



Sexual dimorphism and developmental patterns in the external morphology of the vaquita, *Phocoena sinus*

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ABSTRACT

A total of 56 vaquitas (*Phocoena sinus*) were examined to evaluate their sexual dimorphism and isometric and/or allometric growth in 35 external characteristics. Absolute and relative (to total length) measurements and growth rates were compared between sexually immature and mature females and males. *T*-tests and analysis of variance (ANOVA) and covariance (ANCOVA) were used to evaluate sexual dimorphism. Sexual dimorphism in the vaquita was detected in the total length, head region (from blowhole to tip of upper jaw), anterior section of the body (from dorsal fin to tip of upper jaw), dorsal fin and the genital and anal regions. Fluke width is relatively larger in mature males than immature males, but in females this relative metric does not change during their development. In addition, males present a higher dorsal fin. These somatic changes are probably related to the swimming capacity (speed, agility, maneuvering) during the breeding season and/or foraging activities. A linear model of growth was used to determine possible proportional changes with respect to total body length through the development of 33 external characteristics. The anterior region of the body and the flippers were relatively larger in immature individuals than in mature ones.

Key words: sexual dimorphism, allometric growth, isometric growth, external development, porpoise, vaquita, *Phocoena sinus*.

Sexual dimorphism and the ontogeny of external features have been extensively studied in dolphin species (e.g., *Stenella* spp., Perrin 1975; *Tursiops truncatus*, Tolley *et al.* 1995), but relatively poorly studied in the porpoise family (Phocoenidae), with the exception of Dall's porpoise (*Phocoenoides dalli*) (e.g., Jefferson 1990, Amano and Miyazaki 1993) and harbor porpoise (*Phocoena phocoena*) (e.g., Stuart and Morejohn 1980, Read and Tolley 1997, McLellan *et al.* 2002). Analyses of the other five porpoises—Burmeister's porpoise (*P. spinipinnis*) (Reyes and Van Waerebeek 1995), vaquita (*P. sinus*) (Brownell *et al.* 1987), spectacled porpoise (*P. dioptrica*) (Goodall and Schiavini 1995), Indo-Pacific finless porpoise (*Neophocaena phocaenoides*) (Jefferson *et al.* 2002), and narrow-ridged finless porpoise (*N. asiaorientalis*) (Shirakihara *et al.* 1993)—have been based on small sample sizes or few morphometric features.

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With a population estimated at only 245 individuals, the vaquita is the most endangered cetacean (Gerrodette *et al.* 2011). What is known about the external morphology of the vaquita, the smallest marine cetacean (Brownell *et al.* 1987, Vidal *et al.* 1999), is limited to only two published studies. Brownell *et al.* (1987) described the external morphology and coloration of the vaquita based on 13 fresh specimens collected in 1985, and Hohn *et al.* (1996) compared the total length, body mass, and maximum girth growth curves of 56 male and female vaquitas.

In this paper we examine 35 external morphometric features of the vaquita to determine the presence of sexual dimorphism and its growth patterns, and compare our findings to the published information for other porpoises. These external features have not been previously analyzed. Our specimens are the same 56 that were examined by Hohn *et al.* (1996) for description of life history characteristics (age structure and reproductive patterns), the great majority of which were collected and analyzed by us (see Brownell *et al.* 1987, Vidal 1995, Vidal *et al.* 1999).

MATERIALS AND METHODS

Specimens and Measurements

Fifty-six vaquitas (31 females, 25 males) were collected in the Upper Gulf of California between 1966–1967 ($n = 2$) and 1985–1993 ($n = 54$). Data from the two females collected in 1966–1967 were from stranded animals reported by Brownell (1983). Fifty-one of the vaquitas collected between 1985 and 1993 died incidentally in gill nets (see D'Agrosa *et al.* 1995, 2000, Vidal 1995), two were found dead on the beach and one was floating dead. All the vaquitas were collected between January and May, except two males (one sexually immature, the other sexually mature) collected in July and September, respectively.

