

Conservation of the vaquita *Phocoena sinus*

LORENZO ROJAS-BRACHO*, RANDALL R. REEVES† and ARMANDO JARAMILLO-LEGORRETA*

*Programa de Mamíferos Marinos, Instituto Nacional de Ecología/CICESE, Km 107 Carretera Ensenada-Tijuana, Ensenada, B.C. 22860, México, and †Okapi Wildlife Associates, 27 Chandler Lane, Hudson, Quebec, Canada J0P 1H0

ABSTRACT

1. The vaquita *Phocoena sinus* is a small porpoise that is endemic to the northern Gulf of California, Mexico. It is the most critically endangered marine small cetacean in the world. The most precise estimate of global abundance based on a 1997 survey is 567 (95% CI 177–1073).
2. Vaquitas mainly live north of 30°45'N and west of 114°20'W. Their 'core area' consists of about 2235 km² centred around Rocas Consag, 40 km east of San Felipe, Baja California. Genetic analyses and population simulations suggest that the vaquita has always been rare, and that its extreme loss of genomic variability occurred over evolutionary time rather than being caused by human activities.
3. Gill nets for fish and shrimp cause very high rates of by-catch (entanglement) of vaquitas. Estimates of bycatch rates are from 1993–94 and refer to one of three main fishing ports: 84 per year (95% CI 14–155) using only data collected by observers and 39 per year (95% CI 14–93) using combined data from observers and interviews with fishermen. Boats from other ports may experience similar rates, and the total is probably well above what would be sustainable.
4. Other less well-characterized and longer-term risk factors include the potential for disturbance by trawling to affect vaquita behaviour, and the uncertain effects of dam construction on the Colorado River and the resultant loss of freshwater input to the upper Gulf. However, entanglement is the clearest and most immediate concern.
5. Progress towards reducing entanglement has been slow in spite of efforts to phase out gill nets in the vaquita's core range, and the development of schemes involving compensation for fishermen. The Biosphere Reserve in the northern Gulf has fallen far short of its potential for vaquita conservation. On 29 December 2005, the Mexican Ministry of Environment declared a Vaquita Refuge that contains within its borders the positions of approximately 80% of verified vaquita sightings. In the same decree, the state governments of Sonora and Baja California were offered \$1 million to compensate affected fishermen. The effectiveness of this major initiative remains to be seen.
6. The vaquita's survival does not depend on more or better science but on improved management. As a funding priority, implementation of conservation measures and evaluation of their effectiveness should come ahead of more surveys or improved estimation of by-catch.

Keywords: by-catch, cetacean, critically endangered, Gulf of California, Mexico, porpoise

INTRODUCTION

The Mexican fishery laws must somehow be made to work, or the species will die out before we come to know it. Even a few paid rangers with a couple of good boats might halt the decline, as would new jobs for fishermen. But will those things happen?

Norris (1992)

Those words, written in 1992 by one of the two describers of the vaquita *Phocoena sinus* Norris & McFarland (1958), are as fitting in 2006 as they were then. The vaquita is in close competition with the baiji *Lipotes vexillifer*, or Yangtze River dolphin, for the dubious distinction of being the most critically endangered species of small cetacean in the world. The vaquita is a small porpoise (1.5 m, 50 kg; Fig. 1) and is endemic to the northern reaches of the Gulf of California, Mexico. Its known modern distribution encompasses a water surface area of only about 4000 km², which means that its total extent of occurrence is far smaller than that of any other living species of marine cetacean. By the time of its scientific discovery and formal description in 1958, the vaquita was already seldom seen, difficult to observe, and probably not very abundant. Apart from the few cursory observations reported by Norris & McFarland (1958) and Norris & Prescott (1961), and a few additional records described by Orr (1969) and Noble & Fraser (1971), the vaquita remained largely unknown until the 1980s, when intensive, focused efforts were made to find living animals and to document their numbers, distribution and behaviour.

Only four living species comprise the genus *Phocoena*, two in the Northern Hemisphere (the vaquita and the harbour porpoise *P. phocoena*) and two in the Southern Hemisphere (the spectacled porpoise *P. dioptrica* and Burmeister's porpoise *P. spinipinnis*). All are small in body size and coastal in distribution (although there is some evidence to suggest that the spectacled porpoise has a partly offshore distribution; Brownell & Clapham, 1999a). Another common feature of the four species is that they are highly vulnerable to incidental mortality in gillnet fisheries (Jefferson & Curry, 1994). There is no reason to suppose that the vaquita is any more, or less, susceptible to accidental entanglement in gill nets than any other



Fig. 1. A vaquita showing the head and anterior pigmentation pattern. Note the dark grey dorsal cape and the pale grey lateral field. The most conspicuous features are the relatively large black eye and lip patches. This animal died in an experimental totoaba fishery and was landed in El Golfo de Santa Clara, March 1985 (Photo by A. Robles).

porpoise. However, its restricted distribution in a remote region where fishing has long been a primary economic activity, which provides the sole source of income for many people, makes the vaquita uniquely vulnerable. This situation was acknowledged by the Scientific Committee of the International Whaling Commission (IWC) in 1990 (IWC, 1991a), and reclassification of the vaquita from Vulnerable to Endangered on the International Union for Conservation of Nature and Natural Resources (IUCN) (World Conservation Union) Red List quickly followed (Klinowska, 1991). The species was upgraded to Critically Endangered in 1996 (Baillie & Groombridge, 1996).

Conservation groups, concerned scientists and government officials in Mexico have invested large amounts of time and financial resources in vaquita conservation in the past 25 years. Nevertheless, there is a prevailing sense of displeasure and disappointment that so little has been accomplished, and that the outlook for the vaquita's survival remains at least as bleak in 2006 as it was in 1976 when one of Mexico's foremost mammalogists, Bernardo Villa-Ramírez, described the species as 'seriously endangered' and 'on the border of extinction'. We believe that in 2006, the situation is grave but not hopeless. Tangible progress has been made in terms of scientific understanding, problem definition and public awareness. Government agencies in Mexico have acknowledged the need to confront the bycatch problem if there is to be any hope of preventing the vaquita's extinction. An infrastructure of institutions, regulatory measures and programmes is being developed, with the goal of achieving more sustainable, less wasteful fisheries in the northern Gulf.

For this review, we have three main objectives:

- to provide a concise summary of the scientific issues related to vaquita conservation;
- to describe previous and ongoing efforts to conserve vaquitas and improve their chances for recovery; and
- to identify remaining obstacles to recovery, establish conservation priorities, and provide recommendations.

We emphasize that the information, ideas and opinions expressed in this review reflect the efforts of many people, only some of them specifically identified in the *Acknowledgements*. Although the priorities and recommendations set out here reflect our own beliefs and biases, they are largely selected from other fora (workshops, technical meetings, advisory panels, etc.) and thus are not necessarily original to us.

SCIENTIFIC ISSUES

The vaquita was almost unknown, not only to scientists but also to most people living along the shores of the Gulf of California, before the species was described in 1958 by Norris & McFarland. Apart from cursory descriptions of observations by Norris & Prescott (1961), and a few additional records described by Orr (1969) and Noble & Fraser (1971), no further published reports appeared until the 1980s (although other osteological material was recovered; see Vidal, 1991, 1995).

Our goal here is not to review all aspects of scientific knowledge concerning the vaquita (see Vidal, Brownell & Findley, 1999; Rojas-Bracho & Jaramillo-Legorreta, 2002; Table 1) but rather to focus attention on issues that are of direct conservation relevance. These fall into five categories: distribution, abundance, life history, fishery interactions and other threat factors.

Distribution

The vaquita is believed to represent a relict population of an ancestral species (closer to Burmeister's porpoise than to any other living member of the family Phocoenidae) that

Table 1. Chronology of research on the vaquita and its habitat

| | |
|------|---|
| 1958 | Vaquita described as a new species (Norris & McFarland, 1958). |
| 1961 | First reports of vaquita kills in fishing gear: totoaba gill nets and trawlers (Norris & Prescott, 1961). |
| 1968 | First data on ecology: stomach contents reveal feeding on small, shallow-water, bottom-dwelling fishes (Fitch & Brownell, 1968). |
| 1975 | IWC Scientific Committee mentions biology of vaquita and concerns about incidental mortality in shark and totoaba fishery in the published report of the first meeting on smaller cetaceans, Montreal, 1974 (IWC, 1975). |
| 1976 | Villa-Ramírez expresses concern about vaquita's status. Brownell presents first review of vaquita's status and identifies potential risk factors (FAO Advisory Committee on Marine Resources Research, Working Party on Marine Mammals, Bergen, Norway; not published until 1982). |
| 1983 | 'Experimental' 10-year totoaba fishery initiated by Instituto Nacional de la Pesca. Fourteen vaquita deaths in 1985–86 reported by Robles <i>et al.</i> (1987) and 4 by Fleischer (1994). |
| 1985 | Instituto Tecnológico y de Estudios Superiores de Monterrey-Guaymas (ITESM) starts vaquita research programme that will produce much important new information on vaquita biology, ecology and incidental mortality (Vidal, 1995). |
| 1986 | Seven vaquitas recovered from 1985 to 1986 experimental totoaba fishery and used for studies of external morphology (Robles <i>et al.</i> , 1986). Silber starts first extended field studies resulting in new insights on behaviour, distribution and abundance. |
| 1987 | First description of external morphology (Brownell <i>et al.</i> , 1987) and more reliable field identification during surveys. |
| 1993 | First systematic survey using line-transect methods to estimate vaquita abundance and distribution (Gerrodette <i>et al.</i> , 1995; Barlow <i>et al.</i> , 1997). Taylor & Gerrodette (1993) use vaquita and northern spotted owl as case studies to illustrate importance of statistical power (Type I and Type II errors) in conservation biology. |
| 1996 | First empirical study of vaquita life history reveals lower rate of increase than for other porpoise populations (Hohn <i>et al.</i> , 1996). First estimate of abundance indicates vaquita population size in low hundreds (Barlow <i>et al.</i> , 1997). |
| 1997 | National Marine Mammal Program established by National Fisheries Institute to promote research and international collaboration, particularly with vaquita (Rojas-Bracho & Jaramillo-Legorreta). International Committee for the Recovery of Vaquita (CIRVA) is created and holds first meeting with participation of researchers from Europe, United States, Canada and Mexico; concludes in risk assessment that incidental mortality in fisheries is main threat to vaquita survival (Rojas-Bracho & Taylor, 1999). Joint Mexico–US cruise to estimate vaquita abundance as recommended by CIRVA, covers all known and suspected habitat of the species. Acoustic surveys start with support from International Fund for Animal Welfare (IFAW), World Wildlife Fund – US and Marine Mammal Commission (MMC). |
| 1999 | CIRVA endorses new abundance estimate of 567 individuals (95% CI 177–1073; Jaramillo-Legorreta <i>et al.</i> , 1999) and makes recommendations including to reduce by-catch to zero. |
| 2000 | National Fisheries Chart is published and states that vaquita by-catch should be zero. First quantitatively robust estimate of by-catch is published (D'Agrosa <i>et al.</i> , 2000). Incidental mortality from a single port estimated to be 39 vaquitas/year. |
| 2004 | IFAW and MMC support acquisition of the first research vessel dedicated to studying vaquitas and other marine mammals of northern Gulf of California: KOIPAI YÚ – XÁ, meaning those' who come back with their eyes in the water' in Cucapá language. |
| 2005 | 16th Biennial Conference on the Biology of Marine Mammals (San Diego, California) holds special vaquita event. Officers from Mexico's federal government attend and meet with more than 20 scientists to discuss vaquita science and conservation. |

FAO, Food and Agriculture Organization; IWC, International Whaling Commission.

crossed the equator from the Southern Hemisphere during a period of Pleistocene cooling (Norris & McFarland, 1958). Genetic analyses have corroborated that interpretation (Rosel, Haywood & Perrin, 1995). Burmeister's porpoise is now endemic to coastal and shelf waters of the 'southern cone' of South America from northern Peru in the west to southern Brazil in the east (Brownell & Clapham, 1999b).

The vaquita is known to occur only in the northern quarter of the Gulf of California, Mexico, mainly north of 30°45'N and west of 114°20'W (Gerrodette *et al.*, 1995). The so-called 'core area' consists of about 2235 km² centred around the Rocas Consag archipelago (31°18.2'N, 114°25.0'W), some 40 km east of the town of San Felipe, Baja California (Fig. 2). There is insufficient historical evidence to judge whether the vaquita's overall range has changed in recent decades.

