A review of gray whales (*Eschrichtius robustus*) on their wintering grounds in Mexican waters

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ABSTRACT

The Eastern North Pacific gray whale (*Eschrichtius robustus*) is one population of large cetacean that has recovered from depletion resulting from commercial harvest in the mid- to late-1800s. It is believed that this population may be approaching, or possibly exceeding its carrying capacity as suggested by recent increases in mortality of all age and sex classes. Research on the breeding biology and phenology of gray whales that spend the winter in the coastal waters and lagoons of Baja California, Mexico has been conducted for many years. These studies contribute valuable information on the reproductive biology of this species, and the importance of their coastal lagoon habitats to their reproductive success. This paper reviews and summarises historical exploitation, conservation measures, the findings of research conducted on gray whales in their winter breeding range, potential natural and anthropogenic threats to this population, and makes recommendations for future research and monitoring. This review concentrates on the findings of research conducted since the mid-1970s.

KEYWORDS: EXPLOITATION; CONSERVATION; GRAY WHALE; BAJA CALIFORNIA; MORTALITY; BIRTH RATE; GENETICS; HABITAT; DISTURBANCE; NORTH PACIFIC

INTRODUCTION

The Eastern North Pacific gray whale population (*Eschrichtius robustus*) has been the focus of ongoing research and population monitoring. It is an example of a population of large whales that has successfully recovered from over-exploitation (Jones, M.L. and Swartz, 2002). This population may be approaching, or possibly already exceeding its carrying capacity level (Moore *et al.*, 2001). Recent range-wide increases in mortality of all age and sex classes suggest the population may have become food limited (Le Boeuf *et al.*, 2000). Research on the breeding biology and phenology of gray whales has contributed and continues to contribute valuable information on the importance of their coastal lagoon habitats to their reproductive success. This paper reviews and summarises whaling history, conservation measures and the findings of research conducted on gray whales in their winter breeding range. The latter concentrates on work conducted since the mid-1970s. Natural and anthropogenic threats to gray whales are discussed and suggestions are made for additional research and monitoring.

STUDY SITE

The main winter breeding range of the eastern gray whale population extends from about Point Conception in southern California to Cabo San Lucas, Baja California (Jones, M.L. and Swartz, 2002). Gray whales concentrate in specific areas, particularly near and within coastal lagoons and bays including: Laguna Guerrero Negro; Laguna Ojo de Liebre (Scammon's lagoon); Laguna San Ignacio; Santo Domingo Channel; Bahia Magdalena and Bahia Almejas (Fig. 1). Some gray whales journey around the cape of the Baja California peninsula, into the Gulf of California and along the coasts of Sonora, Sinaloa and Nayarit in mainland Mexico (Berdegué, 1956; Gilmore, 1960a; b; Henderson, 1972; Tershy and Breese, 1991). The ecological characteristics of the wintering grounds presumably offer reproductive advantages to gray whales (Fleischer *et al.*, 1984; Jones, M.L. and Swartz, 1984; Fleischer and Beddington, 1985).

History of exploitation in Baja California

While there are no accounts of gray whale hunts in Mexican waters before the nineteenth century, it is clear that aboriginal Mexicans and Spaniards recognised this species long before the 1800s. It is believed that some indigenous native groups from Baja California occasionally may have eaten meat of gray whales that had died and washed ashore (Russell, 2001). Information on gray whale hunting in Baja California is summarised in the following paragraphs. Information from mainland Mexico is presented elsewhere in detail (Rice and Wolman, 1971; Henderson, 1972; 1984; Reeves, 1977; 1984; Reeves and Mitchell, 1988; Dedina, 2000; Donahue and Brownell, 2001; Russell, 2001).

Nineteenth Century

Bahia Magdalena

The first documented catches of gray whales in Baja California are from the winter of 1845-46 in Bahia Magdalena with the arrival of the ships *United States* and *Hibernia* under Captains Joshua Stevens and James Smith, respectively. During this first season, approximately 32

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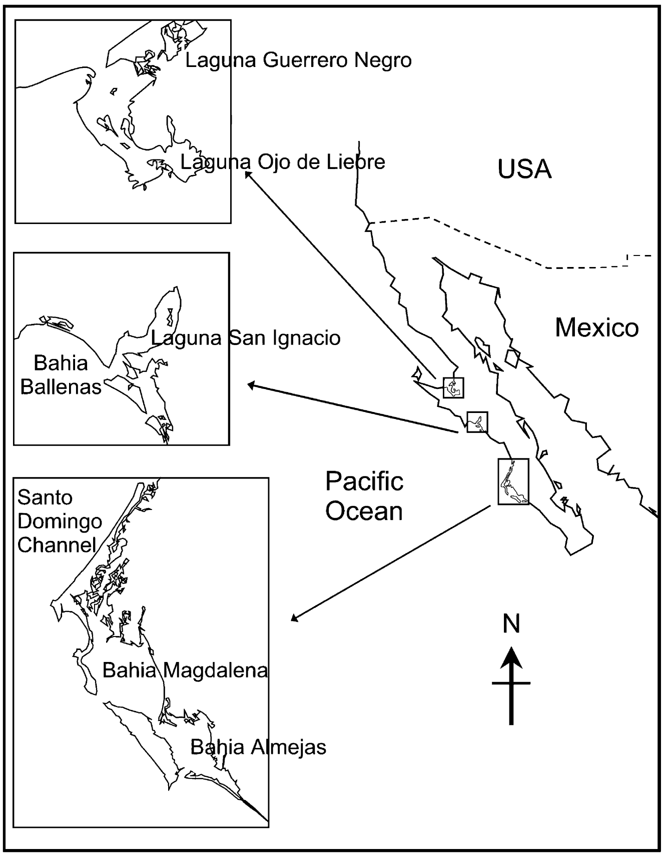

Fig. 1. Study site.

whales were taken[1] (Henderson, 1972; 1984). The peak years of whaling in Bahia Magdalena were from 1845-1847 and from 1851-1865, when 125 whaling vessels captured between 1,950-2,000 whales. During the later period, 34,425 barrels of oil brought US$516,375. The number of whales killed in Bahia Magdalena from 1845-46 to 1873-1874 was estimated at 2,145-2,200; roughly 9% of these whales were lost (Henderson, 1972; 1984).

Laguna Ojo de Liebre and Laguna San Ignacio

In 1855, whaling started in the two lagoons north of Bahia Magdalena: Ojo de Liebre (Scammon's Lagoon) and San Ignacio. In the former, 36 cruises from 1854-1855 to 1864-1865 secured 553 whales but probably killed 608 (Henderson, 1972; 1984). From then until the 1873-1874 seasons, approximately 650 whales were killed and from those about 590 were secured. Laguna Guerrero Negro and Manuela, north of Ojo de Liebre, were not important whaling grounds.

Whaling also took place in the lagoon of San Ignacio and adjacent waters. From 1854-1855 to 1864-65 approximately 350 whales were secured and probably 385 killed. By the 1873-1874 seasons a total of 400 had been secured from 440 killed (Henderson, 1972; 1984).