Most specimens collected between 1985 and 1993 were frozen immediately (<12 h) after they were found dead entangled in gill nets, except six that were frozen between 24 and 48 h after being caught. All these specimens were transported to the Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM)—Campus Guaymas, Sonora, Mexico, where they were kept frozen until measured and necropsied.

The authors took all the measurements. Thirty-four external measurements were analyzed (Table 1). Straight line and girth measurements had a precision of 1 mm using a tape measure. In addition, the relationship between the height of the dorsal fin (HD) and basal length (BD) was evaluated using the dorsal fin index ($DI = HD/BD$).

Measurements for two pregnant females and their respective near-term fetuses (both females) were considered in the analyses but the girths of these females were excluded. The girths of the two males incidentally killed in July and September were also excluded due to possible seasonal variations in body mass, as has been reported for other small cetaceans (Read and Hohn 1995, Neimanis *et al.* 2000) and specifically for the vaquita (Hohn *et al.* 1996). We only used male specimens collected in March and April during the mating season. The size of the vaquitas' testes changed significantly from the nonbreeding to the breeding season (Hohn *et al.* 1996), thus affecting girth measurements.

Information on the sexual maturity of vaquitas analyzed in this paper was taken from Hohn *et al.* (1996). Sexual maturity in females was determined by the presence

Table 1. List of external measurements taken from the vaquita, *Phocoena sinus*.

1. Total length (TL).
2. Tip of upper jaw to angle of gape (TG).
3. Tip of upper jaw to center of eye (TE)
4. Tip of upper jaw to blowhole (TB).
5. Tip of upper jaw to meatus (TM).
6. Tip of upper jaw to anterior flipper (TP).
7. Tip of upper jaw to tip of dorsal fin (TD).
8. Tip of upper jaw to umbilicus (TU).
9. Tip of upper jaw to center of genital aperture (TGA).
10. Tip of upper jaw to center of anus (TA).
11. Notch in flukes to tip of dorsal fin (ND).
12. Notch in flukes to umbilicus (NU).
13. Notch in flukes to center of genital aperture (NGA).
14. Notch in flukes to anus (NA).
15. Basal length of dorsal fin (BD).
16. Height of dorsal fin (HD).
17. Maximum width of flipper (MAF).
18. Basal width of flipper (BWF).
19. Anterior length of flipper (AF).
20. Posterior length of flipper (PF).
21. Width of both flukes (WF).
22. Depth of notch (DN).
23. Length of left half of fluke (LHF).
24. From notch to nearest point of anterior border (left) (NAL).
25. Girth at center of eyes (GE).
26. Girth at axilla (GAX).
27. Girth at anterior insertion of dorsal fin (maximum girth) (GAD).
28. Girth at posterior insertion of dorsal fin (GPD).
29. Girth at anus (GA).
30. Girth at caudal peduncle (GCP).
31. Width of blowhole (WB).
32. Length of blowhole (LB).
33. Length of genital slit (LGS).
34. Anal opening (AO).

of at least one ovarian *corpus luteum* or *c. albicans* and males were considered mature if spermatozoa were present in the seminiferous tubules and epididymides.

Sexual Dimorphism Analyses

Sexual dimorphism was examined with absolute and relative (corrected for total length) measurements in mature vaquitas (11 females, 10 males). Measurements related to the genital aperture (TGA, NGA, and LGS) were excluded from the present analyses because, in cetaceans, they are not comparable between sexes due to the differences in their location (Ralls and Mesnick 2009). We used *t*-tests to examine differences between males and females for each measurement taken. Multivariate analysis of variance (MANOVA) was used to assess overall absolute dimorphism. Not all measurements were available for all the specimens, so we estimated the missing data (12% of the total measurements of mature specimens) by sex using least square regression and the total length as an explanatory variable.

Relative or proportional dimorphism of each measurement was tested with an analysis of covariance (ANCOVA) using the total length as the covariate. However, seven measurements were not included in this analysis (TA, HD, WF, WB, GW, GAX, GAD); they presented significant slopes differences in the regression analysis. In addition, multivariate analysis of covariance (MANCOVA) with the total length as the covariate was applied to evaluate overall relative sexual dimorphism in the vaquita.