In their original species description, Norris & McFarland (1958) mentioned a number of sightings outside the northern Gulf that they thought represented *P. sinus* (also see Norris & Prescott, 1961; Villa-Ramírez, 1976). Those records (south along the Mexico mainland coast to Bahía de Banderas in north-western Jalisco, along the Baja peninsula to Bahía Concepción, and around the Islas Tres Mariás) have been critically considered and rejected as invalid by some other authors (Barlow, 1986; Brownell, 1986). Other researchers (Silber, 1990; Silber & Norris, 1991), while agreeing that the northern Gulf is the centre of abundance for the species, have acknowledged the possibility that small numbers may disperse more widely in the Gulf. Even if vaquitas did have a more extensive distribution before and during the 1950s, there is 'evidence of absence' from the main body of the Gulf in more recent decades to support the idea that they are now effectively confined only to the upper reaches (north of 30°N).

Vaquitas are present in the main area of concentration offshore of San Felipe throughout the year (Silber, 1990; Silber & Norris, 1991; L. Rojas-Bracho & A. Jaramillo-Legorreta, unpublished data). The question of whether they migrate has been contentious. On the basis of vessel surveys in spring months (March–May) and aerial surveys in May and September (see Silber, 1990), Silber & Norris (1991) inferred that the species is adapted to remain in the same environment year-round and thus can tolerate the range of seasonal fluxes in temperature, salinity and other conditions that prevailed in the Upper Gulf before the Colorado River was dammed. Those conditions included periods of extreme flooding in spring [250 000 cu.ft/s (cfs) due to snowmelt] and greatly reduced base flow in autumn (< 5000 cfs) (United States Bureau of Reclamation, <http://www.yao.lc.usbr.gov>; also see Schreiber, 1969; Thomson, Mead & Schreiber, 1969; Brown, Tennenbaum & Odum, 1991; Glenn *et al.*, 1996; Rodriguez, Flessa & Dettman, 2001). The Upper Gulf is an evaporation basin, with salinities normally higher than 39‰ and reaching lower levels of 32‰ or less only during strong downpours, as occur during El Niño–Southern Oscillation (ENSO) events (Lavín & Sánchez, 1999). According to Silber (1990), the vaquita 'deviates remarkably from other phocoenids in its ability to tolerate seasonal water temperature fluctuations'. Although Burmeister's porpoises have been reported to occur in a fairly broad range of water temperatures (as low as 3°C and as high as 19.5°C; Brownell & Clapham, 1999b), these reports may refer to different populations of that species.

Since 1999, the National Marine Mammal Program at the National Institute of Ecology (Programa Nacional de Mamíferos Marinos; PNICMM-INE) has applied passive acoustic techniques to locate vaquitas (Jaramillo-Legorreta *et al.*, 2001, 2002, 2003, 2005) as part of a study to investigate habitat use. The main results confirm that vaquitas remain in the northern Gulf year-round. They also indicate that the current distribution is more restricted than previously thought – confined to a small area between Rocas Consag and San Felipe

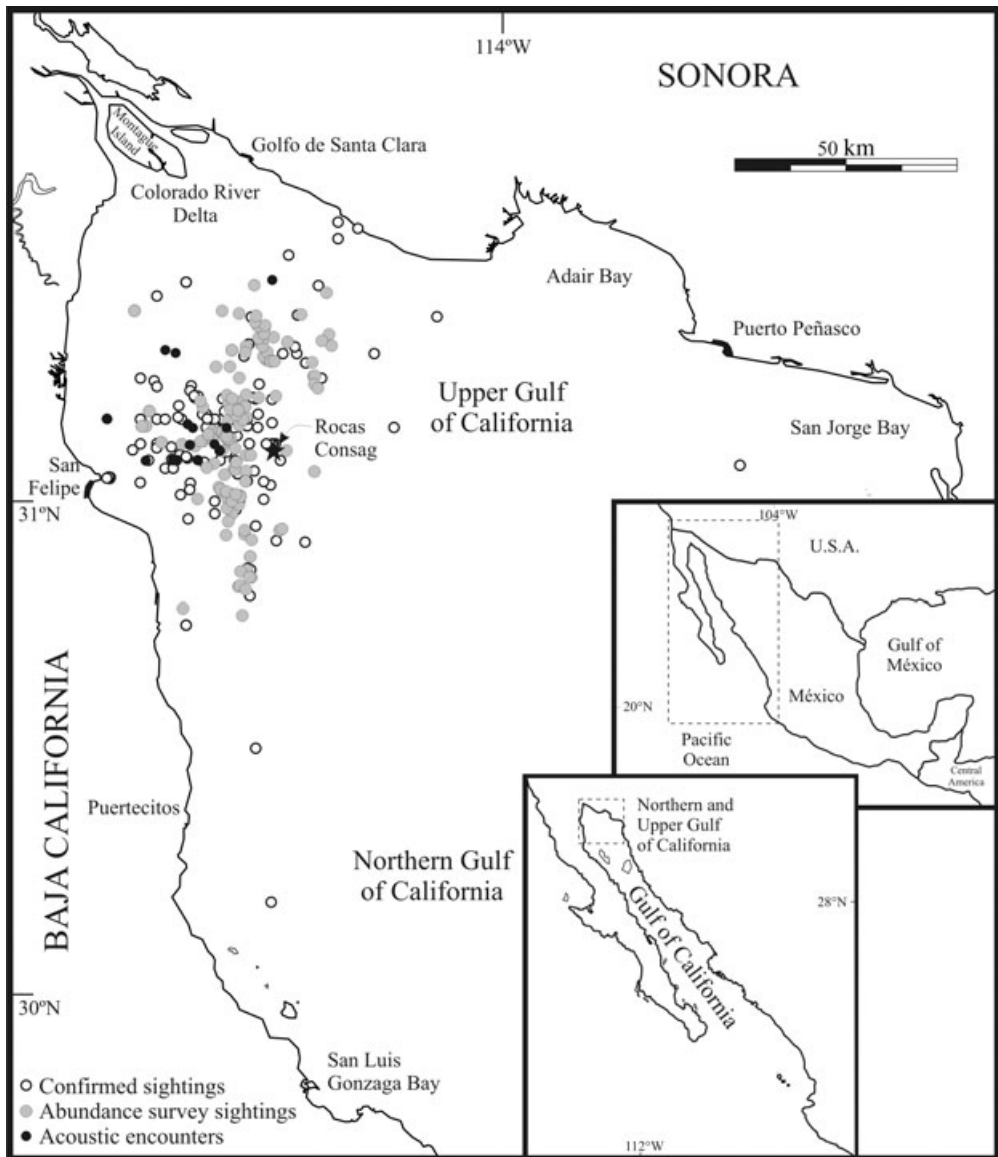


Fig. 2. Northern and upper Gulf of California, showing the approximate distribution of vaquitas. The circles represent vaquita sightings and acoustic encounters. The star represents the position of the Rocas Consag. The Biosphere Reserve is delimited to the south by an imaginary line connecting San Felipe to Puerto Peñasco; therefore part of the vaquita distribution is outside of the reservé.

Bay. This area is generally referred to as ‘The Hot Spot’ for vaquitas, as at least one group has been detected every time the detection equipment has been deployed there.

Norris was told by the captain of a shrimp trawler in 1958 that he had caught vaquitas in nets set for totoaba *Totoaba macdonaldi* (a large fish of the croaker family Sciaenidae that is endemic to the Gulf of California) ‘in the estuary of the Río Colorado at the head of the gulf’ (Norris & Prescott, 1961). He also described having taken them at the entrance to a small lagoon north of San Felipe, where they became trapped in the nets at low tide. Similar

reports were given to the authors by University of Baja California researchers and enforcement officers from San Felipe with long experience in the northern Gulf: N. Castro and V. Zazueta in 1997 and 1999. This information suggests that vaquitas can occur in shallow, tidally influenced estuarine waters. It is important, however, to treat such observations with caution because of the possibility that vaquitas have been confused with bottlenose dolphins *Tursiops truncatus*, which are, according to Silber (1990), 'consistently seen in more shallow water' than vaquitas (also see Silber *et al.*, 1994).

Abundance

Historica

The vaquita presents an essentially insurmountable challenge in trying to produce a plausible estimate of historical abundance. Villa-Ramírez (1976) concluded from talking to fishermen in the northern Gulf that vaquitas were formerly 'very abundant', but he also admitted that the fishermen had difficulty both detecting vaquitas and distinguishing them from other small cetaceans, particularly small bottlenose dolphins. Vaquitas are notoriously difficult to detect and observe, so the usual caution concerning the reliability of qualitative historical observations of animal abundance by non-specialists applies with special force in this case. Even if the memories of fishermen were a reliable source of information on past abundance, few with relevant knowledge would be alive today and therefore available for interrogation. Modern nylon gill nets were being used in the northern Gulf to catch totoaba by the early 1940s (Cisneros-Mata, Montemayor-López & Román-Rodríguez, 1995), so it must be assumed that very high incidental mortality of vaquitas was occurring (see later), and therefore that the vaquita population was already declining by then.

No polymorphism has been found in the mitochondrial DNA control region (Rosel & Rojas-Bracho, 1999) or in the *DQB* locus of the Major Histocompatibility Complex (MHC) (Munguía, 2002) of 43 and 25 vaquita specimens, respectively. These findings are consistent with the hypothesis that the evolutionary history of the species included a bottleneck or founder event, possibly at species inception, followed by a long period (perhaps some 10 000 years) of persistence at a small effective population size. Judging by the results of simulations of plausible population dynamics, vaquitas have probably always been rare, and their extreme loss of genomic variability likely occurred over evolutionary time (Taylor & Rojas-Bracho, 1999; Munguía *et al.*, 2003a,b).

Recent

Qualitative references to rarity and low numbers are scattered throughout the vaquita literature from the time of the species' description (Norris & McFarland, 1958). Even with state-of-the-art survey tools and methods available starting in the 1980s, the vaquita has presented an extreme challenge for abundance estimation because of its murky habitat and elusive surfacing behaviour (Silber & Norris, 1991; Barlow *et al.*, 1993; Fig. 3). Among the characteristics that complicate surveys for vaquitas, even under the best of weather conditions, are:

- The animal's small size, with a triangular dorsal fin up to about 15 cm high;
- They spend most of their time under water and are visible only for about 3 s at a time, at surfacing intervals that average between 1 and 1.5 min (Silber, Newcomer & Barros, 1988);
- When surfacing, they rarely splash or jump;
- Group size averages only about two individuals; and
- They generally avoid boats and ships.

Encounter rates obtained in aerial surveys ranged from 1.8 to 7.2 vaquitas per 1000 km (Silber, 1990; Silber & Norris, 1991; Barlow *et al.*, 1993). These are low figures when com-

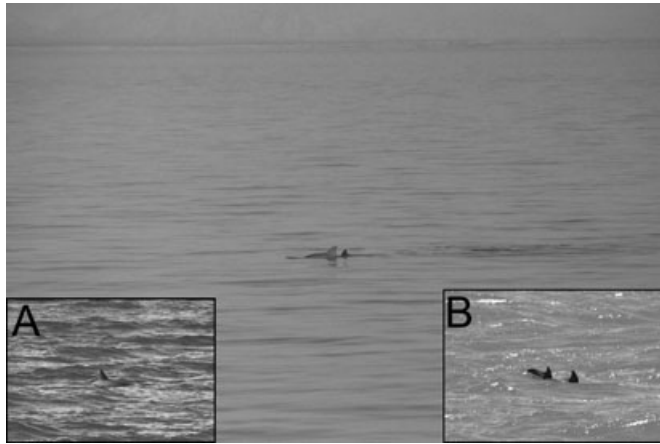


Fig. 3. Center: A vaquita mother and calf sighted in the ‘hotspot’ between San Felipe Bay and Rocas Consag in the winter of 1986. Observers seldom see more than is shown here when the animals surface briefly in the turbid waters of the northern Gulf of California (photo by Michel Newcomer). Insets: Views of vaquitas, also in the ‘hotspot’, during the March 2003 expedition to demonstrate that the species actually exists (both photos by G. Ybarra, WWF – Gulf of California). Inset A shows a single vaquita (31°05′01″N, 114°39′35″W, 31 March). Inset B shows a mother and calf (31°05′03″N, 114°39′39″W, 30 March). Note that the calm sea in the main photo is not typical of the area; the rougher sea surfaces shown in the insets are more representative of ‘average’ conditions in the northern Gulf.

Table 2. Vaquita abundance estimates with associated measures of precision. N is the population estimate from line-transect sampling. CV is the coefficient of variance and CI is the confidence interval associated with the density estimates that give rise to the population estimate

| Survey | N | CV | Lower 95% CI | Upper 95% CI | Reference |
|--------------------|-----|------|--------------|--------------|--|
| Boat 1986–88 | 503 | 0.63 | 163 | 1551 | Barlow <i>et al.</i> (1997) |
| Aerial 1988–89 | 855 | 0.50 | 340 | 2149 | Barlow <i>et al.</i> (1997) |
| Aerial 1991 | 572 | 1.43 | 73 | 4512 | Barlow <i>et al.</i> (1997) |
| Ship 1993 | 224 | 0.39 | 106 | 470 | Barlow <i>et al.</i> (1997) |
| Ship and boat 1997 | 567 | 0.51 | 177 | 1073 | Jaramillo-Legorreta <i>et al.</i> (1999) |

pared with those for other cetaceans in the Gulf of California and for harbour porpoises off central California (47 animals/1000 km; Forney, Hanan & Barlow, 1991).