Western coast of Baja California and Gulf of California

Additional gray whales were killed and taken along the Pacific coast and Islands of Baja California, particularly San Martin, San Benitos, Cedros, Natividad and Asuncion Islands. Henderson (1972; 1984) pinpoints the new whaling grounds including San Diego Bay, San Quintin Bay and Turtle Bay (San Bartholomeu Bay) and indicates that 990 gray whales were killed and 900 were secured from 1854-1865. However this figure seems to include whales taken along the coast of California as well. Within the Gulf of California during this same period 150 whales were taken from 165 killed. By 1874, a total of 220 whales were killed (200 taken) in these waters (Henderson, 1984).

[1] 1,440 barrels of oil, 35 barrels/gray whale.

Whaling summary

During the Nineteenth Century, more than 3,200 whales were killed in the bays and lagoons of Baja California (Dedina, 2000). Henderson (1984) reports a similar amount 3,235-3,290 killed with 2,941-2,991 taken. If those from the Gulf of California are added, at least 3,465-3,510 gray whales were killed in Mexican waters in a period of 29 years ranging from 1845-1874, or an average of about 120 per year.

The lagoon complex of Bahia Magdalena sustained more whaling for a longer period of time than Ojo de Liebre and Laguna San Ignacio. The total kill in Magdalena Bay was probably around 2,200 whales during a period of 25-30 years. Even though Magdalena remained the most important whaling ground, it is interesting to note that based on recent surveys, Laguna Ojo de Liebre is currently used by more whales than Bahia Magdalena and Laguna San Ignacio (Urbán *et al.*, 2001).

Twentieth Century

Bahia Magdalena again became the main focus for commercial whaling in Mexico in the 20th century. Thirty years after the American whalers had withdrawn, Norwegian whalers started whaling with the factory ship *Capella I*. Between 28 November, 1913 and 14 May 1914 they took a total of 19 gray whales. In the next decade the exploitation of gray whales increased with the presence of the Norwegian factory ships *Kommanddoren I, Mexico, Ragnhild Bryde I* and the *Esperanza*. The former two took at least 129 whales between mid-November 1924 and February 1926 in Bahia Magdalena. From 1913 until 1929 Norwegian whalers took at least 200 gray whales in Mexican waters. In the 1960s the gray whale population was considered to be increasing and estimated to be at least 12,000 animals (Rice and Wolman, 1971).

FORMAL PROTECTION OF GRAY WHALES IN MEXICO

History of gray whale conservation

The commitment of the Mexican government to the conservation of gray whales and their habitat in Baja California Sur is the result of: (1) the legacy of foreign overexploitation of natural resources including gray whales prior to the Mexican Revolution (1910), and the subsequent desire of the federal government to re-establish control over national territory and natural resources; (2) the work of policy makers and environmental advocates to protect two gray whale breeding/calving lagoons as sanctuaries and later as biosphere reserves; (3) cooperation between Mexican and US scientists and policy-makers interested in the conservation of gray whales and their habitat throughout their migratory range; and (4) the enactment of laws that provide government agencies in Mexico with the authorisation to protect gray whales and their habitat (Dedina and Young, 1994).

Mexico recognised the Geneva Convention for the Protection of Whales in 1933, and gave its approval to the International Agreement for the Regulation of Whaling in 1938 (Diario Oficial, 1938). In 1949 Mexico became a member of the International Whaling Commission (Diario Oficial, 1949).

In 1965, the Secretariat of Fisheries (Pesca) proposed the opening of a whaling station to harvest gray whales off the Baja California coast (Bunker, 1965). As a result of an international outcry over the proposal, Mexico denied having made plans to resume whaling (Jones, H.Y., 1965; Dedina, 2000). Pressure to allow the hunting of gray whales continued. In 1970, gray whale researcher Raymond Gilmore argued that keeping the population near 10,000 would provide, '...whales for the whalers and the public and science'. He did suggest, however, that Mexico could '...make more money by having the herd conserved...where [the whales]...will breed unmolested and draw tourists' (Gilmore, 1970 cited by Dedina and Young, 1994).

Gray whale habitat protection

In December 1971, Mexican President Luis Echeverria signed legislation that established Laguna Ojo de Liebre as a whale refuge, the first of its kind in the world (Diario Oficial, 1972b; Jones, M.L. and Swartz, 1984). In June 1972, seven months after creating the Laguna Ojo de Liebre Whale Refuge, Echeverria declared both Laguna Ojo de Liebre and Laguna San Ignacio as Migratory Bird and Wildlife Refuges (Diario Oficial, 1972a). In 1979, President Jose Lopez Portillo declared Laguna San Ignacio as a Whale Refuge and Maritime Tourist Attraction Zone. The decree established a permitting mechanism for scientific research and tourism in the area, under the administration of the Ministry of Pesca (Diario Oficial, 1979). The vague wording of the 1971 Ojo de Liebre whale refuge decree prompted Lopez Portillo to revise it in 1980, to include reserve status for Laguna Manuela and Laguna Guerrero Negro (Diario Oficial, 1980).

In 1988, President Miguel De la Madrid signed a law creating the Vizcaino Biosphere Reserve within the frame of the National System of Protected Areas (SINAP) established in 1984 (Poder Ejecutivo Federal, 1984; SEDUE, 1986; Diario Oficial, 1988). In 1993 portions of El Vizcaino Biosphere Reserve consisting of Ojo de Liebre and San Ignacio lagoons were added to the World Heritage Site list of the United Nations Educational, Scientific, and Cultural Organisation (UNESCO).

International cooperation

An important aspect of efforts to protect gray whale habitat has been the international cooperation and research that involved sharing information regarding gray whale behaviour, migratory patterns, habitat, and conservation needs. In 1977, the Mexican government sponsored the First International Symposium on the Gray Whale in Guerrero Negro. During the meeting researchers and policy-makers from both Mexico and the USA discussed the most effective methods of assuring the continued growth of the gray whale population and the conservation of the Laguna Ojo de Liebre complex (Aurioles-Gamboa *et al.*, 1993).

Beginning in the late 1970s, the US National Oceanographic and Atmospheric Administration (NOAA) sponsored three joint meetings between Mexican and US researchers regarding gray whale research. Conferences on marine mammals held annually since the 1970s by the Mexican Society for the Study of Marine Mammals (SOMEMMA) have brought together researchers from various countries to discuss issues related to gray whale and other marine mammal research (Aurioles-Gamboa *et al.*, 1993; Urbán and Rojas, 1999).

Additional legislation

The 1988 General Law of Ecological Balance and Environmental Protection is the responsibility of the new Secretariat of the Environment and Natural Resources (SEMARNAT), established in December 2001. Articles 15 to 19 of the law provide SEMARNAT with a broad mandate to formulate policy and planning initiatives, and to implement management actions for the protection of the nation's natural resources (Estados Unidos Mexicanos, 1993).

One other piece of legislation, a 1991 addition to the Mexican Penal Code, Article 254 *bis*, later transformed into Article 420, imposes a prison term of between six months and six years plus a fine for the unauthorised capture of or injury to marine mammals and sea turtles (Diario Oficial, 1991; Cultura Ecológica, 1999).

