenose dolphins found in this investigation and specimens of *T. aduncus* from Chinese and South African waters are specially pronounced corroborating the morphological distinction between *T. truncatus* and *T. aduncus*. The Adriatic bottlenose dolphin significantly differs from the Australian burrunan dolphin in six of seven compared measurements. Similar morphometrical comparisons to other world populations should be conducted to complete the morphological research of the newly proposed species.

Bottlenose dolphins from the Black Sea were found to be genetically distinct from the rest of the Mediterranean population (VIAUD-MARTINEZ et al., 2008), while population structuring among Black Sea, eastern Mediterranean (Israel, Ionian Sea and Adriatic Sea), western Mediterranean (Tyrrhenian Sea, Spain and Algeria) and eastern North Atlantic populations was found, with boundaries that coincided with transitions between habitat regions (NATOLI et al., 2005). Comparison of morphometrical values between Adriatic bottlenose dolphins and populations from other seas confirms geographical polymorphism within the species *T. truncatus*. Differences are present in body length and mass, but also at the level of fine structures of the skull. Maximum-length data for the bottlenose dolphin indicate that the Black Sea bottlenose dolphins are smaller than the North Atlantic, while the Mediterranean bottlenose dolphins are intermediate in size (PERRIN, 1984). Diverse factors affect overall body size. One of them is surface water temperature, which is thought to be inversely correlated with the body size of bottlenose dolphin (ROSS and COCKCROFT, 1990). This is consistent with Bergmann's rule stating that populations and species from cooler climates tend to be larger than conspecifics and congeners from warmer climates (MEIRI and DAYAN, 2003). DI-MÉGLIO et al. (1996) speculated that the larger body size of the Atlantic compared to the Mediterranean striped dolphins (*Stenella ceruleoalba*) could be explained by Bergmann's rule, as the Atlantic minimum sea temperatures are lower than the Mediterranean. Our study showed that skull size is also consistent with the Bergmann's rule, since larger skulls are found in colder waters, while smaller skulls are found in populations from temperate and tropical seas (Fig. 2). However, the body and skull size could also depend on other factors, such as the environment's productivity, which is indirectly affected by sea temperatures (DI-MÉGLIO et al. 1996). Further studies have to be implemented to detect factors which cause similarities or differences between morphotypes, especially similarities in morphotypes from distinct geographical regions. Our study presents referent craniometrical values for the Adriatic bottlenose dolphin, and should be used when implementing morphometry in population conservation.

Fig. 2. Overall skull dimensions of European bottlenose dolphin (*Tursiops tuncatus*) populations compared to Adriatic specimens (blue - larger, red - equal size, yellow - smaller).

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ĐURAS, M., D. DIVAC BRNIĆ, T. GOMERČIĆ, A. GALOV: Kraniometrija dobrog dupina (*Tursiops truncatus*) iz Jadranskoga mora. Vet. arhiv 84, 649-666, 2014.

SAŽETAK

Dobri dupin (*Tursiops truncatus*) pripadnik je reda kitova (Cetacea) koji nastanjuje gotovo sva mora svijeta i čija se morfologija značajno razlikuje između populacija. Jedna ugrožena i zakonom zaštićena populacija dobrog dupina nastanjuje i Jadransko more. U ovom radu morfometrijski je obrađeno 95 lubanja odraslih dobrih dupina (47 ženki i 43 mužjaka, 5 nepoznatog spola) podrijetlom od dobrih dupina uginulih od 1990. do 2011. u hrvatskom dijelu Jadranskoga mora. Na svakoj lubanji izmjerene su 53 mjere pomoću pomične mjerke s preciznošću od 0,01 cm. Spolni dimorfizam analiziran je pomoću *t*-testa. Ujedno, morfometrijske vrijednosti jadranskih jedinki uspoređene su s objavljenim vrijednostima za rod Tursiops iz drugih zemljopisnih područja također koristeći *t*-test. Mužjaci dobrih dupina iz Jadranskog mora značajno su veći u 19 kraniometrijskih izmjera od ženki. Lubanja mužjaka šira je duž rostralnog dijela, u području lubanjske šupljine i u orbitalnom području. Lubanjska šupljina mužjaka je viša i duža, a i zubi su im viši. Usporedbom morfometrijskih vrijednosti jadranskih dobrih dupina s populacijama iz drugih mora potvrdili smo da postoji zemljopisni polimorfizam unutar vrste *T. truncatus*. Naše istraživanje pokazalo je da veličina lubanje slijedi Bergmannovo pravilo i da veće lubanje dolaze u dobrih dupina koji nastanjuju hladna mora, dok manje lubanje imaju jedinke iz toplih i tropskih mora. Naši rezultati predstavljaju referentne kraniometrijske vrijednosti za jadranskog dobrog dupina potrebne tijekom primjene morfometrije u zaštiti ove životinjske vrste.

Ključne riječi: dobri dupin, *Tursiops truncatus,* Jadransko more, zemljopisni polimorfizam, kraniometrija