Allometric Analyses

All specimens (immature and mature) and measurements were included in these analyses. Allometric growth was examined with the least square regression model: $\log y = \log(a) + b \log(x)$, where y is the response variable (each measurement), x is the explanatory variable (total length), a is a constant, and b is the slope or growth coefficient (Schmidt-Nielsen 1984, Van Waerebeek 1993, Read and Tolley 1997). A measurement was considered isometric (*i.e.*, no relative change occurs during development) if the slope was not significantly different from 1.0. A value lower than 1.0 was an indication of negative allometry (*i.e.*, relative reduction), while a value higher than 1.0 was an indication of positive allometry (*i.e.*, relative increase) (Van Waerebeek 1993, Read and Tolley 1997). We evaluated whether the slope was significantly different from 1.0 by using t -tests: $t_s = (b - 1)/(SEb)$, where b is the slope or growth coefficient tested, SEb is the standard error of the slope and t_s is the sample t value which was compared to $t_{0.05}$ (df) (Read and Tolley 1997). To determine whether there were sexual differences in slopes, a linear model with sex, total length, and its interaction (sex*total length) was applied.

RESULTS

Sexual Dimorphism

Overall absolute sexual dimorphism was present in the vaquita (MANOVA, Wilks' Lambda = 0.65, df = 19, $P = 0.0054$). According to t -test results, dimorphic features were located in the anterior (head) and ventral body regions and in the flippers and dorsal fin (Table 2). Females are larger than males in total length (as previously reported by Brownell *et al.* 1987) and in eight other measurements; they present longer and wider heads (TB, TM, GE, GAX), larger anterior bodies from the dorsal fin (TD) and umbilicus (TU) to the tip of upper jaw, and from the notch in flukes to umbilicus (NU). In addition, females have a larger basal flipper width (BWF) than males. Two dimorphic features were noted in the ventral region of males; firstly, they had larger anal openings than females (AO) and secondly, all males, both immature and mature ($n = 25$), had one blind opening ("second anus") anterior to the anus (first reported for the vaquita by Brownell *et al.* 1987), which is absent in females. In addition, dorsal fin height (HD) and dorsal fin index (DI) ($t = 3.35$, df = 16, $P = 0.004$) were greater in males ($\bar{x} = 0.80$, SE = 0.01) than in females ($\bar{x} = 0.70$, SE = 0.01).

The ANCOVA results demonstrated that only two relative measures were dimorphic (Table 2). Males had a relatively larger anal opening (AO) and shorter distance from the tip of upper jaw to the dorsal fin (TD) than females. In contrast to the results from MANOVA, the sexual difference on the measurements adjusted for total

Table 2. Descriptive statistics for each variable of sexually mature vaquitas and P-values of sexual dimorphism results for absolute measurements (Abs), relative values (Rel), sex that was larger (S), and not apply (na).