The General Law of Wildlife, adopted on 27 April, 2000 (Diario Oficial, 2000a), added Article 60 *bis* on 10 January 2002, which states that: 'No marine mammal specimen of any species can be the subject of subsistence or commercial use, with the exception of captures with scientific research and educational purposes' (Diario Oficial, 2002b).

The Mexican Official Norm, NOM-59-ECOL-1994, defines those species and sub-species of terrestrial and aquatic wildlife flora and fauna that are in danger of extinction, threatened, rare and those subject to special protection, and established the specific provisions for their protection (Diario Oficial, 1994). This norm was updated on 6 March 2002 (NOM-59-ECOL-2001) (Diario Oficial, 2002c). Since 1994 gray whales have been listed under the category of 'special protection' which means that this species faces threats that could affect its survival.

The Mexican Official Norm, NOM-131-ECOL-1998 stipulates guidelines and specifications for whalewatching activities (Diario Oficial, 2000b). Whalewatching activities in Ojo de Liebre and San Ignacio lagoons, Santo Domingo Channel and Bahia Magdalena are included in this norm (Urbán and Gómez-Gallardo, 2000).

Finally, in May 2002 all the Mexican territorial seas and EEZ were declared a refuge for the protection of the large whales (Mysticeti and Odontoceti) (Diario Oficial, 2002a).

GRAY WHALE RESEARCH IN MEXICAN WATERS

Laguna Ojo de Liebre-Guerrero Negro

Since the account by Scammon (1874), no studies of gray whales on their winter grounds were conducted until 1952, when Raymond M. Gilmore made the first of a series of field trips to Baja California (Gilmore and Ewing, 1954; Gilmore, 1960a; b; 1976a; b). Subsequently, several researchers visited Laguna Ojo de Liebre, but their observations were mostly brief and opportunistic (Berdegué, 1956; Eberhardt and Evans, 1962; Eberhardt and Norris, 1964; Eberhardt, 1966; Hubbs and Hubbs, 1967; Spencer, 1973; Balcomb, 1974; Gard, 1974; 1978a; b; Samaras, 1974; White, 1975 and White and Griese, 1978). In 1978, representatives of Mexico's Departamento de Pesca and the US National Marine Fisheries Service's National Marine Mammal Laboratory met to develop a joint programme for the study of the gray whale for an initial period of five years

(1978-1983) (Rice *et al.*, 1981). The findings of this joint programme are available in published and unpublished papers (Fleischer, 1981; Rice *et al.*, 1981; 1982; Fleischer and Beddington, 1985).

In Laguna Guerrero Negro, Bryant *et al.* (1984) conducted vessel surveys from 1980-1982. In 1988, researchers from the new Biosphere Reserve El Vizcaíno began a monitoring programme of gray whales in Laguna San Ignacio and Laguna Ojo de Liebre (Sánchez P, 1991; 1998). In 2000, the Universidad Autónoma de Baja California Sur, began a project to document the current abundance, distribution, duration of residency and mortality of the gray whales in Laguna Ojo de Liebre (Urbán *et al.*, 2001).

Laguna San Ignacio

Aerial surveys to count gray whales wintering in Laguna San Ignacio were conducted between 1947 and 1965 by Gilmore (1960a; b), Hubbs and Hubbs (1967) and Gard (1978a). The first systematic study of gray whales utilising Laguna San Ignacio was conducted by Jones and Swartz (1984) with the twofold aim of providing baseline information on the demography and phenology of breeding whales, and to evaluate the effects of whalewatching activities within the lagoon on the whales. This field research continued for five consecutive winters from 1978 to 1982. It generated information on: (1) the seasonal timetable of lagoon occupation by whales; (2) the numbers and distribution of whales utilising the lagoon interior and inlet area; (3) the proportion of females with calves to whales without calves (singles) that utilise the lagoon throughout each winter season; (4) the location of specific nursery areas and the seasonal abundance of calves in these areas; (5) the seasonal mortality of adults, juveniles and calves; and (6) the number of whalewatching vessels and levels of tourism and other human activities that occur within the lagoon each winter. Between 1996 and 2000 a Mexican research team (Urbán *et al.*, 1997; 1998; 1999; 2001; Urbán and Gómez-Gallardo, 2000) continued the demographic studies of gray whales in Laguna San Ignacio based on the methods of Jones and Swartz (1984) to provide an update to the historical baseline information for this breeding lagoon and to evaluate the potential effects of building an industrial salt production facility on the northern shore of the lagoon.

Bahia Magdalena-Almejas and Santo Domingo Channel

Studies of gray whales in the Bahia Magdalena area have been conducted principally in the region of La Boca de la Soledad at the end of the Santo Domingo Channel. Hubbs and Hubbs (1967), Gard (1974), Rice *et al.* (1981; 1982) conducted aerial surveys to count gray whales. Fleischer and Contreras (1986) compared counts from different platforms. Norris *et al.* (1983) reported on the movements of whales in the mouth of Bahia Magdalena. Loreto *et al.* (1996) and Sánchez (1997) conducted studies to evaluate the magnitude of whalewatching activities in this region, and the effects of those activities on gray whales wintering there. Gardner and Chavez-Rosales (2000) documented changes in the relative abundance of gray whales in Bahia Magdalena during an El Niño event (1997-1999). During this time period the whale sightings were inversely related to temperature. In 1999 they registered 8.1 whales hr^{-1} with a sea surface temperature of 15.7 ± 0.9°C; and in 1998 0.55 whales hr^{-1} with a sea surface temperature of 21.5 ± 0.9°C. Péréz-Cortés *et al.* (2000) recorded the abundance variations of gray whales in Santo Domingo channel from the 1997 to 2000 winter seasons.

Bahía de Todos Santos

Bahía de Todos Santos is located on the northern coast of the Baja California Peninsula off the Port of Ensenada at 31°48’N 116°40’W. Heckel *et al.* (2001) investigated the influence of whalewatching boats on the behaviour of gray whales on their migratory route in Bahia Todos Santos, Baja California. They found significant differences in both speed and direction of the transit of gray whales with and without presence of whalewatching boats and made recommendations on the whalewatching regulations.

BIOLOGY POPULATION KNOWLEDGE

Winter abundance

The various research programmes conducted throughout the Pacific coastal waters and coastal lagoons and bays of Baja California provide minimum counts of gray whales that spend the winter breeding season in Mexican waters each year (Table 1). Although coverage has been fragmentary and less than synoptic over the past three decades, these counts do provide a rough index of the trends in the population of gray whales that winter in this portion of their breeding range.