The first survey-derived estimates were those of Barlow, Gerrodette & Silber (1997), who applied line-transect methods to four disparate datasets to produce a series of statistically bounded estimates for the period 1986–93 (Table 2). Those authors recognized that all four of their estimates were biased to some degree because, for example, none of the surveys covered the entire range of the species. They concluded that such bias for the 1993 estimate of 224 [coefficient of variance (CV) = 0.39] was ‘probably very small’, and that this was likely the most precise and accurate of the four estimates.

‘Current’

The most recent and reliable estimate of vaquita abundance was obtained from a shipboard survey in the summer of 1997 that sampled the entire potential geographical range of the species (Jaramillo-Legorreta, Rojas-Bracho & Gerrodette, 1999). The 1997 survey was designed so that key parameters, such as $g(0)$, the probability that animals directly on the

trackline were detected, and $f(0)$, the probability density function of distance, could be estimated directly rather than by extrapolation or inference from other surveys. The design included four strata as follows: (i) the previously established 'core area' of vaquita distribution, (ii) the deepest basin of the northern Gulf region, (iii) coastal areas and (iv) the channels of the Colorado River Delta.

A well-equipped oceanographic vessel with a viewing platform 10 m high was used to survey the core area and the deep area, while a fisheries research vessel with a 6-m-high platform was used to survey the coastal stratum and also to carry out an independent survey of the core area. Data from the latter were used to adjust the detection parameters derived from the oceanographic vessel's data. A small skiff equipped with an aluminium platform (~3 m high) was used to survey the channels in which strong currents make navigation difficult; interestingly, no vaquitas were observed in these areas. For the overall survey, the encounter rate, detection function and group size were modelled, and the variation was estimated using a bootstrap process that included, at every step, the selection of a detection function model, in order to incorporate this source of uncertainty.

No clear trend can be inferred from the available estimates, in part because of the large uncertainty ($CV \geq 0.50$) associated with four of them and in part because of the differences in survey methods and areas covered. It is generally agreed, however, that the 1997 results are the most representative because that survey generated a large number of sightings, covered the entire range of the species, and did not rely upon information taken from other studies (notably surveys of harbour porpoises). Jaramillo-Legorreta *et al.* (1999) concluded that, as of 1997, the vaquita population was small, isolated, localized and in danger of extinction.

Life history

Most of what is known about the vaquita's life history comes from a study of 56 specimens retrieved from fishing nets, found on shore or examined in museum collections (Hohn *et al.*, 1996). That sample was bimodal: 62% of the individuals were 0–2 years old, 31% were 11–16 years old, and the age interval of 3–6 years was missing entirely. In many respects, the vaquita appears to be similar to the much better-studied harbour porpoise (Read & Hohn, 1995; Read, 1999). Longevity for both species is somewhat more than 20 years, with sexual maturation occurring between 3 and about 6 years of age. Both are seasonal breeders. Most births of vaquitas occur in early March, presumably following a peak in ovulations and conceptions in approximately mid-April. A significant difference between the two species is that the ovulation rate, and thus the pregnancy and calving rates, of the vaquita do not appear to be annual as they are in the harbour porpoise. This could mean that the maximum population growth rate of the vaquita is lower than that of the harbour porpoise (estimated at approximately 4%; Woodley & Read, 1991).

The mating system and social structure of the vaquita have not been studied directly. However, it has been inferred from the large testes size (almost 5% of body mass), sexual dimorphism (females are somewhat larger, or at least longer, than males) and small group sizes that sperm competition plays an important role in the species' reproductive strategy (Hohn *et al.*, 1996). This would mean that males attempt to maximize fitness by mating with as many females as possible.

Interactions with fisheries

Operational

In the late 1950s, K. Norris observed several vaquitas near San Felipe, and the captain of the trawler on which he was travelling told of having 'netted' vaquitas while fishing with gill nets

for totoaba and while trawling for shrimp (Norris & Prescott, 1961). Many years later, Norris (1992) recalled that entanglement occurred ‘often’, and that both the shrimp trawl fishery and the large-mesh gillnet fishery for sharks and totoaba ‘kill[ed] their share of vaquitas’. Unfortunately, no record of any sort was kept or obtained by Mexican fishery authorities and scientists, so it is impossible to estimate the scale of catches in those days.

From around the mid-1930s (Brownell, 1982) to the mid-1970s (Flanagan & Hendrickson, 1976), the most important fishery in terms of vaquita by-catch was the commercial gillnet fishery for totoaba (closed in 1975, see below). Most authors who have considered the issue in detail have reached the same conclusion, starting with Norris & McFarland (1958) and continuing through more recent studies (e.g. Findley & Vidal, 1985; Robles, Vidal & Findley, 1987; Vidal, Van Waerebeek & Findley, 1994; Vidal, 1995). Fleischer (1994, 1996) is the most noteworthy exception to this conventional opinion. Fleischer (1996) reported a vaquita bycatch rate of 0.0058/set for 682 observed sets in an experimental totoaba gillnet fishery between 1983 and 1993, and that no vaquitas at all were caught in 632 sets ‘examined directly’ in 1993 (315 and 317, respectively, in the two main fishing ports). His overall conclusion was that by-catch in fisheries was not necessarily a major threat to the vaquita (see below).

Using Fleischer’s data on vaquita bycatch rate together with his data on fishing effort and yield (Fleischer, 1994), T. Gerrodette (in Rojas-Bracho & Taylor, 1999) estimated the bycatch rate in the totoaba experimental fishery at 58 vaquitas/year – a significantly high number. However, a closer examination of the data now available on vaquita mortality in the experimental totoaba fishery leads us to conclude that 58 porpoises/year may be a negatively biased estimate. Vidal (1995; his appendix table 2) listed 77 vaquitas definitely known to have been bycaught in totoaba gill nets during the period of the experimental fishery, 1983–93 (Fig. 4). These are only the animals for which reliable evidence could be obtained via sporadic and incomplete monitoring. It has proven impossible to determine how or why Fleischer (1994) reported only four vaquitas taken in the experimental fishery over the entire period from 1983 to 1993; in contrast, Robles *et al.* (1987) reported 3.5 times that number (14) taken in the same fishery in one area (near El Golfo de Santa Clara) during the months of March and May 1985 and February 1986. Seven of those 14 specimens were included in a sample of 13



Fig. 4. Five vaquita calves awaiting necropsy at the ITESM-Guaymas laboratory. The calves were killed in gill nets set for totoaba, near El Golfo de Santa Clara, March–April 1991. Photo by Omar Vidal.

individuals used to describe the external morphology and pigmentation of the vaquita (Brownell *et al.*, 1987).

Given what was known already by the 1980s concerning the vaquita's endangered status and its susceptibility to entanglement in totoaba gill nets (and that is without considering the extreme depletion of the totoaba itself), it seems incredible that an 'experimental' fishery was allowed to proceed. Yet even recently, when the vaquita's vulnerability is much better documented, serious consideration has been given to requests to re-evaluate totoaba biomass with a view to reopening the fishery. Clearly, any resumption of fishing for totoaba with gill nets, whether for stock assessment or for commercial purposes, would be potentially devastating to vaquita conservation in the absence of an effective bycatch mitigation component.

The artisanal gillnet fisheries in the northern Gulf generally involve the use of pangas, which are (mainly) fibreglass, outboard-powered boats 6–8 m long crewed by two or three local men (Vidal *et al.*, 1994). The fish are landed fresh and are immediately iced. Much of the market is domestic, but some products from totoaba (illegal but sometimes exported under a different name), as well as from curvina *Cynoscion othonopterus*, sharks (including *Carcharhinus* spp., *Sphyrna* spp., *Rhizoprionodon* spp. and *Mustelus* spp.), skates and rays (including *Myliobatis* spp., *Rhinobatus* spp., *Dasyatis brevis*, *Mobula* spp.), and especially fresh-frozen shrimp, are exported to the United States. Standard mesh sizes for the monofilament nylon nets (locally known as *chinchorros de línea*) are approximately: 70 mm (shrimps), 85 mm (mackerels, curvinas, small sharks), 100–120 mm (chano *Micropogonias megalops*), 100–150 mm (large sharks and rays) and 200–305 mm (totoaba) (Vidal *et al.*, 1994, 1999; D'Agrosa, Vidal & Graham, 1995). As is true for many artisanal fisheries throughout the world, those in the northern Gulf are highly dynamic, poorly documented and difficult to manage (Cudney & Turk Boyer, 1998). Since closure of the totoaba fishery in 1975, some illegal and 'experimental' fishing for that species continued at least into the mid-1990s (Vidal *et al.*, 1994, 1999). The gillnet fisheries for sharks and rays grew rapidly, with no controls, from the early 1940s to mid-1990s (Vidal *et al.*, 1994); recent reports from fishermen indicate that large sharks are now scarce in the region. Directed fisheries for mackerels (sierra *Scomberomorus sierra*; also *S. concolor*), chano and small sharks started in the early 1990s. Although the fishery for curvinas had started with hook and line in the 1940s and crashed in the early 1960s for some 30 years, it restarted in 1993 (Cudney & Turk Boyer, 1998) and remains the most important finfish fishery in the region in terms of wet weight landed and monetary value. The high-value shrimp fishery in the northern Gulf includes a large commercial trawling fleet as well as the pangas that fish with gill nets. While the trawl component has a long history, gillnetting for shrimp from pangas began only in the 1980s, after which it grew rapidly (Cudney & Turk Boyer, 1998; but see below).

Some level of vaquita by-catch is known to occur in most, if not all, types of gill nets fished in the northern Gulf. Vidal (1995) stated that at least 128 vaquitas had been killed in fishing gear between early March 1985 and early February 1992: 65% in the totoaba fishery (nets with mesh sizes of 20–30.5 cm), 28% in the shark and ray fishery (10–15-cm mesh nets), and 7% in the mackerel (including sierra) fishery (8.5-cm mesh nets) or in shrimp trawls. He added that 128 'should be considered a minimum, since the monitoring effort was non-continuous (except for 1985 and 1990–91) and highly localised to the activities of fishermen from just one fishing town (the smallest, El Golfo de Santa Clara)'. After 1992, D'Agrosa *et al.* (1995) documented 14 catches by El Golfo de Santa Clara fishermen in 1993–94: five in chano gill nets, four in shrimp gill nets, two in shark gill nets, one in a mackerel gill net, one in a gill net set for either chano or sharks, and one in a commercial shrimp trawl. They noted that although most of the porpoises had been taken in nets set on the bottom, some had been

taken in driftnets. The question remains open as to whether trawl nets actually catch live vaquitas or instead occasionally pick up carcasses that have fallen out of gill nets. However, there is no reason to believe that vaquitas would be any less susceptible than other phocoenids to capture in trawls, and there is substantial evidence of such capture for other phocoenids (Fertl & Leatherwood, 1997).

The only properly designed study for estimating vaquita by-catch to date is that by D'Agrosa, Lennert-Cody & Vidal (2000), who monitored fishing effort and incidental catch by El Golfo fishermen from January 1993 to January 1995 using two basic methods (see D'Agrosa *et al.*, 1995): (i) placing observers on-board a sample of pangas; and (ii) conducting interviews with fishermen as they returned to the beach from fishing trips. Two alternative estimates of annual vaquita mortality were produced: 84 (95% CI 14–155) using only the data collected by observers, and 39 (95% CI 14–93) using the combined data from observers and fisherman interviews (D'Agrosa *et al.*, 2000). Crude extrapolations were also considered on the assumption that pangas based in San Felipe experienced similar bycatch rates; the highest of these was approximately 168 vaquitas/year for El Golfo and San Felipe combined. D'Agrosa *et al.* (2000) concluded that the estimate of 39 vaquitas/year was 'the most reasonable because it is based on the largest sample size but does not involve extrapolation to fishing ports for which no mortality-rate data were available'.

Table 3 shows fishery landings in El Golfo de Santa Clara from 1987 to 2004. It is difficult to say from these data what a 'typical' year might look like, but it is instructive, for example, to compare the landings in 1993, the year of D'Agrosa *et al.*'s (2000) study, with those in the immediately preceding and succeeding years. It is clear that the artisanal shrimp fishery, which is economically the highest-value fishery in the region, was in a serious slump during the study period, and also that the chano fishery was very strong at that time. According to McGuire & Valdez-Gardea (1997), small-boat fishermen in the northern Gulf began to exploit chano heavily in 1992. The massive quantities of the fish gillnetted in 1992 were in response to an experimental effort by a Korean processor to supply the Asian market. These authors concluded that the vaquita mortality figures reported in the studies by Vidal and D'Agrosa 'may represent an aberrant phenomenon, driven by a marketing experiment and an adaptive response by economically depressed inshore fishermen'. However, landing statistics (see Table 3) indicate that from the early 1980s, massive quantities of chano were being gillnetted in El Golfo de Santa Clara, even higher than those reported in 1992. The two fisheries (shrimp and chano) accounted for most of the observed and estimated mortality reported by D'Agrosa *et al.* (2000). Further analyses of fishery dynamics in the northern Gulf and their implications for vaquita by-catch are clearly desirable.

