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Vaquita
Phocoena sinus
Norris and McFarland, 1958

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Genus and Species

Taxonomy

Phocoena sinus was described by Norris and McFarland in 1958 from three skulls collected along the northeast shore of Punta San Felipe and at Bahia San Felipe, Baja California Norte (BCN), in the Gulf of California, Mexico. Two of these specimens (holotype and a paratype) are deposited in the Museum of Vertebrate Zoology, University of California at Berkeley. The other, a paratype, is in the National Museum of Natural History, Smithsonian Institution, Washington, DC. The late Carl L. Hubbs suggested the specific name *sinus* to Norris and McFarland. In Latin it means "bay", referring to the occurrence of the species in the Gulf of California (Sea of Cortez).

The six extant members of the family Phocoenidae are *Phocoena phocoena, P. spinipinnis, P. sinus, Neophocaena phocaenoides, Phocoena dioptrica* and *Phocoenoides dalli*. The first four have been placed in the subfamily Phocoeninae and the others in the subfamily Phocoenoidinae (Barnes, 1985). The geologically earliest undisputed fossil phocoenid is *Salumiphocaena stocktoni* (Wilson, 1973) from the late Miocene deposits in southern California (Barnes, 1985). Three other fossil phocoenids have been described: *Piscolithax tedfordi* Barnes, 1984 from latest

Miocene deposits in Mexico; *P. longirostris* de Muizon, 1983 from Early Pliocene deposits in Peru; and *P. boreios* Barnes, 1984 from latest Miocene deposits in Mexico (Barnes, 1985). All these fossil phocoenids belong in the Phocoenoidinae. Several periotics of an undetermined fossil species of Phocoeninae were collected recently from the Pliocene at Santa Rosalía, Baja California Sur (BCS), Mexico (Vidal, 1991).

Common names

Vaquita (= "little cow") is the name used by local fishermen in the northern Gulf of California, Mexico, where for many years these porpoises have been taken incidental to fishing operations (Brownell *et al.*, 1987; Vidal, 1995). Cochito (= "little pig") had been a commonly used vernacular name for *P. sinus* because it was adopted by the International Whaling Commission in 1975 (Mitchell, 1975). However, in the Gulf of California, "cochito" is used for more than one species of small cetacean. The English name used for this animal is the Gulf of California harbour porpoise.

Evolution

Phocoenids have been hypothesized to represent a paedomorphic evolutionary lineage (i.e. some or several foetal or juvenile characters persist in adults). Although examples of paedomorphosis may be found in some species in other cetacean families, in no other family group is this phenomenon as universally presented and as pronounced as it is in the living phocoenids (Barnes, 1985). *P. sinus* appears to be strongly paedomorphic (L. G. Barnes, personal communication; Torre-Cosío, 1995).

Norris and McFarland (1958) discussed the possible origin of *P. sinus* from the Northern Hemisphere *P. phocoena* or from *P. spinipinnis*, which lives off South America. Although *P. sinus* is in some respects intermediate between both species, they favoured *P. spinipinnis* as the more likely ancestor because the cranium of *P. sinus* resembles that of *P. spinipinnis* more than that of *P. phocoena*. Noble and Fraser (1971) noted that the axial skeleton of *P. sinus* suggests a closer affinity to *P. spinipinnis* than to *P. phocoena*. All of the axial skeleton material that we and a colleague (Torre-Cosío, 1995) have examined agrees generally with the specimen described by Noble and Fraser (1971).

Externally, *P. sinus* lacks the peculiarly shaped and heavily tuberculated dorsal fin of *P. spinipinnis*. A few low tubercles do appear along the leading edge of the fin and are more pronounced in older individuals. The relative sizes of the flippers and several other external measurements of *P. sinus* are closer to those of *P. spinipinnis* than they are to *P. phocoena* (Brownell *et al.*, 1987). Thus, *P. sinus* and *P. spinipinnis* appear to be more closely related. We believe, as Norris and McFarland (1958) suggested, that *P. sinus* probably evolved as a result of a northward move-

ment of an ancestral *P. spinipinnis*-like population into the Gulf of California during one of the Pleistocene glacial ages.

Distribution

Range

This porpoise is restricted to the relatively shallow waters of the northern Gulf of California, with most of the records from near San Felipe, Rocas Consag, and El Golfo de Santa Clara (Fig. 1). This distribution is based only on confirmed records, and other reputed records of the species in the southern Gulf of California are considered unreliable (Brownell, 1986). Ninety confirmed records of *P. sinus* have been collected, all north of Puertecitos (BCN) and Puerto Peñasco, Sonora (Vidal, 1991, 1995; Brownell, 1986).

The distribution of this porpoise in the upper Gulf of California appears to be highly localized, with the highest densities offshore of San Felipe and Rocas Consag, and offshore of El Golfo de Santa Clara (Silber, 1990a; Silber and Norris, 1991; Gerrodette *et al.*, 1995; Vidal, 1995). An analysis of all available sightings led Silber (1990a) and Silber and Norris (1991) to suggest that vaquitas occupy the northern Gulf year-round.

Two unconfirmed sightings in 1983 near Isla Cerralvo, in the southern Gulf of California (about 850 km south of the southernmost confirmed sighting), were reported by Silber (1990a). A strong El Niño (ENSO) event occurred during 1982–1983, and water temperatures were unusually high at that time in the southern Gulf (Cane, 1983). Extralimital range records have been reported for most species of cetaceans around the world for various reasons, including El Niño events. Therefore, these southern Gulf records, if valid, may be extralimital and thus do not necessarily imply a wider geographic range for this porpoise. In the absence of confirmed records (i.e. voucher specimens or photographs) from the southern Gulf, we conclude that this species' normal range is confined to the northernmost Gulf of California and is the most restricted range of any marine cetacean.