Laguna Guerrero Negro

The abundance of gray whales in Guerrero Negro has varied dramatically since surveys began there in the 1950s (Fig. 2). Aerial surveys conducted in mid-February from 1952 to 1962 indicated that single whales predominated. The count in mid-February 1954 included 120 single whales and 22 mothers with calves (Gard, 1974). Subsequent aerial surveys conducted in 1964 and 1970 detected no whales inside this lagoon. Gray whales were again observed by aerial surveys in 1973 (34 singles and 35 mothers with calves), and in the ensuing three seasons (1974-1976) the numbers fluctuated from 12 to 82 singles and 23 to 34 mothers with calves (Gard, 1978a; b). In 1977, the first boat-based counts were made and included one single whale and 57 mother-calf pairs (Bryant *et al.*, 1984). From 1980 to 1982, Bryant *et al.* (1984) monitored gray whale abundance in Guerrero Negro lagoon during the breeding season. Boat-based counts during this study indicated a predominance of mothers with calves, with the highest count occurring in 1981 (43 singles and 164 mothers with calves). There were no surveys following this effort until 1997. Boat surveys conducted in 1997, 1998 and 2002 found low numbers (>13) of adult whales inside the lagoon.

Gard (1978a) stated that the decline of whale numbers between 1964 and 1970 was probably caused by the vessel activity associated with the commercial shipment of salt from Laguna Guerrero Negro, an operation that took place in that lagoon from 1957 to 1967 (Fig. 2). The constant dredging operation needed to keep the channel open may have been the main source of disturbance to the whales (Bryant *et al.*, 1984). Unfortunately there is no information on the use of the lagoon by gray whales between 1982 and 1997, but recent surveys suggest that the seasonal abundance of whales in the lagoon has decreased 90% since the 1980s. Local fishermen suggest that this decline could be due to the natural closure of the lagoon entrance as sand accumulates in the absence of any dredging operations. At this time there is no conclusive evidence concerning the cause of the extreme fluctuations in whale abundance in this lagoon over the years.

Table 1
Counts of gray whale cow-calf pairs (MC) and single adult or juvenile whales (S) along the Pacific coast and within the breeding lagoons at the peak of the breeding season in February. Key: BA = Bahia Almejas; BM = Bahia Magdalena; SDC = Santo Domingo Channel; LSI = Laguna San Ignacio; LOL = Laguna Ojo de Liebre; LGN = Laguna Guerrero Negro; C = west coast of Baja California Peninsula.

	BA		BM		SDC		LSI		LOL		LGN		C*	
Year	MC	S	MC	S	MC	S	MC	S	MC	S	MC	S	MC	S
1978							67	235						
1979							100	208						
1980	4	135	25	60			118	214	557	187	115	19	116	326
1981							141	207	525	477	164	43		
1982					106	33	137	270	553	483	101	23		
1983					123	36			463	299				
1984					151	7								
1985					173	15			502	283				
1987									534	336				
1988									95	369				
1989									91	178				
1996							92	115	377	245			21	206
1997	15	94	9	72	83	17	126	127	626	317	7	5		
1998	5	15	1	4	12	7	52	178	530	401	5	3	46	138
1999					32	26	17	144	213	324				
2000					16	21	45	182	256	209				
2001					25	44	29	108	333	153				
2002	44	201			97	0	43	170	475	248	6	2		

Sources: Laguna San Ignacio 1978-1982 from Jones and Swartz (1984); Bahia Almejas, Bahia Magdalena, Ojo de Liebre and west coast in 1980 from Rice *et al*. (1981); Laguna Guerrero Negro 1980-1982 from Bryant *et al*. (1984); Laguna Ojo de Liebre 1980-1983, and Santo Domingo Channel 1982-85 from Fleischer and Beddington (1985) and Fleischer and Contreras (1986); Laguna Ojo de Liebre 1985-1989 from Sánchez (1991).

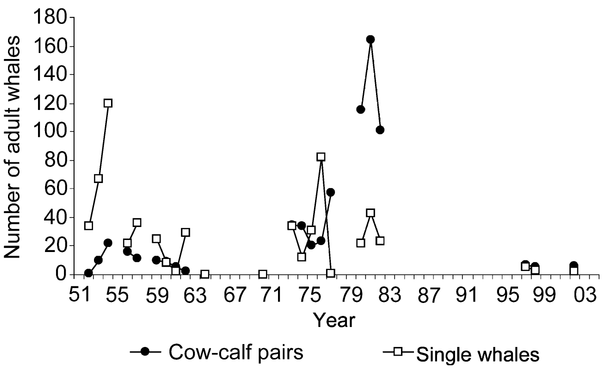

Fig. 2. Abundance of gray whales in Laguna Guerrero Negro.

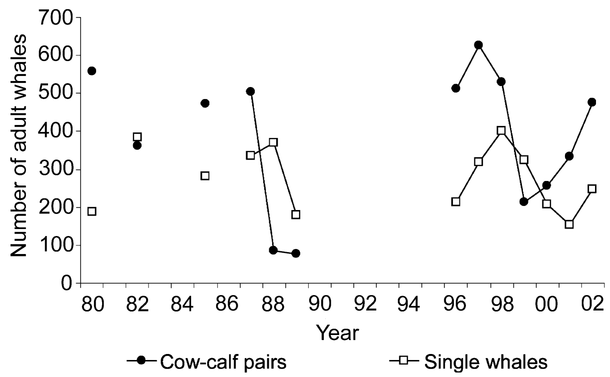

Fig. 3. Abundance of gray whales in Laguna Ojo de Liebre.

Laguna Ojo de Liebre
Historical surveys indicate that Laguna Ojo de Liebre is the most important breeding and calving lagoon in terms of the number of whales that occupy it during the winter breeding season. The maximum counts since the early 1980s are relatively constant with the exception of two drastic declines in recent years (Fig. 3).

During 1988, there was an extreme decline in the counts of mother-calf pairs from 503 in 1987 to 84 in 1988. The cause of this decline remains uncertain, however, apparently it was not related to Sea Surface Temperature (SST) anomalies observed during this period; the SST in the lagoon was the same (17.2°C) as the year before (Sánchez P, 1991). In 1989, low numbers of mothers with calves were observed again, along with lower than expected counts of single whales. The SST in the lagoon that year was 15.5°C (Sánchez P, 1991) and the general winter distribution of gray whales along the Pacific coast of Baja California appeared to have shifted further south, with some whales moving into the Gulf of California and up to Bahia de Banderas along the mainland coast (Urbán *et al.*, 1990). Unfortunately, there were no surveys during the next five years to monitor trends of gray whale occupancy in the lagoons. Surveys resumed in 1996, when winter counts of gray whales had returned to expected levels.

A similar decline in counts occurred in 1999, when the number of mother-calf pairs decreased from 530 in 1998 to 213. Again, the SST was lower than the average and the general whale distribution appeared to have shifted to the south (Urbán *et al.*, 2003). Counts during the 2000 and 2001 winter seasons indicated a slight increase in mothers with calves, but a decrease in single whales. Overall, surveys in 2002 suggest that both classes of whales are utilising this lagoon in expected numbers.