Ecological

The stomach contents from the few tens of vaquitas sampled to date indicate that they feed primarily on a variety (>20 species) of small demersal or benthic teleosts and squids (Findley, Nava & Torre, 1995; Pérez-Cortés, 1996; Vidal *et al.*, 1999). There is no suggestion that ecological competition between fisheries and vaquitas is a significant problem, although a few of the vaquita's prey species (e.g. *Cynoscion resticulatus*, *Lepophidium porates* and *Lolliguncula panamensis*) have been taken as by-catch in trawl nets (Nava Romo, 1994; Findley *et al.*, 1995; Pérez-Cortés, 1996).

Large sharks and killer whales *Orcinus orca* are potential predators of vaquitas. A number of reports from fishermen have described stomachs of sharks containing whole vaquitas or parts of vaquitas, but it was not possible to confirm that the porpoises had been taken in a free-swimming state rather than scavenged from gill nets (Vidal *et al.*, 1999). As indicated

Table 3. Fishery landings (kg/live weight) at El Golfo de Santa Clara, 1987–2004. Source: Headquarters of the Biosphere Reserve. Notes: The Industrial Shrimp Fishery fleet was sold in 1997, and there have been no landings since that year. No reliable data were obtained for sharks, guitarra and manta for the period 1998–2004, and the 2003–04 data for guitarra could include a proportion of manta. 2005 landings data were not yet available at the time of writing

| Fishery/year | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 |
|-------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Industrial shrimp | 221 446 | 121 942 | 77 930 | 35 355 | 68 082 | 46 897 | 12 067 | 263 442 | 246 285 |
| Fishery | | | | | | | | | |
| Artisanal shrimp | 280 592 | 295 067 | 193 958 | 10 803 | 0 | 0 | 3162 | 11 317 | 132 280 |
| Fishery | | | | | | | | | |
| Sharks | 196 295 | 288 695 | 139 193 | 109 325 | 43 149 | 56 160 | 143 992 | 94 293 | 35 693 |
| Chano | 88 | 0 | 3 300 | 0 | 0 | 644 959 | 1 138 035 | 1 245 655 | 581 964 |
| Guitarra | 0 | 0 | 1 500 | 375 | 5 136 | 130 | 6 871 | 3 348 | 5 975 |
| Manta | 1 070 | 3 593 | 1 800 | 1 355 | 3 488 | 2 388 | 7 056 | 10 440 | 3 951 |
| Sierra | 47 134 | 79 688 | 171 265 | 44 206 | 111 697 | 59 713 | 131 399 | 315 988 | 226 716 |
| Totals | 746 625 | 788 985 | 588 946 | 201 419 | 163 538 | 810 247 | 1 442 582 | 1 944 483 | 1 232 864 |
| Fishery/year | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 |
| Industrial shrimp | 113 600 | 13 178 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Fishery | | | | | | | | | |
| Artisanal shrimp | 155 115 | 128 993 | 320 000 | 315 000 | 180 000 | 205 000 | 190 000 | 295 000 | 206 000 |
| Fishery | | | | | | | | | |
| Sharks | 73 680 | 83 653 | | | | | | | |
| Chano | 897 966 | 689 942 | 950 000 | 980 000 | 300 000 | 400 000 | 390 000 | 469 000 | 1 000 000 |
| Guitarra | 9 837 | 1 230 | | | | | | 16 828 | 9 871 |
| Manta | 67 455 | 15 303 | | | | | | | |
| Sierra | 333 810 | 451 480 | 510 000 | 600 000 | 605 000 | 500 000 | 300 000 | 517 000 | 63 600 |
| Totals | 1 651 463 | 1 383 779 | 1 780 000 | 1 895 000 | 1 085 000 | 1 105 000 | 880 000 | 1 297 828 | 1 851 871 |

above, populations of large sharks in the northern Gulf have themselves been subjected to heavy fishing pressure for more than half a century, and both landings (e.g. Table 3) and informal reports from fishermen suggest that their numbers have been seriously reduced.

The question has been raised of whether trawling has deleterious direct or indirect effects on the prey base of vaquitas. A panel of experts (Norse *et al.*, 2004) stated in an open letter tabled at the 2004 meeting of the International Committee for the Recovery of the Vaquita (CIRVA; see later) that ‘the overwhelming majority of scientific studies find that trawling causes significant effects on seafloor ecosystems [and] there is . . . no reason to believe that the results would be any different in the Gulf of California . . .’. We are aware of only two studies dealing explicitly with the impacts of shrimp trawling in the northern Gulf. The first (Nava Romo, 1994) concluded that trawling alters benthic-demersal communities by changing structure and reducing biodiversity. From the perspective of fisheries, it reduces the captured biomass and mean weights of captured organisms. A different study (Pérez-Mellado & Findley, 1985) proposed that chronically trawled areas, such as the Upper Gulf, can suffer hypoxia (< 0.2 mL/L dissolved oxygen), including inclusive anoxia. This condition obviously would lessen the suitability of the sea floor as habitat for most benthic species.

The net effect of trawling on vaquitas in the northern Gulf is difficult to assess. Unquestionably, demersal trawling has physical impacts on the sea bottom, with associated effects on benthic communities wherever it is practised. There is a worldwide scientific consensus that bottom trawls cause more damage to high-relief, structurally complex habitats than to even, soft-bottom, sandy substrates such as those that dominate the northern Gulf (MCBI, 2002). The potential disturbance to vaquitas as they respond to the approach of trawlers also needs to be considered. Particularly given the intensity of trawling and the extremely restricted distribution of vaquitas, such disturbance could have important effects on the animals’ foraging, reproductive and aggregating behaviour (Jaramillo-Legorreta *et al.*, 1999; Rojas-Bracho, Jaramillo-Legorreta & Gerrodette, 2002).

Other risk factors

Consistent with the findings of various international panels that had reviewed the vaquita’s conservation status previously (e.g. IWC, 1991a,b,c, 1995, 1996; Vidal *et al.*, 1999; see below), Rojas-Bracho & Taylor (1999) concluded that incidental mortality in fisheries was ‘the greatest immediate risk for vaquitas’. In addition, they identified and evaluated four other potential risk factors: (i) indirect effects of fishing on vaquita prey populations (see above); (ii) pollution by organochlorides, especially hydrocarbon pesticides used for agriculture in the Mexicali basin bordering the northern Gulf and upstream in the Colorado River basin of the United States; (iii) habitat alteration caused by reduced flow from the Colorado River as a result of dam construction in the United States; and (iv) deleterious effects of inbreeding. They summarized their conclusions regarding those potential risk factors as follows:

The secondary effects of fishing in the Northern Gulf, such as direct and indirect effects of bycatch on prey species and alterations of the benthic habitat by repeated and intense trawling, are unknown and of concern. However, it is likely that any management actions taken to reduce direct kills of vaquitas by fishing activities will also affect these potential indirect threats to the prey and habitat quality of vaquitas. Pollution appears not to be a risk. Reduction of the flow of the Colorado River does not appear to have sufficiently reduced current productivity to pose a short-term risk to vaquitas. Inbreeding is likely to be a factor in vaquita biology but there is no evidence that inbreeding depression (causing a reduction in the population growth rate) should currently be a risk factor. There is no basis for

considering vaquitas doomed because of lack of genetic variability. (Rojas-Bracho & Taylor, 1999; p. 985)

With regard to numbers i and iii in the above list, it is important to maintain a precautionary view. The ecosystem of the northern Gulf has experienced large-scale stresses from flow-control and flow-reduction of the Colorado River and from many decades of intensive shrimp trawling. There is no reason to believe that these stresses have improved habitat conditions for the vaquita. However, it must also be acknowledged that there is no evidence to suggest that food shortages are affecting the reproductive success or increasing the mortality of vaquitas. Bycaught and stranded specimens examined to date have shown no signs of emaciation, and mothers with apparently healthy calves are regularly observed during surveys, indicating that reproduction is occurring in the population. Emphasis on the urgent need to reduce the incidental mortality of vaquitas in fishing gear does not imply that habitat degradation, acoustic disturbance associated with trawlers, and large-scale ecosystem-level perturbations should be dismissed as unimportant. Rather, it mainly reflects a difference in documentation and timescale. Bycatch reduction is the clearest (i.e. well documented) and immediate concern, while the others are less well characterized and longer term in nature.

CONSERVATION AND RECOVERY EFFORTS

In this section, we summarize not only actions taken towards vaquita conservation and recovery, but also the state of awareness about the species and expressions of concern for its threatened status in different forums at different times, starting in the 1970s (Table 4).

International perspectives

International Whaling Commission

The International Whaling Commission (IWC) and its Scientific Committee have provided an important forum for exchange of information about the vaquita and for reviews conducted collaboratively by Mexican and international scientists. In fact, the IWC Scientific Committee is the only truly international expert body that meets regularly to consider, *inter alia*, the status and conservation problems of small cetaceans and develop advice that can help in management-relevant research on small cetaceans.

Considering the high profile of the vaquita during the past decade in the activities of the Scientific Committee's Sub-committee on Small Cetaceans (hereafter 'the Sub-committee'), we were surprised to discover that until 1983 it had been mentioned only in the report of that Sub-committee's inaugural meeting in 1974 (IWC, 1975). This consisted of a short summary of the vaquita's biology, exploitation and status (pp. 938–939) and a guess that the annual incidental catch in finfish fisheries was about five animals (p. 956). Nor was the vaquita even mentioned prior to 1994 in Mexico's annual IWC progress reports (Anonymous, 1982 *et seq.*; Fleischer & Pérez-Cortés, 1995). In 1983, the Sub-committee conducted a review of the vaquita's status with only a handful of source documents available for examination (Villa-Ramírez, 1976; Wells, Würsig & Norris, 1981; Brownell, 1983). It concluded that although a proper assessment was not possible, 'since the fishery for totoaba . . . ceased, *Phocoena sinus* is no longer at risk from the extensive gillnetting for that species' (IWC, 1984; p. 145). It was agreed that a good vaquita abundance estimate was needed, and that a survey of fisheries should be conducted 'to see if the animal is still being taken incidentally'.

The first working document on the vaquita was submitted to the Scientific Committee in 1990 at its annual meeting in Noordwijkerhout, The Netherlands (Vidal, 1990). After reviewing that paper, the Sub-committee (IWC, 1991c; p. 182) concluded: 'Considering the low

Table 4. Chronology of conservation and management actions on behalf of the vaquita and its habitat

| | |
|------|--|
| 1942 | Peak of totoaba fishery (presumably also incidental killing of vaquitas): 2261 tons of meat landed (Flanagan & Hendrickson, 1976). |
| 1955 | Refuge for all species from the Delta of the Colorado River to the south between Bahía Ometepec in Baja California and El Golfo de Santa Clara in Sonora. |
| 1975 | Ban on totoaba fishing due to overexploitation (only 59 tons of meat landed). IWC Scientific Committee first mentions the biology of vaquita and concerns about incidental mortality in totoaba fishery. |
| 1978 | Villa-Ramírez includes vaquita in his list of endangered and rare wildlife species of Mexico (Villa-Ramírez, 1978). Classified as Vulnerable in IUCN Red Data Book (IUCN, 1978). |
| 1979 | First proposal for a cetacean sanctuary in the Gulf of California to protect, <i>inter alia</i> , the vaquita. Listed in appendix I (species fully protected) of CITES. |
| 1985 | Listed as Endangered under US Endangered Species Act. |
| 1990 | IUCN changes status from Vulnerable to Endangered. |
| 1992 | Technical Committee for the Preservation of Totoaba and Vaquita created by Mexico's Ministry of Fisheries. |
| 1993 | Totoaba gill nets banned (mesh size 12 inches and greater). Decree creating Biosphere Reserve of the Upper Gulf of California and Colorado River Delta is published. Vaquita recovery plan is developed by Mexico with support from Marine Mammal Commission (Villa-Ramírez, 1993). Mexican standard NOM -012-PESC-1993 to protect vaquita and totoaba in the Gulf of California is published. |
| 1994 | Publication of Mexican Standard NOM-059-ECOL- 1994 – Mexico's first official list of vulnerable and endangered species. Vaquita is listed as Endangered. |
| 1995 | Publication of the Management Plan for the Biosphere Reserve of the Upper Gulf of California and Colorado River Delta. |
| 1996 | Listed by IUCN as Critically Endangered. |
| 1998 | Vaquita is included in SEMARNAP's Programme of Prioritized Species (PREP). |
| 2000 | National Fisheries Chart is published and establishes that vaquita by-catch should be zero. |
| 2002 | WWF-Gulf of California establishes the Joint Initiative with other non-governmental organizations and CIRVA to promote implementation of CIRVA's recommendations and develop an economic and legal framework. |
| 2002 | SEMARNAT, Mexico's Ministry of Environment, constitutes the National Technical Advisory Subcommittee for the Conservation and Recovery of Vaquita and its Habitat (PREP-DGVS/ SEMARNAT) to pursue recommendations of CIRVA and the Joint Initiative. |
| 2003 | Mexican Standard NOM EM 032 ECOL 2003 is published to protect the biodiversity of the Biosphere Reserve of the Upper Gulf of California (SEMARNAT). Coalition for the Upper Gulf is formed by 17 non-governmental organizations. Biosphere Reserve Management Programme completes its first 10-year revision and update (yet to be published). San Felipe, Baja California, proclaims itself <i>Home of the Vaquita Marina</i> and agreement is signed with the town Council to support vaquita conservation. |
| 2005 | Natural Resources Defense Council (NRDC) explains in a letter to Ocean Garden (the primary exporter of Mexican shrimp and other seafood products) that the company should use its leverage to discourage unsustainable fishing practices that threaten the vaquita. Ocean Garden and NRDC sign an agreement with fishermen to work to prevent the vaquita's extinction and promote conservation and sustainable fisheries. The company takes an active role in forging the agreement while Noroeste Sustentable, a local non-governmental organization, acts as facilitator. SEMARNAT's Programme for the Protection of the Vaquita is published in the Federal Register (29 December) and \$1 million is transferred to state governments of Baja California and Sonora to implement the programme. The vaquita refuge is decreed. |