Variable	Females				Males				S	Abs P	Rel P
	n	\bar{x}	SD	Range	n	\bar{x}	SD	Range			
1. TL	11	140.61	5.02	135.0 - 150.0	10	135.12	5.29	128.3-144.0	F	0.02	-
2. TG	11	7.59	0.62	6.5 - 8.5	10	7.28	0.64	6.0-88.0	F	0.27	0.50
3. TE	11	12.38	0.88	10.5 - 13.5	10	11.79	1.01	10.2-13.7	F	0.17	0.43
4. TB	11	11.20	1.43	9.3 - 14.0	10	10.06	0.79	8.6-11.1	F	0.03	0.10
5. TM	9	17.77	0.56	17.2 - 18.7	9	16.62	1.20	14.7-18.1	F	0.01	0.22
6. TF	11	26.21	1.43	24.2 - 29.7	10	25.40	1.89	23.5-29.5	F	0.27	0.49
7. TD	9	81.27	3.15	76.0 - 86.1	9	74.03	2.85	70.5-78.6	F	0.0001	0.001
8. TU	9	59.27	1.83	56.8 - 61.5	9	56.88	2.55	53.5-62.1	F	0.03	0.87
10. TA	9	96.36	3.20	92.4-100.9	10	93.01	3.96	88.9-100	F	0.06	na
11. ND	9	61.02	3.35	55.8-65.4	8	60.37	3.76	56.5-67.0	F	0.71	0.16
12. NU	9	79.93	3.18	76.4-84.5	9	76.30	2.51	73.2-80.8	F	0.01	0.53
14. NA	9	43.00	1.96	40.4-47.3	10	41.48	2.09	38.9-45.00	F	0.12	0.81
15. BD	9	21.01	1.28	19.0-22.3	10	21.58	2.14	18.5-24.5	M	0.49	0.34
16. HD	9	15.02	0.89	13.7-16.7	9	17.35	1.34	15.0-19.1	M	0.0005	na
17. MAF	9	10.41	0.46	9.9-11.3	10	10.19	0.41	9.6-10.9	F	0.28	0.85
18. BWF	9	9.04	0.46	8.5-10.1	10	8.52	0.46	8.0-9.3	F	0.02	0.10
19. AF	9	28.10	1.03	26.6-29.9	9	27.33	1.08	25.9-28.7	F	0.14	0.34
20. PF	9	21.73	1.01	20.2-23.0	10	21.18	0.96	19.5-22.4	F	0.23	0.77
21. WF	9	41.94	1.94	39.7-44.7	9	42.11	2.35	39.1-46.3	M	0.87	na
22. DN	9	1.95	0.40	1.0-2.6	10	1.83	0.60	1.4-2.8	F	0.59	0.79
23. LHF	9	21.28	1.02	19.1-22.5	10	20.90	1.39	19.0-23.0	F	0.50	0.96
24. NAL	9	11.25	0.98	10.4-13.3	9	11.17	0.66	10.5-12.7	F	0.84	0.96
25. GE	7	51.78	1.16	50.0-53.2	8	49.95	2.06	48.0-54.3	F	0.05	na
26. GAX	7	75.62	1.46	73.0-77.5	8	73.38	2.05	70.2-76.1	F	0.03	na
27. GAD	7	88.70	2.7	84.0-92.3	7	87.51	3.9	82.1-93.0	F	0.52	na

(Continued)

Table 2. (Continued)

Variable	Females			Males			Range	% ^a	S	Abs		Rel	
	<i>n</i>	\bar{x}	SD	<i>n</i>	\bar{x}	SD				<i>P</i>	<i>P</i>		
28. GPD	7	82.30	3.61	8	82.51	2.96	78.0-87.0	-0.25	M	0.90	0.67		
29. GA	7	56.47	1.74	8	59.03	3.7	53.1-65.0	-4.43	M	0.12	0.20		
30. GCP	7	31.50	2.35	8	30.22	1.88	20.2-35.7	4.14	F	0.67	0.93		
31. WFB	9	2.71	0.28	9	2.74	0.20	2.4-3.0	-1.10	M	0.78	na		
32. LB	9	0.74	0.16	9	0.84	0.15	0.6-1.1	-12.65	M	0.20	0.06		
34. AO	9	0.9	0.32	10	1.3	0.28	0.9-1.7	-36.36	M	0.002	0.008		

^a% = Difference between sexes (females minus males) multiplied by 100, the resulting value was divided by an average of male and female mean (Perrin *et al.* 1994).

length was nonsignificant (MANCOVA, Wilks' Lambda = 0.82, $df = 18$, $P = 0.06$). However, the evidence suggests that with larger sample sizes females might measure slightly larger than males in most measures even when total length is controlled (Table 2).

Growth Patterns

Males and females shared isometric growth in nine posterior body measurements (from the dorsal fin to the flukes), 15 anterior body measurements (from the dorsal fin to the tip of upper jaw) and the flippers presented negative allometry, and two measurements were positive (Table 3). Seven measurements were different in their type of growth between sexes. For example, females displayed isometric growth of the dorsal fin (HD) and flukes (WF, LHF) while males displayed positive allometric growth. In contrast, males had isometric growth in the blowhole region (TB and WB), whereas females had negative allometric growth.