Habitat

Vaquitas are known only from relatively shallow waters. Silber (1990a) reported 51 sightings in water depths of 13.5–37 m, and most of these sightings were 11–25 km from shore. All but two of the sightings were less than 40 km from San Felipe (mainly between this locality and Rocas Consag). Water visibility ranged from 0.9 m to 12 m. Both of the sightings by Wells *et al.* (1981) were in water depths of around 19 m, and were about 18 km from shore. All known incidental entanglements of this species in gill nets have occurred in water depths of from
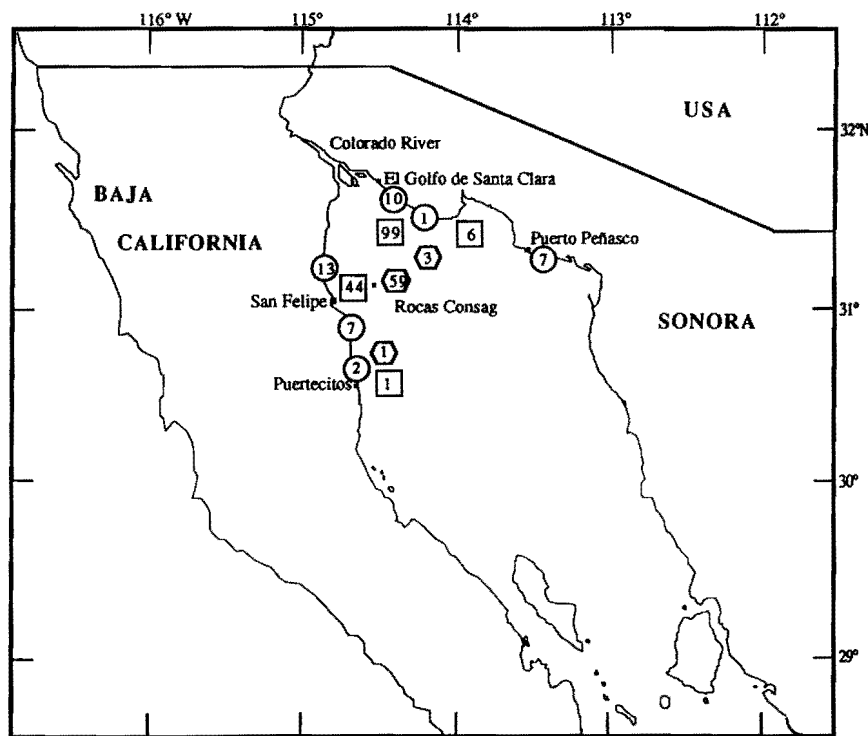
FIG. 1   Range of the vaquita, *Phocoena sinus*: circles indicate beached specimens, squares indicate incidental mortality in gill nets, and hexagons indicate sightings.

4 m to 36 m (estimated by the fishermen operating the nets or by reference to nautical charts) and between 3 km and 33 km from shore (Vidal, 1995).

External Characteristics

Colour pattern

Generally the pigmentation pattern (Figs 2 and 3) can be divided into three parts: dark-grey cape, pale-grey lateral field, and white ventral field (terminology of Perrin, 1972; Perrin *et al.*, 1981). The most conspicuous features of the coloration are the relatively large black eye and lip patches, which contrast sharply with the surrounding light grey of the side of the head and thoracic regions. The flipper stripe is also a dominant feature of the coloration. The shapes of the eye patch, lip patches, and flipper stripe all vary slightly among individuals. Additional details of the colour pattern are given by Brownell *et al.* (1987).
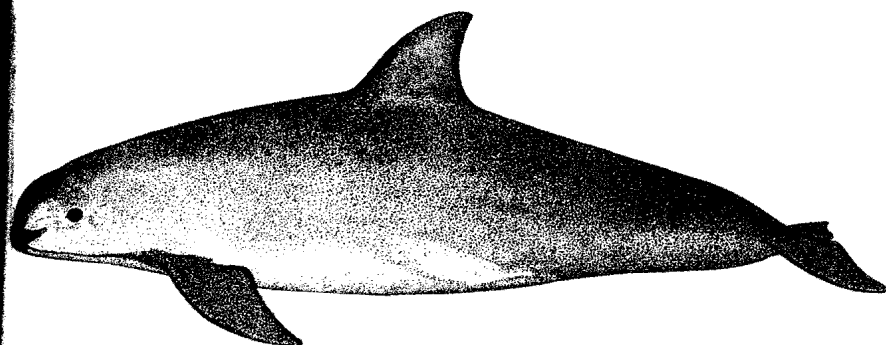
FIG. 2   Lateral view of vaquita, *Phocoena sinus*. (Drawing by Pieter A. Folkens)

Size and shape

This species is the shortest of all delphinoids. Two recently studied series of 13 (Brownell *et al.*, 1987) and 30 (Vidal, 1995) specimens ranged from 70.3 cm to 148.2 cm in total length. A near-term foetus measured 71.5 cm. Some selected external measurements are given in Table 1. No significant sexual dimorphism was noted in any of these measurements.

As with other phocoenids, the vaquita is small but robust, with a mean maximum girth (measured just in front of the anterior insertion of the dorsal fin) of about 70% of total length. In lateral view, the head appears as a truncated cone with the posterior part of the melon sloping downward towards the blowhole, especially in adult males (Fig. 2). Anteriorly, the melon slopes abruptly to the snout tip. There is no "beak" present, but the snout protrudes very slightly from the base of the melon. The lower jaw does not project beyond the snout tip as it does in most delphinoids. The flippers are attenuated and apically pointed (Figs 2 and 3), much like those of *P. spinipinnis* and unlike those of *P. phocoena*. The shape and height of the dorsal fin (Fig. 2) is the most striking external feature of *P. sinus*. It is proportionally much higher than in other species of *Phocoena*. The shape is roughly triangular, with the anterior edge slightly convex and longer than the posterior edge, which is nearly straight or slightly concave. In the mature males we have examined, the dorsal fin is taller and less falcate (i.e. more erect). The genital aperture in males, as in some other phocoenids, is closer to the umbilicus than to the anus, which contrasts with the condition typical of many other delphinoids.