IUCN, International Union for Conservation of Nature and Natural Resources; IWC, International Whaling Commission.

population size, the relatively high rate of incidental take in fisheries, the difficulties and the costs of implementing and enforcing long-term conservation measures quickly, the possible effects of pollution, and the present lack of alternative means for fishermen to make a living, the vaquita is in immediate danger of extinction'. The full Scientific Committee (IWC, 1991b; p. 79) then recommended that as the 'highest priority', 'further action be taken to stop the major cause of entanglement by fully enforcing the closure of the totoaba fishery and reconsidering the issuance of permits for experimental totoaba fishing, . . . immediate action be taken to stop the illegal shipment of totoaba (also an endangered species) across the US border, and . . . a management plan for the long-term protection of this species and its habitat be developed and implemented'. These recommendations, along with the Scientific Committee's recommendation that IUCN list the vaquita as Endangered in the Red List (see earlier), were carried forward by the Commission, also as the 'highest priority' (IWC, 1991a; pp. 37–38).

With the presentation in 1994 of important new data on the vaquita by Mexican and American scientists (Gerrodette *et al.*, 1995; IWC, 1995; Hohn *et al.*, 1996; Barlow *et al.*, 1997), the IWC became a focal outlet and forum for consideration of vaquita research and conservation. As noted in the Mexico progress report that year (Fleischer & Pérez Cortés, 1995): 'Priority was given to projects on the distribution, biology and management of the vaquita . . .'. The Scientific Committee formally recommended (IWC, 1995; p. 87) that: (i) fishery monitoring be conducted to obtain an estimate of total annual incidental mortality; (ii) further surveys of abundance and distribution be undertaken, covering not only the areas of known concentration, but also 'shallow waters of the uppermost Gulf of California'; and (3) 'immediate action be continued to eliminate incidental catches in the area'.

According to the national progress report submitted in 1995 (Fleischer, 1996; p. 262), the Mexican government had taken action to reduce the by-catch 'by enforcing the closure of all commercial fisheries in the reserve zone created for this species in the upper Gulf of California'. All 'totoaba-type nets' reportedly were confiscated, and no more permits were granted for 'experimental' totoaba fishing. However, these official statements did not reflect the true situation in the region. Commercial fishing with a variety of gill nets and trawl nets continued without interruption both inside and outside the Biosphere Reserve. The nets that were banned were gill nets of 10-inch or larger mesh size. To the extent that this measure was enforced, it may have reduced the vaquita bycatch rate to some extent. However, significant numbers of both vaquitas and totoabas continued to be taken in smaller-mesh gill nets as well as in totoaba nets deployed illegally (Cisneros-Mata *et al.*, 1995; D'Agrosa *et al.*, 1995; Almeida Paz *et al.*, 1997).

The progress report (Fleischer, 1996; p. 263) also concluded from the results of experimental fishing and catch monitoring that fisheries were not solely responsible for the declines of vaquitas and totoabas. Instead, environmental change from reduced freshwater flow of the Colorado River was cited as a 'major cause' of the declines. Thus, by the mid-1990s, two contrasting and conflicting views concerning the root causes of the vaquita's current scarcity had been articulated – one that by-catch in totoaba (and other large-mesh) gill nets was principally to blame (the bycatch hypothesis), and the other that damming and abstraction of water from the Colorado River drainage system in the United States was the chief culprit (the environmental hypothesis).

The IWC was critical of the assertions in Mexico's progress report. The Sub-committee on Small Cetaceans (IWC, 1996; p. 173) explicitly rejected the report's reasoning concerning causation, noting that no evidence had been presented to support the environmental hypothesis and that 'the current incidental mortality is the cause for concern'. The main Committee

(IWC, 1996; p. 91) noted its previous expression of 'deep concern' over the status of the vaquita and its recommendation that action be taken to eliminate incidental mortality. Further noting that no information had been presented in the 1995 progress report concerning bycatch monitoring in 1994 or concerning action taken to reduce by-catch, it reiterated 'deep concern' about the vaquita's status and 'encouraged' Mexico to respond to the previous year's detailed recommendations.

From the mid-1990s onwards, the conflict in tone between the official Mexican position and the advisory role of the IWC Scientific Committee underwent a major shift, and this is best explained in the context of the International Committee for the Recovery of the Vaquita (see below).

IUCN (World Conservation Union)

IUCN maintains its Red List of Threatened Animals (<http://www.redlist.org>) as a way of drawing attention to those species and populations most in need of protection and other measures to prevent extinction and facilitate recovery. The vaquita was listed as Vulnerable in 1978, Endangered in 1990, and Critically Endangered in 1996. The most recent listing was based on criterion C2b (1994 Categories and Criteria), requiring that there be fewer than 250 mature individuals in the total population, that the number of mature individuals is declining, and that all individuals are in a single subpopulation (Baillie & Groombridge, 1996). With revised Categories and Criteria having come into force in 2001, the Red List Programme now requires that all species and listed populations be assessed against those and also that full supporting documentation accompany proposed listings. The authors, together with B.L. Taylor, recently proposed continuation of the vaquita's Critically Endangered status based on criteria A4d and C2a(ii). The first of these (A4d) assumes that the total population is reduced by more than 80% over three generations (*c.* 30 years), including both the past and the future, and that the main cause of that reduction has not ceased. The second [C2a(ii)] assumes that there are fewer than 250 mature individuals in the living population, that a continuing decline in that number can be projected and inferred, and that all mature individuals are in a single population.

Besides highlighting the vaquita's plight through its Red List, IUCN plays a role in vaquita conservation through its Cetacean Specialist Group (CSG), a component of the IUCN Species Survival Commission. The CSG has long regarded the vaquita as a global conservation priority (Perrin, 1988; Reeves & Leatherwood, 1994; Reeves *et al.*, 2003), and has reinforced and supplemented the IWC Scientific Committee as a forum for discussion and a conduit for advice to decision-makers. Also, CSG members have been intimately involved in the work of CIRVA from the time of its conception in 1996 (see below).

United States Marine Mammal Commission

Since its formation in 1973 as a US federal government agency, the Marine Mammal Commission (MMC) has focused most of its attention on marine mammal populations inhabiting US waters. It has, however, invested some financial and other resources in vaquita science and conservation over the past three decades. In 1976, the Commission initiated a proposal for the vaquita (under the now-antiquated name 'Gulf of California harbour porpoise') to be classified as Threatened on the US Endangered Species List (MMC, 1977). As a part of that initiative, the Commission sponsored field studies in 1976 (Villa-Ramírez, 1976) and 1979 (Wells *et al.*, 1981), and engaged in bilateral discussions on the vaquita's status with Mexican scientists (MMC, 1978). At least partly in response to the Commission-funded research, as well as the advice conferred directly by the Commission, the National Marine Fisheries

Service agreed in 1985 to list the vaquita not as 'threatened' but as 'endangered' (MMC, 1986).

Beginning in 2001, the Commission provided financial support for development of acoustic methods to detect and monitor the behaviour of vaquitas (MMC, 2003) and in December 2002, a letter was sent by the Commission to the US Department of State, calling attention to the political volatility surrounding the Mexican Environment Minister's announced ban on large-mesh gillnetting and shrimp trawling in the Biosphere Reserve (see the *Biosphere Reserve* section, below) (MMC, 2003). The Commission also co-sponsored and participated in the third meeting of the International Committee for the Recovery of the Vaquita in 2004 (see below). From the early 1970s to the present, the Commission's annual reports to Congress have served the purpose of providing a brief but consistent record of developments in vaquita awareness, science and conservation, and of actions taken by the Commission in the vaquita's interest.

International Committee for the Recovery of the Vaquita (CIRVA)

By 1996, changes were taking place in the Mexican government in response to pressure from non-governmental organizations (e.g. Conservation International) and the IWC (see above). Restructuring by the newly elected federal government combined two ministries and certain offices in additional ministries to form the Ministry of Environment, Natural Resources and Fisheries (SEMARNAT). This was an important development since Fisheries became a junior ministry (instead of a full ministry) and was thus largely subordinated within the broader context of environmental conservation and management. Also in that year, the new President of the National Institute of Fisheries (INP) changed the institute's policies in the direction of a more conservation-orientated approach to marine resource management.

The more receptive attitude in government made it possible to reopen discussion of the status of the vaquita with INP, the main authority for fisheries research and management. Traditionally, the position of the institute and of the Federal Government had been that no proof existed to confirm that the vaquita was endangered. Moreover, the institute's position had been that even if the species was in danger, the principal cause was the lack of freshwater input to the Gulf as a result of the damming of the Colorado River (the environmental hypothesis). During a meeting in June 1996, the President of INP agreed to create a committee to analyse the vaquita's situation and to initiate a research programme on the species. Despite strong opposition from several government officials inside and outside the Fisheries Institute, Mexico presented this proposal at the 48th meeting of the IWC (IWC, 1997).

After the 1996 IWC meeting, two different points of view emerged regarding membership in such a committee: (i) that it should consist only of Mexican scientists and managers, or (ii) that it should be international. Those who supported the first of these positions reasoned that the vaquita is a 'Mexican' species, and that opening its conservation and management to international scrutiny and advice could result in a situation similar to that generated by the tuna-dolphin controversy (e.g. consumer boycotts). However, advocates of the second position pointed out that some of the needed scientific expertise was available only outside Mexico, and that the transparency implicit in a more inclusive process was bound to add to the group's credibility and effectiveness. After intense discussions, the 'internationalist' view prevailed, and it was agreed that the committee should include foreign as well as Mexican experts.

The International Committee for the Recovery of the Vaquita (Comité Internacional para la Recuperación de la Vaquita, or CIRVA) was established in 1996 as a standing committee with a mandate to develop, oversee and promote a recovery plan for the vaquita. It was

expected from the outset that the plan would be a step-by-step manual for use by current and future agencies responsible for vaquita conservation. Importantly, the committee was expected to consider not only scientific issues, but also socio-economic aspects, such as the implications for local communities of restrictions on fishing to reduce vaquita by-catch. CIRVA meets on an *ad hoc* basis, and its composition varies according to the need for expertise of particular kinds on different occasions.

At its first meeting (Ensenada, 24–27 January 1997), the Committee concluded that given the precarious status of the vaquita, a reasonable short-term goal of the recovery plan would be simply to observe an increasing trend in the vaquita population. Consideration of what might constitute a ‘safe’ abundance level could be deferred until some future time after that short-term goal has been reached. It was emphasized that because of the vaquita’s life-history characteristics, recovery would not be rapid even if the recovery plan were implemented fully and immediately. Because of the great uncertainty surrounding the risk factors, monitoring abundance and human-caused mortality seemed the best way to measure the success of recovery efforts. Participants acknowledged that reaching even the fairly simple short-term goal of an index showing positive population growth would be difficult (it has turned out to be even more difficult than expected).

The Committee agreed that the following elements should be included in the recovery plan:

- Known and potential risk factors affecting vaquitas should be identified and ranked in importance. Conservation actions to address the various risks should be discussed.
- The adequacy of current information on abundance and distribution should be discussed with the goal of recommending strategies for future surveys, particularly considering the problems posed by shallow waters inaccessible to large boats.
- Research should be identified that would yield data needed to design conservation actions, e.g. studies of vaquita movements and habitat use.