DISCUSSION

Sexual dimorphism in vaquitas is present in the total body length, head region (from blowhole to tip of upper jaw), anterior part of the body (from the dorsal fin to the head), dorsal fin and the genital and anal regions. Sexual dimorphism in the total body length has been reported for all porpoises (Gaskin *et al.* 1984). Female harbor porpoises and vaquitas are larger than males (Gaskin and Blair 1977, Gaskin *et al.* 1984, Brownell *et al.* 1987, Vidal 1995, Hohn *et al.* 1996, Read and Tolley 1997, Vidal *et al.* 1999). In contrast, the males of the other five species of porpoises are larger than the females (Jefferson 1990, Shirakihara *et al.* 1993, Gao and Zhou 1995, Goodall and Schiavini 1995, Reyes and Van Waerebeek 1995). Females are larger than males in several small cetaceans that exhibit a relatively simple social structure, where, for example, little physical combat during mating season is present and sexual dimorphism maybe more related to agility and visual displays (Ralls and Mesnick 2009). The harbor and finless porpoises and vaquitas have relatively large testes (4%–5% of their body weight) and thus the potential for sperm competition (*i.e.*, a female mates with several males during each estrus) (Slooten 1991, Hohn *et al.* 1996, Vidal *et al.* 1999, Ralls and Mesnick 2009). Read and Tolley (1997) suggested that male harbor porpoises invest energy in the development of large testes instead of somatic tissue—a strategy that may be shared by the vaquita. Another important factor that probably contributes to the reversed sexual dimorphism is that a larger female will be able to have a larger calf with a better chance of survival (Ralls 1976, Ralls and Mesnick 2009). A newborn vaquita weighs about 7.5 kg (Vidal 1995), not far above the theoretical minimum size of 6.8 kg (for river dolphin species); below this value a newborn calf would be unable to maintain its body temperature due to an increasing surface area relative to its volume (Downhower and Blumer 1988). Thus, sexual dimorphism in the vaquita may result from the combination of selection pressures favoring small sized males and large sized females.

Males have larger dorsal fins than females in several odontocete species, as in the (exaggerated) case of the killer whale (*Orcinus orca*) or they have some other type of sexual difference in the dorsal fin (*e.g.*, canting) (Ralls and Mesnick 2009). In the vaquitas analyzed, the size of the dorsal fin is strongly dimorphic as is the relationship between the height and basal length of the dorsal fin. Sexual dimorphism in the dor-

Table 3. Allometric and isometric growth results in vaquitas using the model $y = ax^b$. All the interception points (a) and slopes (b) were significant ($P < 0.001$ and $P < 0.0001$, respectively). The coefficient determination (r^2) and the standard errors (SE) of each parameter of the equation are also reported. Gf is the type of growth in females and Gm in males, Neg. is for negative allometry, Pos. is for positive allometry, iso. is for isometry, and Dp is the P-value of the sexual dimorphism results for the slopes.