Laguna San Ignacio
Abundance records for Laguna San Ignacio come from two time-series of counts from small-boat transects during the peak of the gray whale winter breeding season in February

(Fig. 4). The first series, from 1978 to 1982, showed that winter occupation of Laguna San Ignacio began in December and reached its maximum by mid-February (Jones, M.L. and Swartz, 1984). The seasonal distribution was bi-modal: the major mode represented the maximum combined counts for each year and consisted of single whales and some mother-calf pairs. Following the February peak, the density of whales in the lagoon decreased as single whales departed and began their northward migration. During this five-year period mother-calf pairs increased in numbers during March and slowly declined through April each year. This late-season increase in mother-calf pairs appeared to be the result of an influx of mothers and calves from other areas, rather than of continuing births of calves. This was confirmed by the estimated length of the late-season calves indicating that they were not newly born, and by matching photographs of females indicating that some of them were coming to Laguna San Ignacio from other lagoons during the same winter season. The maximum combined mid-February counts of non-calf gray whales increased significantly at an average rate of 7.3% per year from 300 in 1978 to 407 in 1982 [$F(1,3) = 32.88$, $p < 0.025$, $r^2 = 0.916$]. Counts of single whales in Laguna San Ignacio reached a maximum in mid-February each year and averaged 226 whales (range 207-270), but did not show a significant trend [$F(1,3) = 0.52$, $p > 0.50$, $r^2 = 0.147$]. Mid-February counts of mothers and calves showed a significant increase each year [$F(1,3) = 16.13$, $p < 0.05$, $r^2 = 0.843$] and averaged 112 pairs (range 67-137). The greatest numbers of mother-calf pairs were observed during March following the mid-February maximum total counts, and averaged 225 pairs (range 186-282).

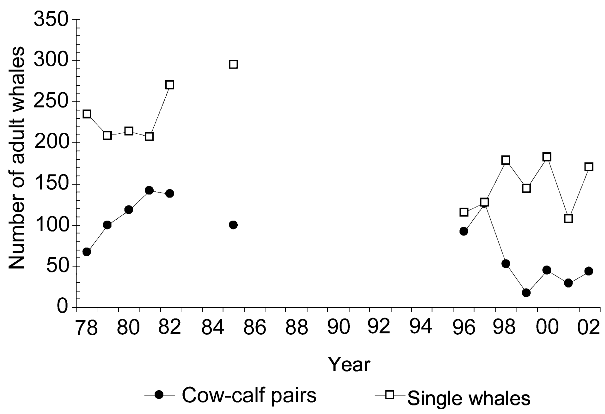

Fig. 4. Abundance of gray whales in Laguna San Ignacio.

The second time-series of whale counts from 1996 to 2000 was generated by Urbán *et al.* (2000) using basically the same survey and counting procedures as Jones and Swartz (1984). This series yielded total combined maximum counts that averaged 204 whales (range 137-253), suggesting an approximately 30% decrease in the mid-February counts of whales in the lagoon since the 1978-1982 time period. This decrease was seen in counts of single whales that averaged 146 whales (range 108-178), and in counts of mother-calf pairs that averaged 58 pairs (range 17-126). The late-season increase in mother-calf pairs observed in March in the years 1978-1982 was not evident during the 1996-2002 period. Counts of all whales decreased following the 1998 El Niño event, and these decreased counts may be the result of changes in the SST that persisted during 1999 and 2000 (Urbán *et al.*, 2003).

Bahía Magdalena Region

Although Magdalena Bay is frequently mentioned as a winter congregation area for the gray whale, the evidence shows that the different parts of this lagoon complex act as separate breeding sites. Whale counts in this region have been irregular and conducted from different platforms (Table 1). The most studied area has been the Santo Domingo Channel including the entrance, Boca de la Soledad. Two time-series of counts from small-boat transects along the channel during the peak of the gray whale winter breeding season in February are available. The first one from 1983 to 1985 documented the presence of gray whales from mid-January to mid-March (Fleischer and Beddington, 1985; Fleischer and Contreras U., 1986). Maximum counts were obtained in 1985 and included 173 mothers with calves and 15 single whales (Fig. 5). The second time series, from 1997 to 2002, documented abrupt changes in the abundance of both mothers with calves and single whales likely related to the influence of ENSO (Pérez-Cortés M. *et al.*, 2000; and this paper). Abundance decreased from 1997 to 1998, and then gradually recovered until 2002 when the number of mothers with calves was similar to 1997. Surprisingly, single whales were absent from this area in mid-February (Fig. 5). Thus, it seems that Santo Domingo Channel is used mainly as a calving/nursing area in contrast to the other parts of the lagoon complex (e.g. main Magdalena Bay and Almejas Bay) that apparently serve as mating areas or sites for congregation of young and immature gray whales.

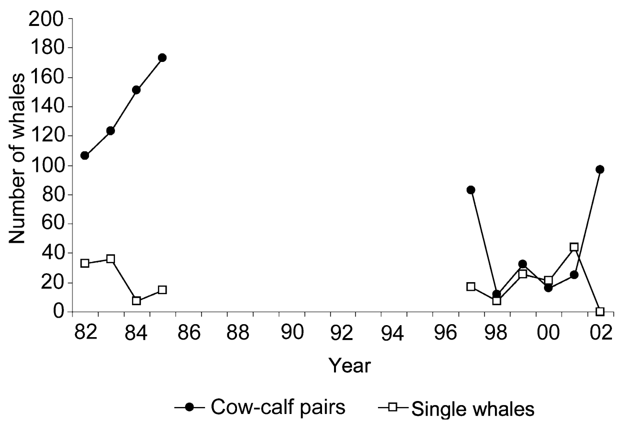

Fig. 5. Abundance of gray whales in Santo Domingo Channel.

Distribution among the breeding lagoons and coastal areas

The core of the winter breeding range of the eastern North Pacific gray whale stock lies along the west coast of the Peninsula de Baja California, from Morro de Santo Domingo (28°05'N) south to Isla Creciente (24°20'N). Some whales may be found north of this area all winter, but they are mostly transiting to and from the core winter breeding range. For example, in central California the earliest northbound migrants are seen before the last of the southbound whales have passed this area. In some years, a few whales also continue migrating south past the principal breeding lagoons and travel around Cabo San Lucas, the southern extremity of the peninsula, and enter the Gulf of California (Rice *et al.*, 1981). As noted above, the 'normal' winter distribution appears to be influenced by periodic SST anomalies; when the SST is higher the distribution shifts to the north, e.g.

1998 breeding season, and when is lower the winter distribution of gray whales shifts to the south, e.g. 1989 and 1999 breeding seasons (Urbán *et al.*, 1990; 2003; Gardner and Chávez-Rosales, 2000; Sánchez *et al.*, 2001).

Surveys for gray whales in different winter congregation and breeding areas during the same season were conducted in 1997 and 1998. The 1998 El Niño affected the whale distribution; therefore, the distribution of whales observed in 1997 is believed to best represent the usual distribution of gray whales in the winter range when no major SST anomalies are occurring.

With regard to the distribution of mothers with calves in the different breeding and calving aggregations, Laguna Ojo de Liebre is the most important, followed by Laguna San Ignacio and Santo Domingo Channel (Fig. 6). These three areas included 91% of all the mothers and calves counted in 1997. A comparison, counts of mother with calves obtained during the 1980 and 1997 breeding seasons indicates changes in the preference of the whales. Their proportional distribution increased in Laguna Ojo de Liebre from 53% in 1980 to 72% in 1997, decreased in Laguna Guerrero Negro from 10% to 1%, and decreased in Bahia Magdalena from 5% to 1% (Table 2) (see Rice *et al.*, 1981).