The main conclusions were as follows:

- Reduced flow of the Colorado River seems not to be an immediate (i.e. short-term) threat to the vaquita, based on three factors: (i) nutrient concentrations and rates of primary productivity reportedly are high in the northern Gulf of California; (ii) vaquitas have a fairly diverse diet and do not appear to depend exclusively on one or a few prey species; and (iii) none of the vaquita specimens examined thus far has shown signs of starvation or poor nutritional status.
- In the long term, changes in the vaquita’s environment due to the reduced flow of the Colorado River (e.g. nutrient decline) are matters of concern and should be investigated.
- Incidental mortality in gill nets represents the greatest immediate threat to the survival of the species (Fig. 5).
- Vaquita abundance is likely in the hundreds and probably the low hundreds.
- A more reliable and precise abundance estimate is required as soon as possible.

At its second meeting (Ensenada, 7–11 February 1999), after reviewing the abundance estimate from the 1997 cruise ($n = 567$, $CV = 0.51$; 95% log-normal CI 177–1073), the Committee agreed that this was the best available estimate of the total vaquita population.

The meeting’s recommendations were as follows:

1. The by-catch of vaquitas must be reduced to zero as soon as possible.
2. The southern boundary of the Biosphere Reserve should be expanded to include all known habitat of the vaquita.
3. Gill nets and trawlers should be banned from the Biosphere Reserve, in the following sequence:

Stage One (to be completed by 1 January 2000)



Fig. 5. A sexually and physically mature female vaquita (148.2 cm, 44 kg) killed in a gill net set illegally for totoaba near El Golfo de Santa Clara, 2 February 2002. Photo by Christian Faesi; copyright Omar Vidal. Used with permission.

- (a) Eliminate large-mesh gill nets (6-inch stretched mesh or greater);
- (b) Cap the numbers of pangas at present levels; and
- (c) Restrict fishing activities to residents of San Felipe, El Golfo de Santa Clara and Puerto Peñasco.

Stage Two (to be completed by 1 January 2001)

- (a) Eliminate medium-mesh gill nets (i.e. all except *chinchorra de linea*).

Stage Three (to be completed by 1 January 2002)

- (a) Eliminate all gill nets and trawlers.

4. Effective enforcement of fishing regulations should begin immediately. The development of effective enforcement techniques should be given a high priority because all of the committee's recommendations depend on effective enforcement.

5. Acoustic surveys should start immediately to (i) monitor an index of abundance; and (ii) gather data on seasonal movements of vaquitas.

6. Research should start immediately to develop alternative gear types and fishing techniques to replace gill nets.

7. A programme should be developed to promote community involvement and public awareness of the importance of the Biosphere Reserve and the vaquita, stressing their relevance as part of Mexico's and the world's heritage. Public support is crucial.

8. Consideration should be given to compensating fishermen for lost income resulting from the gillnet ban.

9. Research should be conducted to better define critical habitat of the vaquita, using data collected during the 1997 abundance survey.

10. The international community and non-governmental organizations should be invited to join the government of Mexico and provide technical and financial assistance to implement the conservation measures described in the recovery plan.

At the third meeting (Ensenada, 18–24 January 2004), participants reiterated their grave concern about the vaquita's status and agreed that:

- The best available abundance estimate is from the 1997 survey: around 570 animals (95% CI 170–1070).

- Previously estimated bycatch mortality (D'Agrosa *et al.*, 2000) was clearly unsustainable.
- Since the time of D'Agrosa *et al.*'s study (1993–94), fishing effort (numbers of pangas) has at least doubled, and therefore, the rate of decline in the vaquita population has likely increased.
- The current (2004) abundance therefore is probably below the 1997 level.

The Committee recommended that, at a minimum, immediate action should be taken to prevent any net fishing within the core area of vaquita distribution. In noting that only a portion of the core area was contained within the Biosphere Reserve (see later; Fig. 2), participants emphasized the importance of finding mechanisms not only for eliminating net fishing in that part of the Reserve's buffer zone, but also for extending the net ban to a sizeable area outside the Reserve (e.g. establishment of a wildlife refuge). For details on this issue, see the sections below on 'Biosphere Reserve' and 'Recent developments with regard to the core area or "polygon"'. The results of the socio-economic session are reflected in the following section.

Progress on CIRVA recommendations

Important progress has been made on most of the 10 recommendations from the second CIRVA meeting. However, two of the more critical ones related to the ban on gill nets (items 6 and 8 in the above list) have lagged behind: the development of alternative gear or methods, and consideration of compensation and alternative livelihoods.

After several unsuccessful attempts at developing alternative fishing gear or methods, a serious effort funded by World Wildlife Fund – US was finally made in the summer of 2004 to test the feasibility of using traps (or pots) instead of gill nets to catch shrimp (Walsh *et al.*, 2004). The project involved the National Marine Mammal Programme (INE) in Ensenada and the Center for Sustainable Resources Marine Institute of Memorial University in St John's, Newfoundland. Both traps and gill nets were set at four relatively deep (24–31 m) and cool-water (19–23 °C) sites located well away from shore. Blue and brown shrimp *Panaeus stylirostris* and *P. californiensis* were captured in the gill nets, but no shrimp at all were captured in the traps. The gillnet catches proved that blue and brown shrimp were present in the area, so the failure of the baited traps to catch any shrimp was interpreted to mean that a different fishing strategy should be used in future trapping experiments.

An obvious drawback of the gear trials to date is that they have pertained only to the shrimp gillnet fishery and not to the gillnet fisheries for finfish. Of course, the very large-mesh gill nets for totoaba and large sharks are now illegal in the northern Gulf, and therefore, efforts to develop alternatives to them should not be a high priority. Also, in the case of curvina, the normal fishing method is encirclement with gill nets; no reports have been received of vaquita by-catch in this type of gillnet deployment. Nor has the presence of vaquitas ever been confirmed (either visually or acoustically) in the delta region where the curvina fishery is centred. Nonetheless, since the nets used to capture curvina are used at other seasons to target other finfish, at which time they are deployed in the normal manner (i.e. passively), it would be beneficial to develop alternative methods for catching curvina. Despite an agreement announced in August 2000 by the Fisheries Commission for El Golfo de Santa Clara indicating that gill nets with mesh sizes > 6 inches would no longer be used by fishermen from that community, there is no evidence that this or any other agreed measure for eliminating or reducing fishing effort with small- and medium-mesh gill nets has been implemented. Therefore, the search for alternative ways of catching commercially important finfish (e.g. chano and sierra), sharks and rays must continue (e.g. new trials of pots or traps,

longlines; see results of the first international 'Smart Gear' competition promoted by World Wildlife Fund – US; <http://www.smartgear.org>).

No specific implementation has occurred with respect to compensation of fishermen even though this is a crucial aspect of the overall recovery strategy. Conservation efforts in developing countries often fail because insufficient attention is paid to the social needs of local inhabitants. A delicate balance must be maintained between the protection of ecosystems or species and the well-being of the humans living in and near protected areas. Public and private efforts to protect vaquitas should include the active participation, and consider the particular needs, of the fishing communities in the northern Gulf.

The basic approach has involved a combination of short- and long-term strategies to avoid confrontations that would likely jeopardize conservation efforts. It has been assumed that sole reliance on fishery buy-outs, surveillance and monitoring of habitat, or complete closure of fisheries with no alternatives in place for resource users, would not work and could even be counterproductive. Recent unrest in one of the communities demonstrated the need to identify economic alternatives, jointly with the fishermen, before expecting them to modify their fishing patterns. An array of social and economic strategies will have to be implemented if there is to be any hope of making such changes attractive to fishermen.

Ideally, fishing communities would agree by consensus to abandon the use of nets that pose a threat to the vaquita. However, achieving such a consensus promises to be a very difficult task. CIRVA's recommendations include the elimination of trawling, a phase-out of gillnet fishing and enlargement of the Biosphere Reserve. Concerned about the willingness of stakeholders to support such drastic measures, the Intercultural Center for the Study of Deserts and Oceans (Turk-Boyer & Flores, 2001) developed a programme in 2001 to motivate small-scale fishermen and the general public to participate in the search for alternatives. This programme consisted of: (i) three workshops on 'Vaquita, Fishing and the Future' with small-scale fishermen in Puerto Peñasco (PP) and El Golfo de Santa Clara (EGS), Sonora, and San Felipe (SF), Baja California; (ii) publication of a newspaper, 'Voces del Mar y del Desierto'; and (iii) publication of a booklet on vaquitas and conservation issues in Spanish and English. These communication tools targeted fishermen, government officials, schools and the general public.

Based on those results and their previous work, Turk-Boyer & Flores (2001) concluded that fishermen wished to be involved in finding solutions to the vaquita bycatch problem. In general, fishermen said that they wanted better regulation and management of fisheries in the northern Gulf. The authors offered the following conclusions and recommendations:

- Immediate control (i.e. limitation) of entry into the fisheries and enforcement of existing regulations are essential.
- Given its importance to the local economy, the shrimp gillnet fishery will be the most difficult fishery to eliminate.
- Highest priorities should be given to the search for alternative shrimp-fishing methods and to the development of mechanisms to increase the market value of 'vaquita-safe' products.
- Support should be given to the two cooperatively managed sustainable fisheries that are emerging as regional models at Puerto Peñasco, both with participation of non-governmental organizations. One is a community-based initiative and the other is government-led.
- Tourism represents a viable and ongoing alternative to fishing, especially in the two larger communities (Puerto Peñasco and San Felipe).
- A growing regional 'ecotourism' association is intended to spur local efforts, but local communities need training and other kinds of support to develop their options.

- A comprehensive regional environmental education programme could provide training for fishermen and teachers, and would represent a long-term investment for the region.
- Each community's ability to respond to the various options is distinct, and local outreach persons are needed to maintain and coordinate involvement at the individual and community level.
- At El Golfo, in which no viable alternatives to fishing currently exist, careful study is needed to identify fishing zones and seasons where/when sustainable fishing might be conducted to benefit the local economy.
- At San Felipe, there is strong interest in participating in vaquita research. Therefore, observers should be placed on-board all boats, and fishermen should be trained to release vaquitas that are found in nets alive (an exceedingly rare event).
- San Felipe could probably benefit from education programmes and assistance in promoting vaquita conservation through tours or exhibits.

Bracamonte (2001) used social-accountability-matrix and multisector models to analyse the existing socio-economic structure and the implications of a change in economic policy at San Felipe, which is among the most important communities of the region in terms of size and economic influence. His goal was to improve understanding of the prevailing economic conditions in San Felipe and to predict the consequences for the local economy of a transformation in fishing activities, including their disappearance. He began by examining previous studies that had concentrated on specific aspects of the local economy. A social accountability matrix was then used to identify the main characteristics of the community's productive structure and to evaluate different economic scenarios and their effects on the local economy. For example, what would happen if a segment of the fishing sector were eliminated, or if all gillnetting were banned?

The analysis by Bracamonte (2001) showed that interesting opportunities for diversification exist and therefore that the San Felipe economy is not without alternatives to fishing. In the event of a severe cutback in fishing, the local economy would not be devastated. This means that in San Felipe at least, it should be possible to impose fishing regulations and introduce new fishing gear or methods in a staged or stepwise manner without causing major socio-economic dislocation.

Biosphere Reserve

Establishment of the Upper Gulf of California and Colorado River Delta Biosphere Reserve (hereafter termed 'the Reserve') in June 1993 was heralded as a major step towards protecting both the vaquita and the totoaba (IWC, 1997). The presidential decree was read in a ceremony attended by governors of the Mexican states of Baja California and Sonora and the US state of Arizona and by the US Secretary of the Interior. In his decree, President Salinas stated the intention of the government of Mexico to establish a central 'nuclear' zone in which all exploitative activities would be prohibited. Further, he envisioned a prohibition on shrimp trawling in both the core and buffer zones, i.e. north of a line traversing the northern Gulf from Puerto Peñasco to San Felipe. All gill nets with mesh sizes greater than 4 inches were also to be excluded from the Reserve's buffer zone. To offset the social and economic impacts of these measures, Salinas promised to support economic alternatives in the region, such as tourism, sport fishing and aquaculture.

The management programme for the Reserve was approved in 1995, calling for the preservation, sustainable use and conservation of biodiversity (SEMARNAP, 1995). Among the endangered species cited as intended beneficiaries of the reserve were the vaquita, totoaba,

desert pupfish *Cyprinodon macularius macularius*, Yuma clapper rail *Rallus longirostris yumanensis* and Delta silverside *Colpichthys hubbsi*. Among the commercially important species expected to benefit were the blue, brown and white shrimp *Penaeus vannamei*, and the yellowfin curvina *Cynoscion xanthulus* (SEMARNAP, 1995).