Small tubercles of variable development were present along the upper 1/2 to 3/4 of the anterior edge of the dorsal fin. These were more prominent and more numerous in some of the largest individuals. Although the tubercles were prominent to the touch in the larger individuals, none of our specimens had the more prominent horny tubercles found in *P. spinipinnis* (Allen, 1925; Brownell and Praderi, 1984). All of the 17 males we examined had a small, blind opening (not
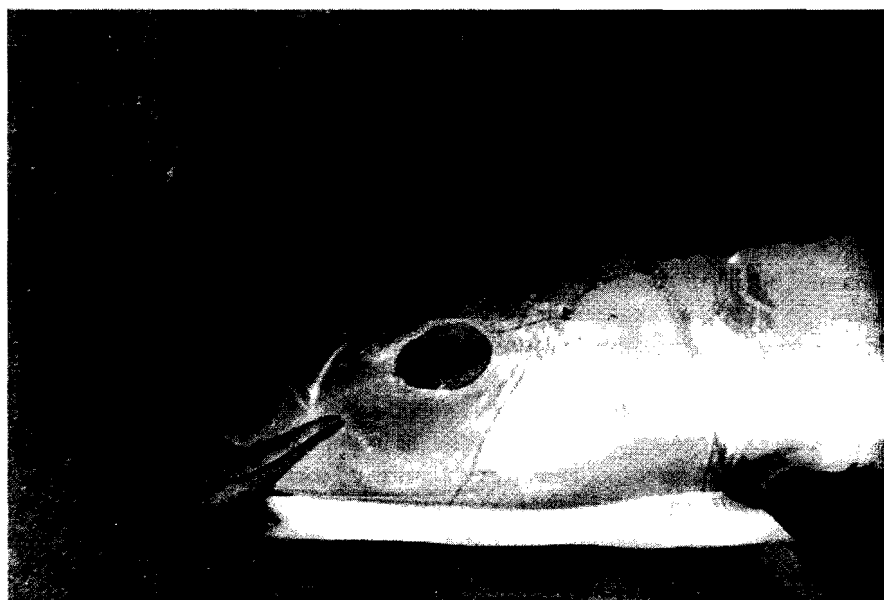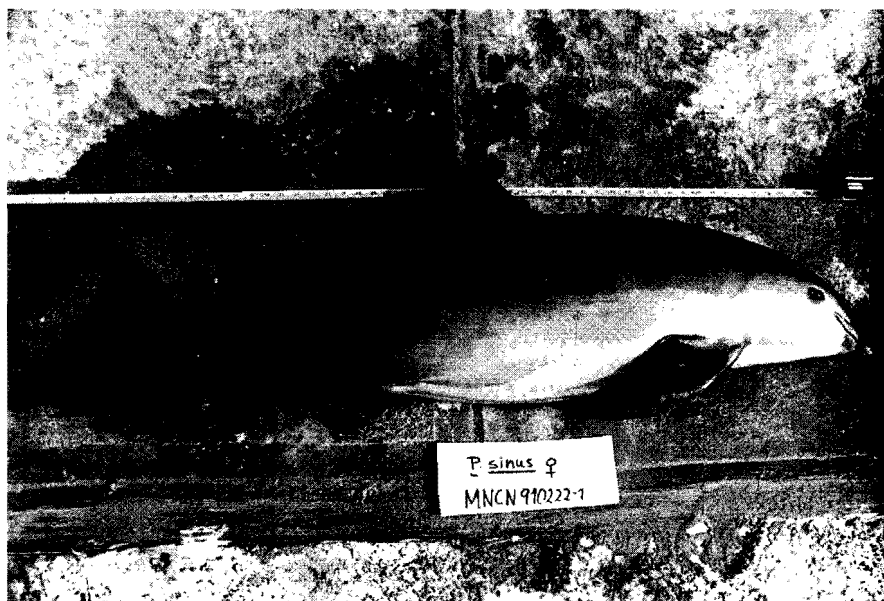
FIG. 3   External views of *Phocoena sinus* incidentally caught near El Golfo de Santa Clara, Sonora, Gulf of California, Mexico. (Photos by J. M. Nava)

TABLE 1   Ranges of selected external measurements (cm) of vaquitas, *Phocoena sinus*, from Brownell *et al.* (1987), based on a sample size of 12

Measurement	Range	Mean	Percentage of mean
Total length	90.3–143.5	113.7	—
Tip of upper jaw to:			
angle of gape	4.9–11.8	6.9	6.1
centre of blowhole	8.0–13.0	10.3	9.1
centre of eye	8.5–12.0	10.6	9.3
auditory meatus	12.6–17.6	15.5	13.6
ant. insertion flipper	18.0–25.3	21.9	19.3
umbilical scar	42.5–61.0	50.2	44.1
tip of dorsal fin	54.5–85.0	68.8	60.5
centre of genital slit	52.0–95.0	70.0	61.6
centre of anus	66.1–100.1	79.1	69.6
Ant. length of flipper	17.5–29.1	23.5	20.7
Axilla length of flipper	13.2–22.5	17.7	15.6
Max. width of flipper	6.4–10.1	8.5	7.5
Height of dorsal fin	9.6–15.0	12.3	10.8
Length of dorsal fin base	12.7–21.0	16.3	14.3
Width of flukes	23.8–44.7	34.6	30.4
Width of fluke, from notch to nearest point on anterior border	7.2–10.9	9.3	8.2
Depth of notch	1.2–2.6	1.9	0.2
Width of blowhole	1.7–2.8	2.3	0.2
Girth, at axilla	51.5–75.5	65.7	57.8
Girth, maximum	63.0–93.0	77.0	67.7
Girth, at anus	38.5–58.0	47.2	41.5

yet described in detail) just anterior to the anus that appeared to be much like that described for *Neophocaena phocaenoides* by Nishiwaki and Kureha (1975). One of the males had two of these openings (parallel to each other).