Laguna Ojo de Liebre also contains the highest number of single whales during the winter, followed by Laguna San Ignacio, Bahia Almejas and Bahia Magdalena (Fig. 7). Compared to the distribution of single whales observed during the 1980 breeding season (see Rice *et al.*, 1981), the main changes in the proportional distribution of single whales seen in 1997 include an increase of single whales in Laguna San Ignacio from 12% to 20%, a decrease in Laguna Laguna Guerrero Negro from 7% to 1%, and a decrease in the Santo Domingo Channel from 10% to 3% (Table 3).

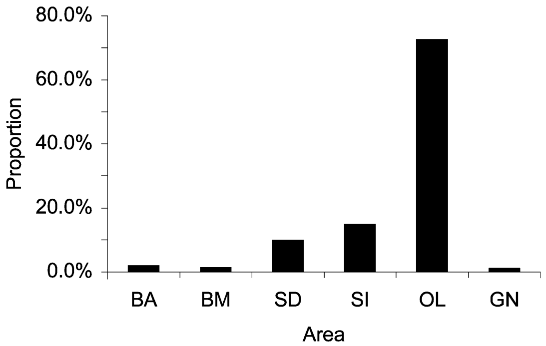

Fig. 6. Mothers with calf distribution in the 1997 winter season.

Table 2

Percentage of cow-calf pairs distribution during the 1980 and 1997 winter seasons. For key see Table 1.

Year	BA	BM	SDC	LSI	LOL	LGN	Total
1980	<1	5	13	13	58	10	100
1997	2	1	10	14	72	1	100

Table 3

Percentage of single whale distribution during the 1980 and 1997 winter seasons. For key see Table 1.

Year	BA	BM	SDC	LSI	LOL	LGN	Total
1980	19	8	10	12	44	7	100
1997	15	11	3	20	50	1	100

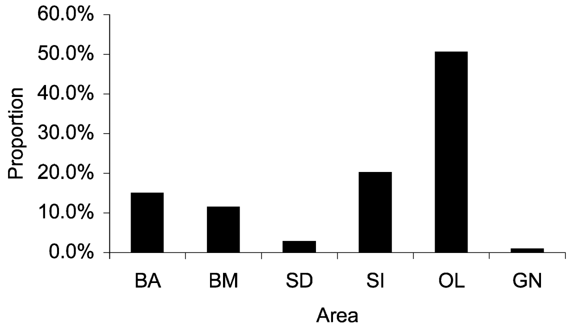

Fig. 7. Single whales distribution in the 1997 winter season.

Calf production and mortality in the lagoons

Jones and Swartz (1984) estimated the minimum calf mortality rate during the winter breeding seasons between 1978 and 1982 by dividing the number of dead calves discovered each season by the number of living and dead new-born calves counted each season. The mortality rates ranged from 2.8% in 1980 to 5.8% in 1978, with a five-year average of 3.5%.

Swartz and Jones (1983) estimated annual gray whale calf production and mortality from data collected in Laguna Guerrero Negro, Laguna Ojo de Liebre and Laguna San Ignacio between 1980 and 1982. A gross annual production of 1,185 calves with a 5.4% mortality based on lagoon strandings yielded a net production of 1,121 calves. This represented a 7.0% annual rate of production (no confidence intervals were reported) based on the best estimate of the 1981 population size of 15,942 whales. By comparison, the proportion of calves passing Pt Piedras Blancas in central California during the spring migration in 1980 and 1981 was 4.3% (679) and 4.8% (769) respectively (Poole, 1981 in Swartz and Jones, 1983), suggesting that a 31% calf decrease may have occurred during the northward spring migration between the breeding lagoons and central California. Based on these results, they postulated two periods critical to calf survival: the first period immediately follows birth, and the second corresponds to the calves' departure from the lagoons and the beginning of the northward migration when potentially some calves fall prey to sharks and killer whales (*Orcinus orca*), or become lost, disoriented and ultimately separated from their mothers prior to weaning (Swartz and Jones, 1983).

For the winter seasons 1997 to 2002 annual calf production was estimated using the assumption that counts of mother-calf pairs in Laguna Ojo de Liebre, Laguna San Ignacio and Santo Domingo Channel comprised 91% of the annual calf production in all of the winter breeding areas, based on the proportional distribution of mother-calf pairs counted during the 1997 winter season in all areas (Table 2). These estimates ranged from a low of 286 calves in 1999 to a high of 910 calves in 1997. Estimates based on counts of mother-calf pairs suggest a decrease in calf production from the 1997 high (910 calves estimated) to a low in 1999 (286 calves), followed by a gradual increase to 670 calves during the period 2000 to 2002 (Table 4).

Additional estimates of annual calf production are based on counts of northward migrating mother-calf pairs at Piedras Blancas in central California (Perryman, 2001; Perryman and Rowlett, 2002; Perryman *et al.*, 2002). These estimates peaked at 1,431 in 1997 and gradually declined to 256 calves in 2001. For the years 1997 to 1999 the estimates of calf production based on counts of mother-calf pairs in the breeding lagoons were lower, suggesting that counts made within the breeding lagoons were underestimating total calf production. It is possible that in those years additional calves were located outside of the lagoons along the coast of Baja California and thus were not counted in the lagoon surveys. If true, this would suggest that areas outside the breeding lagoons constitute important calving or nursery habitat that has been used to a greater extent as the population has increased. Estimates of the percentage of mothers with calves using areas outside the lagoons ranged from lows of 33% to 36% (1997 and 1999) to a high of 53% in 1998. This could be explained by changes in the winter distribution of whales as a result of higher than normal SST in their winter range. During such years, a larger percentage of gray whales can be expected to give birth and rear their newborn calves outside the lagoons and in the coastal waters of northern Baja California and southern California. In contrast, estimates of calf production based on mother-calf pairs migrating past central California in 2000 and 2001 were less than those based on counts within the lagoons (24% and 65% respectively) (Table 4). Assuming these differences are significant could suggest that for these years fewer calves were surviving during the northward spring migration from the lagoons to the summer feeding areas to the north. Increases in calf mortality could be caused by low body fat reserves of the adult females, which in turn are due to a decrease in their principal prey on their feeding grounds as suggested by Le Boeuf *et al.* (2000).

Calf mortality inside the lagoons was estimated using the same methodology described by Swartz and Jones (1983), and varied from 2.3% in 1999 to 0.5% in 2001, with an average of 2.0% (Table 5). These rates are lower than the 5.4% estimated by Jones and Swartz (1984). Between the 1999 and 2001 winter seasons estimated calf mortality declined from 2.2% to 0.005%, and then increased to 1.0% in 2001. Assuming these differences are significant, this trend in mortality may be due to the greater numbers of mother-calf pairs residing outside the breeding lagoons between 1997 and 1999, and thus, fewer dead calves were available to be discovered inside the lagoons.

Table 5

Average calf mortality rate in the breeding lagoons. For key see Table 1.