It was anticipated in 1993 that the funds (\$1 billion) for developing economic alternatives to gillnet fishing and trawling in the Reserve would come from the National Programme of Solidarity (Programa Nacional de Solidaridad, or PRONASOL) (McGuire & Valdéz-Gardea, 1997). For whatever reason, the funding and the development still have not materialized, and the Reserve has fallen far short of its potential as an instrument for vaquita conservation. It was reported at the second CIRVA meeting in 1999 that 700 pangas were actively fishing out of the three ports – El Golfo de Santa Clara, Puerto Peñasco and San Felipe. They were targeting 70 species of fishes, mollusks, crustaceans and echinoderms, approximately 40% of which species were being exported to markets in California, Japan and Korea. According to data from the Reserve's office files (José Campoy, personal communication, January 2006), some 1000 pangas still fish in the Reserve each year. Close to 450 commercial shrimp trawlers were also fishing in the Reserve's buffer zone each year until 2003, from which time only boats from the three northern Gulf communities have been allowed to operate there. Currently, about 162 vessels from the northern Gulf are allowed into the Biosphere Reserve (José Campoy, personal communication, January 2006). Relations between the panga fishermen and the shrimp trawling industry have been generally hostile, and violent confrontations have occurred. Another source of tension has come from Cucupah Indians, who fish in the northern part of the Reserve's buffer zone and enter the nuclear zone between February and April to fish for gulf curvina. They are perceived by the panga gillnetting fleet as having an unfair advantage in the competition for curvina.

Recent developments with regard to the core area or 'polygon'

Participants in the CIRVA meetings in 1997 and 1999 used the available survey data, both visual and acoustic, to identify a 'core area' of vaquita distribution – between Rocas Consag and Bahía de San Felipe, spanning a north–south distance of approximately 75 km. This core area encompasses approximately 2235 km², almost 40% of which is outside the Biosphere Reserve. The core area has been recognized for a considerable time as the highest priority for vaquita protection. In 2003, during the 10th anniversary review of the Reserve's management plan, it was proposed that an area ('the polygon') should be designated where productive activities would be allowed but only if they did not involve the use of gill nets or trawlers. Several counterproposals were presented to relevant government agencies during meetings with fishermen throughout the year. These were ultimately rejected because the proposed alternative polygons did not meet the conservation needs of the vaquita as recommended by CIRVA. They would have encompassed only about 3–20% of the core area. In fact, some of them covered deep waters (> 200 m), in which vaquitas have never even been observed or reported.

The report and recommendations from the third CIRVA meeting were presented to Mexican authorities in February 2004 and to the IWC Scientific Committee in June 2004. Although the Secretary of Agriculture and Fisheries agreed in early September 2004 to accept the polygon, none of the agencies proved willing, after lengthy negotiations, to implement any of the CIRVA recommendations. Finally, on 5 June 2005, President Vicente Fox announced the creation of a vaquita refuge. Although the state governments of Baja California and Sonora were unreceptive to Fox's announcement and refused to cooperate in imple-

menting the refuge, the federal Ministry of Agriculture and Fisheries and the Ministry of Environment proceeded to develop the concept of a polygon covering 1263.77 km². Of that area, 900.02 km² is inside the Reserve, representing somewhat less than 17% of the total marine surface area within the Reserve boundaries. To put it in a wider perspective, the polygon as proposed by the ministries would create a vaquita refuge occupying only 0.36% of the total surface area of the Gulf of California – hardly a large area in global terms. It must be said, however, that the polygon does incorporate a very large proportion of the vaquita's known range (see below).

The Programme for the Protection of Vaquita was published in the Mexican Federal Register on 29 December 2005. It called for the transfer of \$1 million to the state governments of Baja California and Sonora to support implementation. Besides establishment and enforcement of the polygon, the programme addressed some other CIRVA recommendations, e.g. those calling for development of economically productive alternatives to gillnet fishing, alternative fishing gear and methods, and environmental education and research programmes.

For the following reasons, we regard this officially declared programme as an important step towards vaquita conservation:

- It was the first measure taken by any Minister of Environment specifically to address the vaquita's need for protection against gillnet entanglement. As explained earlier, the actual design and configuration of the Biosphere Reserve may have benefited other threatened species but were ill-suited to the purpose of vaquita conservation.
- It explicitly acknowledged and attempted to implement recommendations of CIRVA and the Joint Initiative (a coalition of non-governmental organizations; Table 4).
- It redirected the focus of concern away from trawlers and towards the artisanal gillnet fleet, which is responsible for most vaquita mortality. Previously (from the early 2000s), the emphasis on trawlers and their supposed role in causing vaquita by-catch had made it impossible to establish a constructive dialogue with a major part of the fishing sector. The 2005 programme identified the artisanal fleet using gill nets as the main risk factor and included potential solutions involving social and economic approaches and participation by all stakeholders.
- The strategy embodied in the programme for dealing with the polygon issue avoided the difficulties that would come from reopening the Biosphere Reserve Decree to negotiation. Instead, it resorted to an entirely different legal instrument: the wildlife refuge. In this way, it managed to extend protection to at least a substantial part of the 40% of the vaquita population estimated to be outside the Reserve boundaries at any given time.

Although it may represent progress, this 2005 programme does not represent a complete or final solution to the vaquita bycatch problem. This would be true even if the programme were implemented and enforced immediately and with 100% effectiveness. The need would still exist for further bycatch reduction measures to allow the severely depleted vaquita population to recover to a point where it is no longer at risk of extinction. Shortcomings of the programme include the following:

- Design of the polygon. Although the Ministry had agreed in 2004 and early 2005 to implement the polygon proposed by CIRVA without change, the final design failed to grasp the underlying philosophy of the survey methodology (distance sampling for density and abundance estimation). Rather than recognizing that survey sighting positions represent moments in time ('snapshots') for highly mobile creatures, the ministry's published polygon was created simply by drawing lines to connect the sighting positions with no consideration given to encompassing a 'buffer' area around them.

- Difficulty of compliance and enforcement. The irregular shape and dimensions of the polygon will make it difficult for fishermen to locate their pangas in relation to its boundaries; on-board global positioning systems are not standard equipment in the artisanal gillnet fisheries. Agents responsible for enforcement will face the same challenge, and there is obvious potential for confrontations over whether a given net was deployed inside or outside the polygon.

The BioGem campaign

In 2005, the Natural Resources Defense Council (NRDC) announced a 'BioGem' campaign to help save the vaquita and stop overfishing in the northern Gulf. The campaign's goal was to convince Ocean Garden, the Mexican national exporter of seafood products, to take greater responsibility for the ecological consequences of fishing in the region and thus to honour its claim that it sells 'environment-friendly' products. Ocean Garden and NRDC signed an agreement with fishermen, stating their joint commitment to the goals of preventing extinction of the vaquita, promoting vaquita conservation and ensuring the sustainability of fisheries. Ocean Garden took an active role in forging the agreement, and a local non-governmental organization, *Noroeste Sustentable*, provided important facilitation during the negotiations. This agreement resulted in the formation of a further coalition, *Alto Golfo Sustentable*, which includes representatives of artisanal fisherman cooperatives, shrimp trawlers from Puerto Peñasco, and several non-governmental organizations. The grass-roots and inclusive character of the coalition give reason for hope that it will help turn the various decrees and agreements over the years into actual changes in fishing activity. Experience has shown that key sticking points, such as elimination of large-mesh gill nets, requirements that nets be attended at all times, and limits on gillnet soak times, can be addressed relatively easily by proclamation but prove hard to resolve in practice.

Additional socio-economic options

Other ideas that deserve consideration include (i) an investment risk fund that would co-finance sustainable enterprises through partnership schemes; and (ii) a socio-economic analysis of the industrial shrimp trawler fleet. The former could be expected to promote activities that offer income alternatives for fishermen, such as nature-orientated, low-impact tourism; aquaculture, with due regard for the associated environmental implications; and regulated, thoughtfully organized sport fishing. Together with such a fund, it would be necessary to establish a business council of some kind to evaluate the feasibility, effectiveness and environmental effects of proposed enterprises. The analysis of the trawl industry would assess the character and magnitude of the impacts of regulations on local communities, define alternative scenarios and elaborate various socio-economic models for the communities of San Felipe, Puerto Peñasco and El Golfo de Santa Clara.

REMAINING OBSTACLES

The recommendations from the CIRVA meetings remain appropriate based on the current state of knowledge. Progress has been made on some of them, but overall, the situation is far from satisfactory and the implementation process needs to be reinvigorated and strengthened. Here we consider some of the main obstacles that are slowing or preventing progress.

Scientific and political-technical obstacles

Although it seems inconceivable, the governors of Sonora and Baja California, the two states bordering the vaquita's range in the northern Gulf of California, have cast doubt on the vaquita's existence. According to a news article, the governor of Sonora said that 'nobody wants to wipe out shrimp or the vaquita, if indeed it exists' ('expuso . . . que nadie quiere acabar ni con los camarones ni con la vaquita marina "si es que existe"'). Various officials in state fisheries agencies, members of the Fisheries Chamber of Commerce, representatives of fishing cooperatives, and even university researchers receiving contracts from the fisheries sector, have made similar declarations doubting or denying the vaquita's existence. Needless to say, attempting to gain support for a recovery strategy on behalf of a 'non-existent' species would be a futile task. However, thanks to the positive results of a photographic expedition to obtain vaquita images (well publicized in the media) and as a result of intensive discussions and negotiations, this issue has largely been set aside. Mexican officials have accepted that the vaquita does exist, although many remain unwilling to acknowledge its critically endangered status.

Another obstacle has been the refusal by state government officials, as well as some federal fishery officers, to credit the scientific evidence indicating that immediate action is needed to reduce the vaquita by-catch. In recent meetings, representatives of Sonora and Baja California have rejected the scientific consensus – that the vaquita population is very small and declining and that by-catch in gill nets is the main risk factor. This has been in spite of repeated expressions of that consensus in letters and published statements by scientific bodies such as the American Society of Mammalogists, the Society for Marine Mammalogy, the European Cetacean Society, the Latin American Society for Aquatic Mammals, the Scientific Committee of the International Whaling Commission, and the IUCN Cetacean Specialist Group. Counterarguments by government and fishery representatives have generally hinged on three main points, as follows: (i) the best current estimate of population size (Jaramillo-Legorreta *et al.*, 1999) is outdated as the survey was conducted almost a decade ago (1997); (ii) the bycatch estimate (D'Agrosa *et al.*, 2000) is even more out of date (1995); and (iii) there is no direct evidence of population decline and therefore the vaquita population could be stable or even increasing. In the absence of unequivocal proof that the population is declining towards extinction, decision-makers and representatives of fishing interests are unwilling to support conservation actions that would be unpopular in their constituencies. The vaquita is a classic example of situations in which 'the political costs of more surveys and more planning meetings are slight compared with those of actions affecting employment and short-term human welfare' (Reeves & Reijnders, 2002).

The points raised by the politicians and industry advocates lead to the following key questions:

1. Would a new vaquita abundance estimate tell us whether the population is declining?
2. How often must new estimates or indices be obtained to adequately monitor trends in the vaquita population?
3. Is a new bycatch estimate required to determine whether fishing restrictions are necessary?

These kinds of questions are certainly not unique to the vaquita. In fact, the dilemma of how much and how conclusive the evidence needs to be before taking remedial action is at the heart of the much-maligned but still vital (in our view) 'precautionary principle' (see, e.g. Mangel *et al.*, 1996; Meffe, Perrin & Dayton, 1999). As more frequent and more precise estimates of key parameters are sought, the critically endangered species becomes more rare and vulnerable to extinction.

As stated in the report of the 2004 CIRVA meeting: 'Given (i) the inevitable lack of precision in obtaining abundance estimates of cetaceans, particularly rare ones; and (ii) that bycatches continue at unsustainable levels, power analysis studies show that the species will become extinct before it is possible to detect a statistically significant decline through abundance surveys (Taylor & Gerrodette, 1993). There is no evidence to suggest that a new survey would alter the view that the vaquita is critically endangered. Similarly, even under the most optimistic scenarios of population growth and no bycatches, it would require five surveys at five-year intervals to detect a significant increase in population size'.

More recently, at a 'Special Vaquita Event' during the 16th Biennial Conference on the Biology of Marine Mammals (San Diego, California, 11–16 December 2005), Barbara L. Taylor addressed the first two of the questions posed above. Ship surveys are expensive and could not be expected to detect population declines or increases on an acceptable timescale for such a critically endangered species. According to her analysis, a single survey in 2006 or 2007 would have a probability of only 11% of detecting a 3%/year decline in vaquita abundance and a 16% probability of detecting a 10%/year decline. Achieving an acceptable probability (e.g. 95%) of detecting a 3% decline would require annual surveys over a period of 39 years at a cost of approximately \$29 million. Moreover, by that time (*c.* 45 years from now), only 184 vaquitas would be left. If surveys were conducted at intervals of 10 years instead of annually, the cost would decline to \$8 million, but the number of vaquitas remaining (23) would be far too few to allow any reasonable chance of population recovery (or persistence). If detection of a 10% decline rate were the objective, the required time series would be shorter and the costs lower, but the risks for vaquitas would be correspondingly greater.