Variable	Female						Males							
	n	a	SE a	b	SE b	Gf	n	a	SE a	b	SE b	r^2	Gm	Dp
2. TG	28	0.27	1.38	0.68	0.07	Neg.	24	0.20	1.58	0.73	0.09	0.71	Neg.	0.59
3. TE	28	0.48	1.23	0.66	0.04	Neg.	25	0.38	1.34	0.70	0.06	0.83	Neg.	0.52
4. TB	28	0.39	1.38	0.67	0.07	Neg.	24	0.16	1.90	0.84	0.13	0.63	Iso.	0.20
5. TM	28	0.75	1.14	0.64	0.03	Neg.	24	0.46	1.31	0.73	0.06	0.86	Neg.	0.14
6. TF	28	0.57	1.14	0.77	0.03	Neg.	25	0.53	1.12	0.78	0.04	0.92	Neg.	0.79
7. TD	28	0.93	1.07	0.90	0.01	Neg.	22	1.77	1.20	0.76	0.04	0.94	Neg.	0.06
8. TU	29	1.09	1.07	0.80	0.01	Neg.	21	1.12	1.12	0.80	0.02	0.98	Neg.	0.91
9. TGA	29	0.74	1.12	0.95	0.02	Neg.	23	1.23	1.17	0.82	0.03	0.95	Neg.	0.06
10. TA	29	0.74	1.07	0.98	0.01	Iso.	24	0.99	1.09	0.92	0.02	0.98	Neg.	0.02
11. ND	27	0.22	1.17	1.13	0.03	Pos.	23	0.12	1.31	1.25	0.06	0.95	Pos.	0.07
12. NU	28	0.29	1.07	1.13	0.01	Pos.	22	0.38	1.12	1.07	0.02	0.98	Pos.	0.06
13. NGA	28	0.30	1.14	1.02	0.03	Iso.	25	0.35	1.41	1.05	0.07	0.89	Iso.	0.67
14. NA	28	0.31	1.09	0.99	0.02	Iso.	24	0.25	1.12	1.04	0.02	0.98	Iso.	0.19
15. BD	28	0.10	1.13	1.08	0.06	Iso.	25	0.08	1.69	1.12	0.11	0.81	Iso.	0.72
16. HD	28	0.12	1.28	0.97	0.05	Iso.	23	0.01	1.51	1.49	0.08	0.93	Pos.	<0.001
17. MAF	28	0.19	1.17	0.80	0.03	Neg.	25	0.14	1.28	0.87	0.05	0.91	Neg.	0.29
18. BWF	28	0.19	1.28	0.78	0.05	Neg.	25	0.30	1.38	0.68	0.06	0.80	Neg.	0.29
19. AF	28	0.45	1.23	0.83	0.04	Neg.	24	0.38	1.28	0.86	0.05	0.91	Neg.	0.65
20. PF	28	0.13	1.09	0.88	0.04	Neg.	25	0.25	1.28	0.90	0.05	0.92	Neg.	0.73
21. WF	27	0.25	1.23	1.03	0.04	Iso.	22	0.10	1.38	1.21	0.06	0.93	Pos.	0.03
22. DN	27	0.02	2.81	0.86	0.22	Iso.	24	0.03	2.34	0.82	0.18	0.48	Iso.	0.92
23. LHF	27	0.12	1.25	1.04	0.04	Iso.	25	0.05	1.41	1.20	0.07	0.91	Pos.	0.07
24. NAL	27	0.26	1.28	0.75	0.05	Neg.	23	0.21	1.41	0.79	0.07	0.84	Neg.	0.68

(Continued)

Table 3. (Continued)

Variable	Female						Males								
	<i>n</i>	<i>a</i>	SE <i>a</i>	<i>b</i>	SE <i>b</i>	<i>r</i> ²	Gf	<i>n</i>	<i>a</i>	SE <i>a</i>	<i>b</i>	SE <i>b</i>	<i>r</i> ²	Gm	Dp
25. GE	26	3.09	1.23	0.57	0.04	0.87	Neg.	21	7.5	1.12	0.38	0.02	0.90	Neg.	0.002
26. GAX	26	1.77	1.17	0.75	0.03	0.94	Neg.	21	5.37	1.34	0.52	0.06	0.77	Neg.	0.002
27. GAD	27	1.14	1.20	0.87	0.03	0.95	Neg.	20	2.75	1.28	0.69	0.05	0.88	Neg.	0.01
28. GPD	27	0.38	1.23	1.07	0.04	0.95	Iso.	20	0.74	1.47	0.95	0.08	0.87	Iso.	0.15
29. GA	26	0.34	1.23	1.03	0.04	0.95	Iso.	22	0.53	1.44	0.95	0.08	0.87	Iso.	0.30
30. GCP	25	0.61	1.69	0.79	0.11	0.67	Iso.	21	0.99	2.08	0.69	0.16	0.49	Iso.	0.60
31. WB	26	0.07	1.31	0.73	0.05	0.86	Neg.	23	0.01	2.63	1.13	0.20	0.59	Iso.	0.03
32. LB	26	0.01	3.09	0.84	0.24	0.33	Iso.	23	3.6 ⁻³	3.16	1.11	0.24	0.50	Iso.	0.50
33. LGA	25	2.7 ⁻³	5.37	1.66	0.35	0.48	Iso.	21	0.01	4.78	1.32	0.33	0.45	Iso.	0.59
34. AO	27	9.5 ⁻⁶	6.60	2.30	0.40	0.56	Pos.	24	3.8 ⁻⁴	0.71	1.65	0.34	0.51	Iso.	0.18