The four largest males (134.5, 135, 142.2 and 144 cm) and the nine largest females (135, 135, 135, 139.7, 139.7, 140.5, 140.9, 143.5 and 148.2 cm) examined by Brownell *et al.* (1987) and Vidal (1995) were all physically mature. Three additional large specimens include two females (both dehydrated and decomposed), 139 cm and 150 cm; and one male (decomposed), 145 cm long (Brownell, 1982; Silber and Norris, 1991). Although the sample is small, the maximum female body length is greater than that of males, as in the harbour porpoise, *P. phocoena*.

Weight

Whole body weights of the above-mentioned 43 fresh specimens ranged from 7.5 kg to 47.5 kg. The total lengths of these specimens ranged from 70.3 cm to 148.2 cm.

Internal Anatomy

Skull

Norris and McFarland (1958) described the first skulls, and additional details were reported by Orr (1969), Noble and Fraser (1971), Brownell (1983), Magatagan *et al.* (1984), Barnes (1985), G. Carvallo and L. T. Findley (unpublished data), and Torre-Cosío (1995). The adult skulls are smaller, and have relatively much broader and shorter rostra than those of other phocoenids. The condylobasal lengths of 36 skulls (of immature and mature individuals) range from 180 mm to 243 mm. Ranges of additional selected skull measurements (in mm) are zygomatic width 123–157 ($n = 21$), mandible length 158–184 ($n = 21$), and rostral length 79–93 ($n = 17$) (Brownell, 1983 and unpublished data; Torre-Cosío, 1995). The skull is illustrated in Fig. 4. The tympanic bullae and periotics were illustrated by Brownell (1983).

The teeth have spatulate crowns and essentially are uniform throughout the mouth, as in other species of *Phocoena*. In 24 specimens, the number of erupted teeth in the maxillary tooth rows was 16–22 and in the mandibular tooth rows 17–20 (Brownell *et al.*, 1987; O. Vidal, unpublished data).

Postcranial skeleton

In most individuals examined by us the first three of the seven cervical vertebrae were fused, as in *P. spinipinnis*. In three specimens the first four vertebrae were fused. In another specimen the fourth and fifth vertebrae were also fused but separated from the first three. There are 12 or 13 thoracic, 11–15 lumbar, and 29–31 caudal vertebrae, with 19–23 chevron bones (Noble and Fraser, 1971; Brownell, 1983; Magatagan *et al.*, 1984; L. T. Findley, G. Carvallo, and J. Torre-Cosío, unpublished data). The total number of vertebrae ranges between 58 and 64. The first six or seven ribs have both capitular and tubercular attachments to the vertebrae. Six or seven pairs of sternal ribs are present of which the first three are attached to the sternum. Based on counts from radiographs or prepared flipper skeletons of nine individuals, the phalangeal formula is I_2, II_{7-10}, III_{7-9}, IV_{4-5}, V_{1-2} (L. T. Findley and J. Torre-Cosío, unpublished data).

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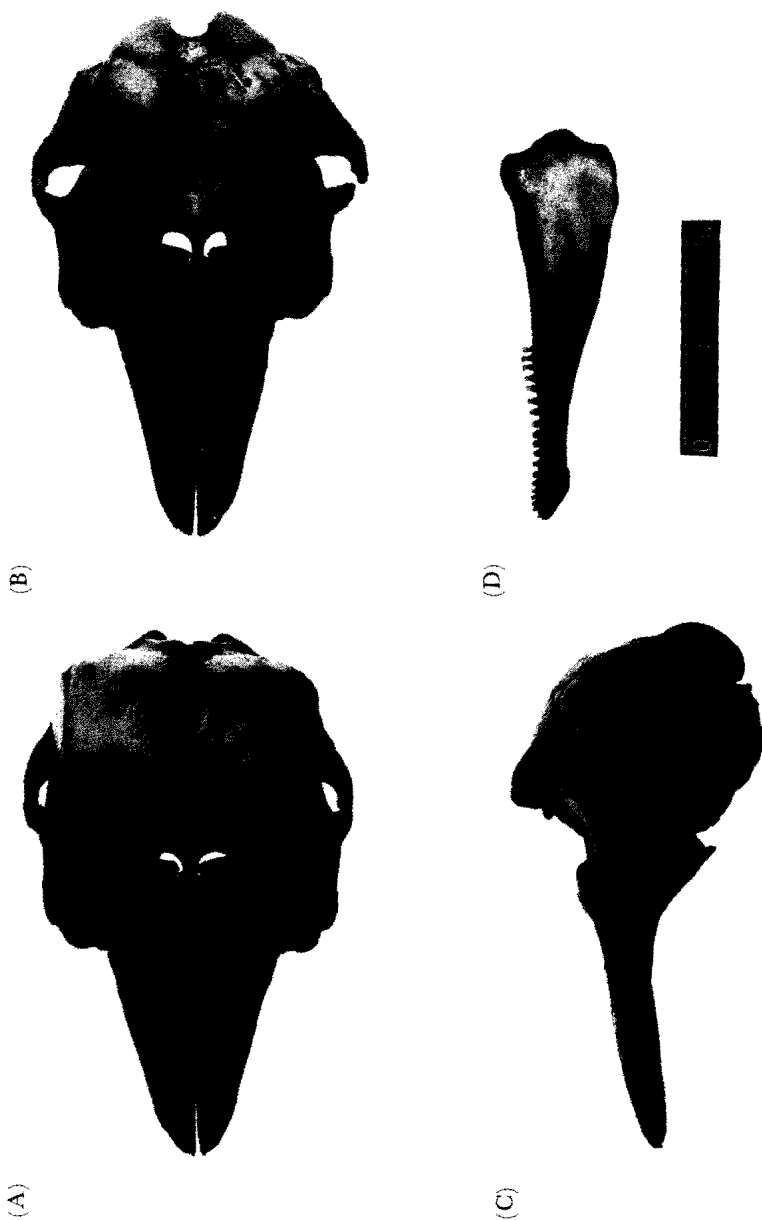tween
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FIG. 4 Ventral (A), dorsal (B) and lateral (C) views of the skull and the mandible (D) from a 150 cm *Phocoena sinus* (LACM 28259) from San Felipe, Baja California, Mexico.