Another difficulty is that some stakeholders, including fishermen, have continued to insist that acoustic alarms or deterrents ('pingers') offer an alternative to an outright gill-net ban in the Gulf (e.g. Vásquez-León, McGuire & Aubert, 1993). Therefore, the pinger issue has been discussed on several occasions by the IWC Scientific Committee's Sub-committee on Small Cetaceans. At its 1999 annual meeting, the Sub-committee explicitly endorsed the views expressed by other international panels (including CIRVA in February 1999) that pingers should not be used with gill nets in the northern Gulf of California to reduce vaquita by-catch (IWC, 2000; pp. 242–243). Then, in 2002 during its consideration of a proposal to introduce pingers in the Baltic Sea as a way of reducing the entanglement rate of harbour porpoises in gill nets there, the Sub-committee elaborated on its earlier position regarding the vaquita (IWC, 2003; pp. 370–371). The differences between the two situations (Baltic harbour porpoises vs. Gulf of California vaquitas) were summarized as follows:

- The vaquita exists as a single population endemic to a small area of the northern Gulf of California, whereas the harbour porpoises in the Baltic represent one of several populations of that species in the North Atlantic Ocean.
- Pingers have been shown to be effective in reducing by-catches of harbour porpoises, but they have not been tested with vaquitas, through either a controlled experiment (which would *require* some animal mortality in the control sample to produce conclusive results) or a field trial.
- The considerable variety of types of gill nets and target species implicated in the incidental mortality of vaquitas, as well as the artisanal nature of most of the relevant fisheries in the northern Gulf, create major practical difficulties with implementation and effectiveness. In comparison, the relevant Baltic fisheries are homogeneous and manageable.

Furthermore, at the aforementioned 'Special Vaquita Event' in December 2005, Jay Barlow summarized the pinger issue this way:

- Reductions in the by-catch of marine mammals have been achieved in other fisheries by changing how fishermen use particular types of gear, changing the types of gear used, reducing fishing effort or using pingers on gill nets.
- Pingers do not work for many species, and an expensive experiment (~ \$620 000) would be needed to determine whether pingers would reduce vaquita by-catch in gill nets.
- If pingers do work for vaquita bycatch reduction, they likely would not reduce it by more than 50%, which is not nearly enough.
- The management measure most likely to be effective in achieving a significant reduction in vaquita by-catch is either a complete ban on gillnetting or a dramatic reduction in gillnet-fishing effort.

An additional major concern with regard to the possible deployment of pingers within the vaquita's very limited range in which the risk of by-catch is most severe has to do with the potential for displacement. This has been discussed by the IWC's Sub-committee, which acknowledged that intensive use of pingers in or around areas that constitute critical foraging habitat for porpoises could create 'acoustic barriers' and reduce their access to prey resources (Carlström *et al.*, 2002).

Finally, a widespread problem is the deeply entrenched idea that all living resources (perhaps especially marine resources) can be exploited sustainably. In other words, what is needed is to determine an allowable (sustainable) level of vaquita by-catch and set up a management regime that triggers fishing suspensions when the specified level of mortality has been reached in a given year (e.g. the potential biological removal, or PBR, formula; Wade, 1998). However, in situations involving critically endangered populations, where there is substantial scientific uncertainty and the management and enforcement infrastructure is weak or unreliable, that concept is impractical. In general, 'populations of small cetaceans [given their very low rates of potential increase] are not good candidates for sustainable development' anywhere, but especially in less-developed regions of the world in which absolute estimates of population size are difficult to obtain and trends are essentially impossible to monitor (Perrin, 1999). The vaquita is a clear case in point.

Socio-economic obstacles

As in many other situations in the world characterized by widespread human poverty and severe resource constraints, the highest priority of politicians and community activists in the northern Gulf is likely to remain 'achieving a decent standard of living for everyone' (Perrin, 1999). Even though it is an endemic species with high value in biodiversity terms, the vaquita is economically worthless in comparison with species that can be caught and sold for profit (e.g. blue shrimp). The shrimp fishery produces the most valuable sea product in an isolated region with poor roads and limited amenities, such as fresh water. As Perrin (1999) paraphrased Vidal (1993), 'When a fisherman tries to feed his family, he cannot reasonably be expected to stop fishing because he kills an occasional vaquita unless he is offered a viable economic alternative'.

Management of by-catch is an intrinsically difficult proposition. Protection of a resource from deliberate use may be unpopular among would-be users, but at least it involves a transaction that can be 'tuned' to achieve straightforward goals in a predictable manner. In contrast, restrictions on by-catch (i.e. non-deliberate 'use'), absent a technological fix (e.g. pingers; see above) or a credible compensatory mechanism (e.g. buy-outs, alternative livelihoods) tend to mean reduced investment in valuable fisheries with no clear or certain benefits to the human community apart from what are often viewed as abstract 'elitist' concepts. The

vaquita case is an exceptional example because the goal is not just to reduce the bycatch rate to some acceptable level, but to eliminate by-catch entirely.

Cultural and political obstacles

The way in which the vaquita is regarded by federal and local authorities, the fishing sector and Mexicans more generally, will have a major bearing on whether practical measures are taken to protect the species. At times, Mexican authorities have insisted that vaquita conservation is exclusively a national prerogative, and that other countries and international organizations have no standing to comment or intervene. For example, in 1978 when the US National Marine Fisheries Service proposed to collaborate with Mexican scientists in an abundance survey, it was advised that because the vaquita is found only in Mexican waters, it 'should not be a subject of joint research' (MMC, 1979). More recently, officials representing the state government of Sonora have expressed their opinion that the international character of CIRVA is inappropriate, and that an all-Mexican committee should be the only authorized scientific body to give advice on vaquita science and conservation. These same officials, together with representatives of the fishing industry in Mexico, have insisted that findings reported in Mexican scientific journals should be accorded more weight than those published in international journals, such as *Marine Mammal Science* (L. Rojas-Bracho, personal observation).

The jurisdictional tension between federal and state governments is a complicating factor in this situation, as it is in many other resource-use conflicts. Mexico is not exceptional in this regard. To some extent, such tension is an intrinsic feature of all large, diverse nation-states regardless of their form of government or level of economic development.

There is a striking inconsistency in the way foreign aid or investment is viewed in Mexico, as well is in many other countries. Generally, governments are eager to accept support for economic development from transnational companies and *maquiladoras* (factories in Mexico run by foreign companies and exporting their products to those companies' countries), but are reluctant to accept any funds for environmental causes. In the states of Baja California and Sonora, there are more than 1500 such *maquiladoras*, including Ford and Toyota plants. In addition, liquid natural gas (LNG) offloading facilities are being developed by US companies in Ensenada, B.C., and Puerto Libertad, Sonora, for delivery to US border states. Indeed, 'Governments are often more open to acceptance of people-directed aid than they are to acceptance of pro-environment initiatives that smack of interference in "internal affairs" or infringement on "private property rights" (Domning, 1999). This tendency has been exacerbated by the tuna embargo that devastated the tuna industry in Ensenada and engendered strong animosity in Baja California towards many non-governmental organizations and international bodies. For example, the state governor declared recently that 'alien interests' (environmental groups, especially those based in the United States) were seeking to undermine the productivity and competitiveness of Mexico's fishing sector (El Vigía 005-07-20 15:08:26; <http://www.elvigia.net>). In his view, proposals for marine protected areas were motivated less by the need to conserve marine fauna than by a desire to weaken Mexico's ability to develop its fisheries and take full advantage of the huge emerging markets for seafood products in, e.g. Japan, China and Korea. This view seems to be shared by many fishermen in the northern Gulf (Greenberg, 1993). The fishing sector and many government officials apparently still regard the Biosphere Reserve as a manifestation of 'environmental imperialism – the marshalling of the international cetacean lobby in the service of President Salinas's free trade and neoliberal agenda' (McGuire & Valdéz-Gardea, 1997).

RECOMMENDATIONS

Scientific

At this stage, the vaquita's survival does not depend on more or better science. Rather, what is needed now is political will combined with more imagination on the part of environmental activists, conservation strategists and decision-makers at all levels of government. Also, it is essential to maintain the role of the international scientific community in supporting Mexico with technical advice and moral encouragement. Any funds available in the near future for another abundance survey or even for a new bycatch estimate would be better spent on improved management and on evaluating the effectiveness of management measures.

One scientific problem that has not been addressed to date concerns the natural history and phenology of blue shrimp. According to an experienced trawler captain (J. Osuna, personal communication), these shrimp, as they mature, move south and away from the core area of vaquita distribution. If this were shown to be true, it might mean that larger shrimp are available to be fished in areas where the conflict with vaquitas is less acute, or perhaps even non-existent. Unless it has already been addressed through studies with which we are not familiar, this question should be pursued through research.

Socio-economic

The challenge of achieving socio-economic change that will benefit the vaquita without disrupting the lives of large numbers of people cannot be overstated. Socio-economic alternatives need to be both financially viable and sustainable in the medium and long terms. Considerations that need to be taken into account include the following:

- A goal must be to create attractive economic alternatives for fishermen and to keep them economically productive.
- Strategies rooted in paternalistic attitudes towards fishermen have failed in many parts of the world, and it is important to avoid paternalistic approaches, e.g. simply paying fishermen to abandon fishing. Fishermen need to be consulted at every stage and their perspectives represented in any decision-making framework.
- Economic alternatives should be capable of providing fishermen with incomes similar to those gained from fishing. However, it is unlikely (at least in a Mexican context) that a market economy without subsidies can create such employment opportunities. Although subsidization will certainly be necessary, phase-out of subsidies should be built into any long-term strategy.
- Even if new types of employment can be made available, there is no guarantee that fishermen will be inclined or able to take advantage of them. Therefore, any job-creation initiative must be accompanied by appropriate training and skills development.
- Any strategy for socio-economic change (e.g. job creation) will require direct, coordinated involvement by a number of players, ideally including federal, state and local government authorities, business groups and non-governmental organizations.
- No strategy is likely to succeed without buy-in from the local community. That is, the fishermen and their families must be made to feel that their views and interests have been respected, and that they stand to benefit (or at least not be harmed) from any change in the status quo.
- Puerto Peñasco, like San Felipe, has a sufficiently high level of urbanization and infrastructure to facilitate the transition from fishery dependence to a more diverse local economic base. El Golfo de Santa Clara, in contrast, depends completely on fishing and therefore may pose a greater challenge.

SUMMARY AND CONCLUSIONS

Although a degree of uncertainty still surrounds both the total population size of vaquitas and the scale of annual incidental mortality in fisheries, there is a strong international consensus among scientists that the species remains critically endangered and is in serious danger of extinction, and that there is an urgent need for reduction or elimination of vaquita entanglement.

The gillnet bans proposed and promulgated at various times and at various levels of government have been problematic for several reasons – political, administrative, economic, cultural and social. Most importantly, livelihood alternatives to fishing simply do not exist in much of the northern Gulf of California. Considering the limited resources of these isolated communities (e.g. fresh water, communications), their marginal status within the wider Mexican socio-economic and political structure, and the large amount of inertia behind fishing as a way of life, the search for practical, economically viable alternatives represents an enormous challenge. In contrast to the biological side of the conservation effort, in which the state of knowledge is adequate to provide a basis for management, the socio-economic component of the conservation effort is languishing.

In a major recent study of threats to global biodiversity, Ricketts *et al.* (2005) identified and pinpointed places in which highly threatened species are confined to single sites, i.e. hotspots for imminent extinctions worldwide. The results showed that, among 89 countries or regions, Mexico ranked first in terms of rate of extinctions of endangered species. The vaquita is hanging on the edge of survival. The reasons for its precarious condition are well understood and accepted by all major international marine mammal scientific bodies. Mexico, with the support and cooperation of international partners, needs to act quickly and decisively to prevent this, the world's most endangered marine cetacean, from being added to the list of losses.

ACKNOWLEDGEMENTS

This article would not have been possible without the enthusiastic and generous support of Tim Ragen of the Marine Mammal Commission, who personally invested a great deal of time and thought in the project. Others on the staff of the Commission helped in many ways by giving us intellectual, administrative, logistical and moral support. Mike Simpkins, in particular, provided an excellent technical review of the manuscript. The willingness of the Commission and its Committee of Scientific Advisors to underwrite our costs while preparing the report is greatly appreciated. We also wish to record our appreciation for the special status accorded the vaquita by the Commission from its earliest days when Ken Norris and John Twiss took the plight of this rare little porpoise to heart. World Wildlife Fund – US (especially Karen Baragona) and the International Fund for Animal Welfare (especially Bettina Bugada) have been instrumental in keeping the candles burning on the vaquita's behalf, and we thank them. Barb Taylor offered sage comments on the manuscript.

Finally, we dedicate this article to two scientists who have made singular contributions to humanity's understanding of vaquita biology and conservation: Greg Silber and Omar Vidal.

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Submitted 13 June 2006; returned for revision 11 July 2006; revision accepted 28 August 2006

Editor: PC