Year	SDC	LSI	LOL	Total	Stranded calves	Gross calf production	Mortality (±SE)
1997	83	126	626	835	17	852	0.020 (0.0048)
1998	12	52	530	594	7	601	0.012 (0.0044)
1999	32	17	213	262	5	267	0.020 (0.0086)
2000	16	45	256	317	7	324	0.022 (0.0081)
2001	25	29	333	387	2	387	0.005 (0.0036)
2002	97	43	475	615	6	621	0.010 (0.0040)

Duration of stay within the breeding lagoons

Laguna San Ignacio

Resightings data from the photographic identification of 975 single whales and 519 mothers with calves during the winter seasons of 1996 to 2000 revealed that the mother-calf pairs remain within the area of Laguna San Ignacio approximately three times longer than single whales. (Urbán *et al.*, 1997; 1998) (Table 6; Fig. 8). The longest period between first and last sighting for a mother with calf was 61 days during the 1998 winter season. The average time between first and last sightings ranged from 25.5 days (95% CI = 20.1-30.9; $n = 39$) in 1999 to 19.1 days (95% CI = 14.3-23.9; $n = 20$) in 1996. In contrast, the average time between first and last sightings for single whales ranged from 6.8 days (95% CI = 3.6-10.0; $n = 19$) in 2000, to 2.6 days (95% CI = 1.7-3.5; $n = 5$) in 1996.

These results are consistent with findings by Jones and Swartz (1984), Harvey and Mate (1984) and Swartz (1986) who estimated from whale counts that the length of the winter season for mother-calf pairs is 16-18 weeks, whereas the length for single whales (males and females without calves) is 11.5 weeks. This difference can be attributed to the need for mothers to remain in the lagoon habitats for longer periods following the birth of their calves, while single adults gather at the lagoons during the period of highest whale densities to obtain mating opportunities. The longest period between the first and the last photographically documented mother with calf sighting within one season was 91 days (Swartz, 1986).

Laguna Ojo de Liebre

In the 2001 season, a total of 404 gray whales were photo-identified, 219 mothers and 182 single whales. Four of the mothers were first photographed without calves and a few days later with newborn calves. Similar to Laguna San Ignacio, different residency intervals were documented for each class based on re-sightings and photographs of identified individual whales. The photographic records suggest that mothers with calves stayed in the lagoon area for periods of one to at least 76 days with an average of 22.1 days (95% CI = 18.0-26.2; $n = 69$). Similarly, single whales stayed in the lagoon area for a period of one to at least 70 days with an average of 13.2 (95% CI = 4.7-21.7; $n = 20$).

Birth rate

Jones (1990) analysed approximately 6,000 photographs of at least 562 distinctively marked gray whales that were photographed in the breeding lagoons of Baja California. These included 55 mature females that were seen in two to six winter breeding seasons from 1977 to 1982. These females produced a total of 115 calves over the six-year

Table 4

Estimated total annual calf production. For key see Table 1.

Year	SDC	LSI	LOL	Total	Estimate for all breeding areas	Calf estimate for California (±SE)*	Difference	Difference (%)
1997	83	126	626	835	910	1,431 (82.02)	521	36%
1998	12	52	530	594	647	1,388 (91.84)	741	53%
1999	32	17	213	262	286	427 (41.10)	141	33%
2000	16	45	256	317	345	279 (34.79)	-66	-24%
2001	25	29	333	387	422	256 (28.46)	166	-65%
2002	97	43	475	615	670			

* From Perryman and Rowlett (2002); Perryman *et al.* (2002).

Table 6

Duration of stay (days) in Laguna San Ignacio 1996-2000 (95% CI).

	1996		1997		1998		1999		2000	
	X	*n*	*X*	*n*	*X*	*n*	*X*	*n*	*X*	*n*
Single whales	2.6 ± 0.9	5	6.2 ± 3.2	4	5.6 ± 2	5	4.3 ± 2.0	11	6.8 ± 3.2	19
Cow-calf pairs	19.1 ± 4.8	20	19.6 ± 3.5	43	20.6 ± 4.1	43	25.5 ± 5.4	39	23.0 ± 6.6	25

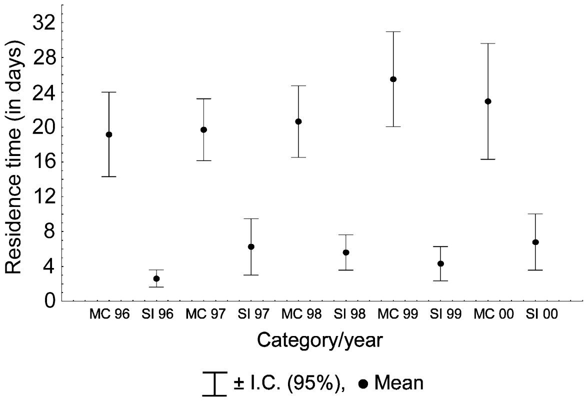

Fig. 8. Residency time of gray whales in Laguna San Ignacio Winter seasons 1996-2000. Key: MC = mothers with calf; SOL = single whales.

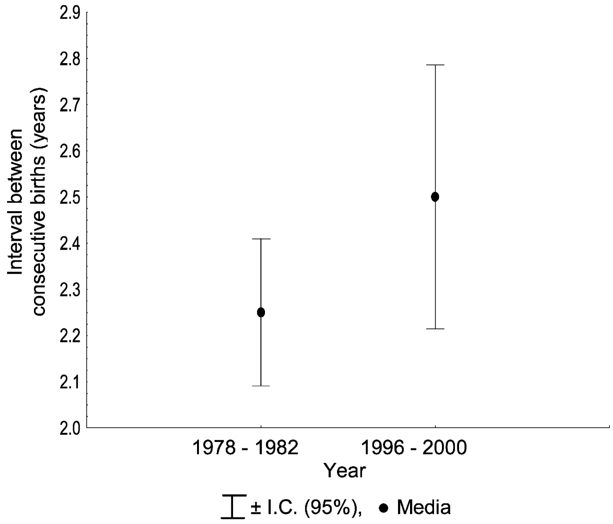

Fig. 9. Birth rate estimates in Laguna San Ignacio.

period. The length of time between birth and consecutive calves was documented for 42 of the females. Calving intervals ranged from 1-4 years but were predominantly 2 years (1 calf every other year). The observed calving intervals were: 1 year ($n = 1$), 2 years ($n = 48$), 3 years ($n = 6$) and 4 years ($n = 5$). The mean length of the calving interval, or breeding cycle, for the population from 1977 to 1982, was estimated as 2.11 (SD = 0.403) years.

Between 1996 and 2000, 1,494 gray whales were identified from photographs in Laguna San Ignacio. From these, 34 females were seen in more than one year, and 18 with calves in different winter seasons. Calving intervals ranged from 2-4 years: 2 years ($n = 11$), 3 years ($n = 7$), 4 years ($n = 1$). The mean length of the calving interval was estimated as 2.50±0.29 years (95% CI = 2.21-2.8; $n = 19$). This interval is significantly higher than 2.11 (SD = 0.403) years estimated for the period 1977 to 1982 (H (1, $n = 78$) = 4.165557 $p = 0.0413$) (Urbán and Gómez-Gallardo, 2000) (Fig. 9).