Blubber thickness

The range of blubber thickness in 19 vaquitas that varied in total length between 72.8 cm and 148.2 cm was: 8–33 mm mid-dorsal (adjacent to the anterior edge of dorsal fin), 8–19 mm mid-lateral, and 8–21 mm mid-ventral (O. Vidal, unpublished data). The relative blubber weight in one of the smallest porpoises (93.5 cm) was 33.3% but only 26.5% in one of the largest specimens (148.2 cm).

Internal organs

Ranges of selected organ weights from 19 specimens we examined are presented in Table 2.

Microanatomy

G. E. Michel (unpublished data) provides histological descriptions for tissues of 13 organs from a total of nine vaquitas. In general, the microanatomy of *P. sinus* was found to resemble that of other delphinoids, such as the bottlenose dolphin, *Tursiops truncatus*.

TABLE 2   Organ weights (g) of the largest and smallest male and female vaquitas, *Phocoena sinus*

Organ	Male 93.5 cm	Female 105.9 cm	Male 142.2 cm	Female 148.2 cm
Heart	82.2	121.7	198.1	233.7
Lungs				
left	180.7	149.9	204.7	436.4
right	168.6	176.3	284.9	472.6
Stomach	118.5	390.0	—	—
Intestine	367.8	940.0	610.6	—
Liver	300.0	502.0	806.3	1235.0
Kidneys				
left	64.7	86.4	153.5	180.8
right	65.3	92.4	142.0	177.3
Pancreas	15.4	43.2	75.3	77.2
Spleen	4.0	6.8	7.0	4.6
Thyroid	5.0	—	—	—
Adrenals				
left	1.0	1.7	3.5	6.3
right	1.1	2.9	4.1	6.7
Gonads				
left	4.0	—	284.3	2.5
right	3.7	—	325.6	1.2
Blubber	5.5 kg	9.5 kg	7.36 kg	11.65 kg
Total weight	16.5 kg	22.0 kg	42.50 kg	44.00 kg

Physiology and biochemistry

Nothing has been published on the physiology or biochemistry of this porpoise. Recent genetic studies based on samples of vaquitas taken at different times and locations in the upper Gulf found no sequence polymorphisms (i.e. no genetic variability in mitochondrial DNA) which may represent the results of a population bottleneck, founder effect, or severe inbreeding in the species (Rosel, 1992; Rosel and Rojas-Bracho, 1993).

Life History and Population Dynamics

Growth and reproduction

The life history of the vaquita appears, in many ways, to be similar to the harbour porpoise from the Bay of Fundy, Canada (Read and Gaskin, 1990). Nothing is known about the gestation period, but it is probably similar to that of *P. phocoena* (about 11 months) (see also Hohn *et al.*, 1996). Neonates ($n = 11$) are approximately 70–78 cm in total length and weigh at least 7.5 kg; they are born mainly in March and April (Brownell, 1983; Brownell *et al.*, 1987; Silber and Norris, 1991; Vidal, 1995; Hohn *et al.*, 1996). Vidal (1995) also reported six other possible neonates (two referred to by fishermen as "very small" and the others estimated by them at around 50, 60, 70, and 80 cm) that died during fishing operations in March 1989 and February and April of 1990. Silber (1988, 1990a) reported seven calves (8.2% of all individuals) sighted during his surveys, six between 25 and 27 March 1986 and one "very young, probably less than two days old" on 9 April 1987. Based on the limited data, parturition occurs in the late winter and early spring, between February and April, with the peak of calving in late March and early April (Vidal, 1995; Hohn *et al.*, 1996). The age structure of a recently studied sample of vaquitas killing in fishing nets was bimodal, with 62% of the specimens of 0–2 years and 31% of the specimens of 11–16 years (Hohn *et al.*, 1996). The oldest individual was estimated to be 21 years (Hohn *et al.*, 1996).

We examined a total of 43 fresh individuals of known sex (19 males and 24 females). The smallest adult male and female were 128.3 cm and 135 cm, respectively. The weights of these two porpoises were 39 kg and 41 kg, respectively. Also, both of these porpoises were physically mature. The largest immature male and female were 127 cm and 128.7 cm long, respectively.

Based on the minimum testes weights (i.e. the weight of the smaller of the pair, with the epididymis removed) of six males (284.3, 359.4, 480, 620, 642.1 and 643.8 g), vaquitas appear to conform to the general delphinoid pattern of large testis size relative to body size noted by Kenagy and Trombulak (1986). Such relatively large testes suggest some type of multi-male breeding system. The

largest immature testis weight (i.e. the weight of the larger of the pair, with the epididymis removed) was 74.3 g.