sal fin has been reported for three other species of porpoise, Dall's (Jefferson 1990, Amano and Miyazaki 1993), Burmeister's (Reyes and Van Waerebeek 1995), and spectacled (Goodall and Schiavini 1995), and is most extreme in the spectacled porpoise in which the dorsal fin area of the adult male is about three times the size in the vaquita.

Locomotory muscles surround the cetacean reproductive system. Therefore, this region is exposed to higher temperatures than the rest of the body, which could negatively affect spermatogenesis and fetal development (Rommel *et al.* 1992, 1993, 1998). To cool this body region, odontocetes have a countercurrent heat exchanger composed of veins and arteries that are connected from the dorsal and caudal fins to the posterior abdominal cavity (Rommel *et al.* 1992, 1993, 1998). In vaquitas the potential for overheating is compounded by the fact that the species lives year-round in minimum water temperatures of 14°C and summer temperatures that reach 36°C, which is a higher temperature than experienced by other porpoises. It has been hypothesized that the larger flippers, dorsal fins and flukes of vaquita, relative to other porpoises, may be a functional adaptation to its environment (Brownell *et al.* 1987). We observed sexual dimorphism in these three characteristics; females have wider basal flippers, and males have a higher dorsal fin and relatively larger flukes. These somatic changes in vaquitas probably play an important role in regulating their temperature.

In addition, the development of the dorsal fin and width of both flukes in the vaquita exhibits a pattern of dimorphism, although not so exaggerated as for Dall's porpoise and other small cetaceans (Jefferson 1990, Amano and Miyazaki 1993). The dorsal fin and flukes of male vaquitas increase proportionately during development, while in females the relative size of the dorsal fin and the flukes remains constant as the individual grows. These sexual differences are probably related to the swimming capacity (*i.e.*, propulsion, maneuvering, and agility); mature males may swim more rapidly and be more agile than females, which may be an advantage during the breeding or foraging seasons as hypothesized in harbor porpoise (McLellan *et al.* 2002) and other cetaceans (Tolley *et al.* 1995, Ralls and Mesnick 2009).

All male cetaceans have the genital aperture farther forward than females (Ralls and Mesnick 2009), but in male harbor porpoises and vaquitas it is much farther forward than in any of the marine dolphins (Brownell *et al.* 1987, Read and Tolley 1997). The umbilicus and anus are closer to the snout in male vaquitas than females and the anal opening is larger in males of all ages than in females. Females have a larger genital aperture than males as in other cetaceans. The blind opening or "second anus" just anterior to the anus was present in all the male specimens and appeared to be much like that described in *N. asiaorientalis* from Japan (Nishiwaki and Kureha 1975).

Vaquita growth patterns are similar to those reported for the harbor porpoise (Read and Tolley 1997) and spinner dolphin (*Stenella longirostris*) (Perrin 1975). The anterior body features and flippers have negative allometric growth and those from dorsal fin to the flukes have positive allometry and isometry. Developing larger flippers and anterior portions of the body in an early stage of life may ensure that calves are able to swim more effectively (Amano and Miyazaki 1993).

Biological and ecological information on vaquita is limited, and the collection of specimens and observations in the wild are extremely difficult. In the present study we analyzed the largest collection of specimens available in the world to document sexual dimorphism and growth patterns of this species. Vaquita present several sexually dimorphic characteristics and similar growth patterns as other odontocetes, especially the harbor porpoise in which females are larger than males.

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