Abundance

Little is known about the abundance of the vaquita. Although various sightings have been reported, many were opportunistic and do not allow reliable estimates of the population size of this porpoise. Prior to 1986, only one cruise was specifically planned to survey for *P. sinus* (Wells *et al.*, 1981). These authors surveyed a 1959 km transect but recorded only two sightings. Since then, the only other surveys wholly dedicated to *P. sinus* have been those of G. K. Silber and co-workers (Silber, 1988, 1990a; Silber *et al.*, 1988) and of T. Gerrodette and his co-workers (Gerrodette *et al.*, 1994, 1995). A total of 4216 km of boat and aircraft surveys conducted during 77 days in 1986–1989 resulted in only 58 sightings, representing a total of 110 individuals (Silber, 1990a,b). Forty-three of these vaquitas (19 sightings) were recorded during 1715 km of vessel transects, a sighting rate of 2.51 individuals per 100 km surveyed (Silber, 1990a). The remainder of the sightings occurred during non-transect time (Silber, 1990b). In an aerial survey for vaquitas in the northern Gulf, there was only one certain sighting of two vaquitas and a possible sighting of another single vaquita (Barlow *et al.*, 1993). Noting the difficulty of observing vaquitas in the turbid waters of the upper Gulf of California, it was recommended that ship surveys would be more effective for future surveys (Barlow *et al.*, 1993).

Only three serious attempts have been made to estimate the total size of the vaquita population. Based on Silber's censuses for 1986 ("30" individuals in "11" sightings; these figures were later amended by Silber (1988) to "27" and "12" respectively) and on 14 specimens caught incidentally in gill nets and examined during 1985 and 1986 (Findley and Vidal, 1985; Brownell *et al.*, 1987; Robles *et al.*, 1987), Barlow (1986) estimated 50–100 individuals as an approximate lower limit for the population. He noted that it was not possible to estimate any upper limit based on the limited data. It appears that Barlow's minimum estimate was (understandably) too low. It is now known that a minimum of 143 vaquitas were killed in various fishing operations between March 1985 and January 1994 and an annual incidental mortality of 35 vaquitas was estimated (D'Agrosa *et al.*, 1995; Vidal, 1995). Based on a largely separate data set, Turk-Boyer (1989) and Turk-Boyer and Silber (1990) estimated that the annual fishing-related mortality of vaquitas is 32. These recorded kills must represent only a fraction of the total number of vaquitas that are killed in the various regional fishing operations. A population significantly larger than Barlow's (1986) estimate would be necessary to permit this level of mortality.

Recently, the abundance of vaquitas was estimated from four surveys conducted between 1986 and 1993, using a variety of methods (Barlow *et al.*, 1997).

A line-transect method was applied, using parameters from the harbour porpoise. Vaquita abundance was estimated at 503 ($CV = 0.63$) from 1986–1993 boat surveys, 885 ($CV = 0.50$) from 1988–1989 aerial surveys, 572 ($CV = 1.43$) from a 1991 aerial survey, and 224 ($CV = 0.39$) from a 1993 ship survey. All of these abundance figures indicate that the species is at a critically low level. A weighted log–linear regression indicated a rate of population decline of about 18% (95% CI $= -43.2\%$ to $+19.3\%$) between 1986 and 1993.

Based on four years of seasonal surveys, Silber (1990c) presented, but did not discuss quantitative details for, his estimate of 200–500 individuals for the entire population. Silber and co-workers documented 16 sightings with 27 individuals for 1986, 22 sightings with 46 individuals for 1987, 13 sightings with 23 individuals for 1988, and seven sightings with 14 individuals for 1989. The total number of vaquitas observed is only 110. Given the brevity of most sightings (because of the low surfacing profile and relatively short time that this porpoise spends at the surface; e.g. see Silber *et al.*, 1988; Silber, 1990b), the relatively restricted area searched (simply because of the restricted geographical distribution of the vaquita), and the inherent difficulty of differentiating one individual from another, Silber and co-workers probably observed some of the same individuals during different days, months, and years. Thus, considering the scarcity of sightings relative to survey effort, the few individuals per sighting, and the limited geographical range of the vaquita, there can be no doubt that the population of this species is very small.

Behaviour

Social organization

Like other phocoenids, *P. sinus* occurs singly or in small groups. In 58 sightings, 91% comprised from one to three individuals, with a mean group size of 1.9 and a range of 1–7 (Silber, 1990a,b). Loose aggregations of vaquitas in which they were dispersed as single individuals or as small subgroups (from two to four members, greatest number eight to ten) throughout several hundred square metres were observed by Silber (1988). All previous sightings comprised from one to three vaquitas (Norris and McFarland, 1958; Norris and Prescott, 1961; Wells *et al.*, 1981; Vidal *et al.*, 1987).

Wells *et al.* (1981) suggested that these porpoises typically avoid boats, but Silber *et al.* (1988) noted no apparent response to their small boat when following two different female/calf pairs for several hours at distances of 40–200 m, nor to the presence of several nearby fishing skiffs. In each case, however, abbreviated surfacing sequences were noted as a possible reaction to the boats.

Movements

Nothing is available on local or regional movements. Most sightings of these porpoises have been made in a relatively small area during winter and spring months (the seasons when most surveys have been carried out).

Feeding

The remains of bronzestriped grunt, *Orthopristis reddingi* (Haemulidae), and Gulf croaker, *Bardiella icistia* (Sciaenidae), were recovered from the stomach of one *P. sinus* carcass north of San Felipe in 1965 (Fitch and Brownell, 1968). Both fishes are found throughout the demersal zone of the northern Gulf of California. Another beached specimen, collected near El Golfo de Santa Clara in 1984, had remains of sciaenid fishes ("croakers") in its stomach (R. L. Brownell Jr., unpublished data). Two vaquitas collected in 1988 contained several whole fish ("probably *Anchoa nasus* or *Sardinops* spp."), numerous unidentified fish otoliths, and squid beaks (Silber, 1990b). If generic identification of the *Sardinops* is correct, then it could only be *S. sagax caerulea*, the Pacific sardine. Squid beaks, *Lolliguncula panamensis*, were also found in the stomachs of the porpoises collected in 1965 and 1984. Stomach contents of six vaquitas necropsied by us in 1985 yielded upper and lower beaks of the squids *L. panamensis* (103 total beaks and one whole squid body) and *Loliolopsis diomedeae* (25 total beaks) (F. G. Hochberg, personal communication). The former species was present in all six stomachs analysed, and the latter species was found in two of the six stomachs. These squids appear to be abundant in coastal waters throughout the Gulf of California and southward. A recent analysis of stomach contents from 24 vaquita showed the presence of the same two squids plus 17 species of teleost fishes. The sample did not include *Sardinops* or *Anchoa nasus*, although five other species of anchovies were present. Also, the other 12 species of fishes encountered did not include the two species reported by Fitch and Brownell (1968), but we have no doubts about their identifications. All of the 17 fish species can be classified as demersal and/or benthic species inhabiting relatively shallow water in the upper Gulf of California, and it appears that the vaquita is a rather non-selective feeder on small fishes and squids in this zone (Findley *et al.*, in prep.).

Association with other species

No mixed-species aggregations have been encountered, but Silber (1990a) reported two sightings of Bryde's whales, *Balaenoptera edeni*, and three sightings of common dolphins, *Delphinus delphis*, within < 1 km and < 1.5 km of groups of *P. sinus*, respectively. Numerous black storm petrels, *Oceanodroma melania*, and Bonaparte's gulls, *Larus philadelphia*, were observed dipping into the wake of surfacing vaquitas (Silber, 1990a).

Predation

Several shark fishermen of El Golfo de Santa Clara, who regularly capture vaquitas incidentally, reported to one of us (O.V.) that in February to May 1990 and 1991 they found whole or chewed parts of vaquitas in the stomachs of several species of large sharks. The sharks were identified from photographs and/or jaws provided by the informants, and they included at least six species: great white (*Carcharodon carcharias*), shortfin mako (*Isurus oxyrhynchus*), lemon (*Negaprion brevirostris*), black-tipped (*Carcharhinus limbatus*), bigeye thresher (*Alopias superciliosus*) and broad-snout seven-gill (*Notorhynchus cepedianus*) (Vidal, 1995). Both the great white and shortfin mako are known locally as "tiburones tonina" or "dolphin sharks" because of the nearly equal sizes of their caudal-fin lobes. On 18 February 1990, the stomach from a great white shark about 3 m long and 160 kg in weight was said to contain a vaquita that was bitten into three pieces. Two more "tiburones tonina", caught in March 1985 and in early February 1990, reportedly each had a vaquita in their stomachs. These sharks may attack free-swimming vaquitas, or perhaps feed on individuals trapped in gill nets, or both. Other large sharks that may be considered as potential predators of vaquitas include the tiger shark (*Galeocerdo cuvier*) and the scalloped hammerhead (*Sphyrna lewini*).

Killer whales, *Orcinus orca*, are potential predators of *P. sinus*. Killer whales are not uncommon in the Gulf of California (Vidal *et al.*, 1993), and they have been observed harassing and attacking large cetaceans (Vidal and Pechter, 1989; Silber *et al.*, 1990), but no information is available regarding possible predation by them upon vaquitas.

Swimming and diving

Silber *et al.* (1988) provided the only available information on the behaviour and ventilation cycles of the vaquita. Two different female/calf pairs were observed for periods of about 3 hr each. Dive characteristics were similar to those reported for *P. phocoena*. However, mean dive times (see definition for this and the following terms in Watson and Gaskin, 1983), roll intervals, surface times, and rolls per surfacing reported for *P. phocoena* by Watson and Gaskin (1983) were of somewhat greater length than those of *P. sinus*.

Sound production

High frequency sounds were recorded near free-ranging vaquitas in 1986 and 1987 (Silber, 1991). Clicks were sharp, intense, and narrow band ($\bar{x} = 17.1 \pm$ s.d. 5.38 kHz) signals in a frequency range of 122.2–146.9 kHz. The duration of these clicks was 79–193 μsec. The acoustic signals produced by *P. sinus* are similar to those reported for other phocoenids and for one genus of dolphins (*Cephalorhynchus* spp.) (Evans *et al.*, 1988).

Parasites and Diseases

Commensal pseudo-stalked barnacles, *Xenobalanus globicipitis*, were found attached on or near the posterior edges of the dorsal fins, flippers and/or flukes of 14 of 43 fresh vaquitas examined by us. Neither of the larval cestodes (*Phyllobotrium* sp. and *Monorygma* sp.) that have been found in most genera of marine odontocetes was present in the individuals we examined.

Three parasitic trematodes from the intestine of a vaquita were identified as *Synthesium tursionis* and utilized in a redescription of this species by Lamothe-Argumedo (1988). Although this author noted several characters that differed from "typical" specimens of this species, he considered them to be minor and not worthy of recognition as a new species. However, examination of a separate specimen of *Synthesium* from a different vaquita necropsied by us has led M. D. Dailey (California State University at Long Beach, personal communication) to believe that recognition of a new species may be warranted. More specimens are needed to clarify the taxonomic status of this trematode in *P. sinus*. In materials resulting from necropsies of eight vaquitas in 1985, M. D. Dailey (personal communication) identified two specimens of the nematode *Crassicauda* sp., one from muscle connective tissue in the area of a mammary gland of one vaquita, and the other located in the blubber layer 1 cm below the skin and 5 cm anterior to the anus of the other vaquita. Unidentified larval nematodes were found in the stomachs of three vaquitas from the same sample and from muscle tissue in the area adjacent to a mammary gland (one vaquita) and the wall of the pleural cavity (one vaquita).

Live Maintenance

No vaquitas have been maintained in captivity.

Human Effects

By-catches

The major human-induced problem affecting this species is incidental mortality in fishing gear. Vaquitas frequently die in illegal and sporadically permitted "survey-sampling" gill nets set for the endemic and endangered large corvina-like fish called the "totoaba" (*Totoaba macdonaldi*); in legal gill nets set for sharks, rays, mackerels (*Scomberomorus sierra* and *S. concolor*), chano (*Micropogonias*

megalops) (a "croaker"), and shrimp (*Penaeus* spp.); and occasionally in commercial shrimp trawls.

The commercial fishery for totoaba in the upper Gulf of California, initially using primitive gill nets, had started by at least the mid-1930s, and unidentified small cetaceans were taken at that time (Brownell, 1982). More efficient nylon gill nets were used during (and probably before) the 1960s and 1970s. After a peak catch of 2261 tons of totoaba meat in 1942, and despite intensified fishing efforts, the annual catches declined to a minimum of approximately 59 tons in 1975. As a consequence of this dramatic decline, the Mexican government declared an indefinite closed season that prohibits any capture of these fish by commercial and sport fisheries (Flanagan and Hendrickson, 1976). Despite the closure, illegal fishing for totoaba continued off El Golfo de Santa Clara and San Felipe until at least January 1994 (Román Rodríguez, 1990; Lagomarsino, 1991; D'Agrosa *et al.*, 1995; Vidal, 1995). Although lacking any quantitative data, some fishing cooperatives in the northern Gulf have claimed that the totoaba stock has recovered and that the fishery should be legally reopened. This pressure has resulted in the issuing of some temporary permits (since 1983) for gill net operations by the Secretariat of Fisheries (SEPESCA) to assess the population status of totoaba or to study various aspects of its biology (Findley and Vidal, 1985; Rosales and Ramírez, 1987; Barrera-Guevara, 1992; Vidal, 1995). To date, however, efforts to assess the totoaba population have proved unsuccessful. Between March 1985 and January 1994, 76 vaquitas were confirmed to have been killed incidentally in totoaba gill nets (Vidal, 1995).

In addition to gill net fishing for totoaba (mesh size 20–30.5 cm), a gill net fishery for several species of large sharks and rays (mesh size 10–15 cm) has been growing rapidly in the upper Gulf of California since the early 1940s, probably together with the totoaba fishery. The shark fishery continues to operate without control (Vidal *et al.*, 1994; D'Agrosa *et al.*, 1995). In recent years, a gill net fishery for mackerel (*Scomberomorus* spp.), chano (*Micropogonias megalops*) and various species of small sharks (mesh size 8.5 cm) has started in the upper Gulf. Between 1985 and 1994, the shark and ray, mackerel, and chano fisheries have incidentally captured at least 45 and three vaquitas, respectively (D'Agrosa *et al.*, 1995; Vidal, 1995). Also, four vaquitas were killed during 1993–1994 in gill nets ("chinchorro de línea") (D'Agrosa *et al.*, 1995).

Norris and Prescott (1961) briefly mentioned a report by a fisherman who had accidentally captured vaquitas in a shrimp trawl. The deaths of nine vaquitas in shrimp trawls (two in 1985, one in 1988, two between 1984 and 1989, three in 1990, and one in 1993) were reported to O. Vidal, A. Robles, or C. D'Agrosa by residents of El Golfo de Santa Clara or San Felipe. All the porpoises taken were referred to as "very small", probably calves or juveniles. Considering the large number (ca. 500) of shrimp boats operating in the upper Gulf of California at the beginning of each typical shrimping season, this fishery poses an additional threat to vaquitas, particularly younger ones.

Pollution

Concerns have been expressed about organochlorine pollutants in the food web containing the vaquita in the upper Gulf of California (Barlow, 1986; Klinowska, 1991). Based on high concentrations of DDT in bivalve molluscs near the mouth of the Colorado River, Guardado (1975) concluded that the adjacent Mexicali Valley, with all of its agricultural activities, is an important source of pollutants in the upper Gulf of California. In the past, pollutants could also have been carried to the upper Gulf by Colorado River water used for irrigating agricultural areas in the southwestern United States. Today, in years with normal precipitation, essentially all of the surface flow of the Colorado River is diverted and utilized before it reaches the Gulf (Flanagan and Hendrickson, 1976). When samples of blubber from eight vaquitas, incidentally killed in fishing activities during 1985 (see Brownell *et al.*, 1987) were analysed for chlorinated hydrocarbons (Calambokidis *et al.*, 1993), relatively low concentrations of total DDT, alpha-BHC, and PCBs were found. These low concentrations were generally much lower than those reported for various odontocetes and marine birds from most other areas. Henny and Anderson (1979) reported pesticide residues (DDE and PCBs) in osprey, *Pandion haliaetus*, eggs from the Gulf of California that were among the lowest for this fishing bird in North America. Therefore, it appears that chlorinated hydrocarbons do not pose as great a threat to the vaquita population in the Gulf of California as they may for some populations of small cetaceans in other areas.

Barlow (1986) reported that exploratory drilling for oil and natural gas started in the uppermost Gulf in the early 1980s. However, the two drilling platforms that were erected near Puerto Peñasco and El Golfo de Santa Clara have been removed (Barlow, 1986). We know of no other planned exploration for fossil hydrocarbons in the upper Gulf at this time. Future development, however, could pose a serious problem for the vaquita and other species of marine organisms if a large oil spill occurred in the upper Gulf of California.

Acknowledgments

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