It is difficult to judge whether this increasing trend in the calving interval is a density-dependent response for a population approaching carrying capacity (Moore *et al.*, 2001), or related to the 1998-1999 change in SST associated with the ENSO events, which is believed to have caused changes in the distribution, abundance and mortality of this population, or a combination of these. It is also possible that some other factor(s) is increasing the calving interval (Brownell and Weller, 2001).

Mortality

Jones and Swartz (1984) summarised published records of dead gray whales found in the breeding lagoons from 1954 to 1983. They also reported on 194 dead gray whales that were discovered in the breeding lagoons between 1977 and 1982, including 57 males and 44 females for which the sex could be determined. Calves were the most frequent age-length class of dead whales averaging 91% (range 78%-100%). The percentage of immature whales ranged from 0% to 19.6% among the lagoons, while adults ranged from 0% to 5%.

Le Boeuf *et al.* (2000) summarised records of stranded gray whales in Laguna Ojo de Liebre, Laguna Guerrero Negro, Laguna Manuela and in the shoreline outside of these lagoons from 1984 to 1999. This compilation was based on the review by Sánchez Pacheco (1991; 1998), unpublished records from the Biosphere Reserve El Vizcaíno (1997-1999), and aerial surveys during 1999. Years with the highest mortality were 1991 with 45 stranded whales (37 adults, 2 yearlings and 6 calves), and 1999 with 71 stranded whales (14 adults, 10 yearlings, 5 calves and 42 unknown ege class).

During the winter season of 2000, relatively high numbers of stranded gray whales were again observed throughout the population's distribution. Along the Mexican coast there were 207 stranded whales, 61.8% adults, 3.9% yearlings, 12.6% calves and 21.7% unknown (Table 7). The number decreased to 10 whales (1 adult, 2 yearlings, 1 calf and 6 unknown) in 2001; and 13 whales in 2002 (4 adults, 6 calves and 3 unknown).

According to Le Boeuf *et al.* (2000), the apparently high mortality rate of gray whales in 1999 and 2000, the low calf production, shifts in the timing of winter occupation of the lagoons, changes in distribution and behaviour during migration and the reproductive season, are consistent with the hypothesis that the animals were suffering from low reserves of body fat and had insufficient energy to survive the regular period of fasting between feeding seasons. They argued that the most likely cause of this condition was a decrease in the gray whale's principal prey on the summer feeding grounds, a decrease brought about by increased predation and the depressing effect of increasing water temperature over the last decade on amphipod biomass.

Moore *et al.* (2001) argued that this event could be an indication that the Eastern gray whale population is reaching environmental carrying capacity. However, Brownell and Weller (2001) argued against the 'carrying capacity hypothesis' and suggested that some global or ocean basin change in the North Pacific may be influencing the availability of or access to primary prey for both the eastern and western populations of gray whales.

Movements, telemetry

Harvey and Mate (1984) and Mate and Harvey (1984) utilised VHF-radio tags to monitor the movements and behaviour of 18 gray whales in Laguna San Ignacio between 1979 and 1980. Ten of the whales tagged in February 1980 had mean dive duration from 1.0 to 2.6 mins (mean = 1.57 ± 0.02 min (SE)). Of the 11,080 dives recorded, 99% were less than 6 min and 49% less than 1 min in duration. The longest dive was 25.9 minutes. Tagged whales averaged 4.4 ± 0.6 sec (SE) at the surface per surfacing. Eight of the tagged whales averaged less than 2.9% of the time at the surface (range 1.56-16.3%). The tagged whales averaged 35.6 surfacing per hour. Three surfacing patterns were documented: regular-long, regular-short and clumped. These accounted for approximately one-half of all dive sequences analysed for two whales. Three radio-tagged whales were monitored for 4, 5 and 11 days, and moved into the ocean on 2, 2 and 7 occasions, respectively. Most oceanic movements were at night and 40% were against the tide. Seven of the tagged whales did not remain in the lagoon for more than 2 days. Those whales that left the lagoon travelled an average of 87km day^{-1} during the northward migration. No differences were found between maximum swimming speeds of single adults and those of mothers with calves. Some tagged whales moved both to the north and south of their tagging site in Laguna San Ignacio to adjacent breeding areas. Some tagged whales lingered around Laguna Ojo de Liebre and one whale was found apparently feeding with up to 60 other whales in an area along the northern coast of Baja California. One whale tagged in 1979 travelled 6,680km from San Ignacio to Unimak Pass, Alaska, which it reached 94 days after its tagging in Mexico.

Ludwig *et al.* (2001) investigated movements and diving of female gray whales in Laguna San Ignacio during the winter seasons of 1999-2001. Twenty-five VHF transmitters were successfully deployed with a crossbow on female gray whales with calves to investigate their preference for specific areas within and around the lagoon. Movements were documented for up to nine successive days, including night movements. Mother-calf pairs used the entire lagoon interior and periodically exited the lagoon. Most animals preferred the middle and lower lagoon, with mothers with older calves preferring the lower zone nearest the entrance. There was a trend for movements to the lower lagoon and to leave the lagoon area during night time (significant in six females). Some females with calves stayed outside the lagoon for extended periods of up to 2 to 3 days (i.e. in the Bahia Ballenas). It confirms the assumption that the Bahia Ballenas area is important to the whales, and should be included in any conservation plan for the lagoon area. During winter 1999 and 2001, Multi-Sensor/VHF tags were attached to female gray whales with calves, using suction cups with dissolvable magnesium release mechanisms. Data on depth, duration, tilt, temperature and light intensity were recorded. Tags were deployed successfully on 17 females with calves, recording a total of 40 hours of diving data, representing 1,080 dives. Overall mean dive duration was 1.54 min ± 0.27 SD (max. 10.5 min). It is interesting to note that there is no significant difference in average dive duration between the data recorded in 1999 and 2001, and those reported by Harvey and Mate (1984) in 1980 (U-test, U = 93.0, $n = 28$, $p = 0.98$). Regular long dives (> 60s) lasted 2.81 ± 0.85 min in 1999, and 2.58 ± 0.5 min in 2001. Two different dive profiles were distinguished: V- and U-shaped dives. Maximum dive depth was 27.4m. Mother-calf pairs used the whole depth profile of the lagoon. Bouts consisting of adjacent, extended U-shaped dives were recorded. There was a positive correlation between the durations of dives preceding and following a surfacing. Thus, a whale tended to make a series of dives of similar length rather than alternating short and long dives. Mean breathing rate was 0.61 breaths min^{-1} ± 0.10 SD. Resting females had significantly more breaths per surfacing than travelling whales (U-Test, $p < 0.01$). Resting was apparently an important part of the surface-dive characteristics of mother-calf pairs in the breeding grounds (Ludwig *et al.*, In prep).

Environmental and anthropogenic threats

Climate change

Although not a threat in Mexican waters, the major climatic regime shift in the Arctic region, probably coupled with a shortened feeding season due to extensive seasonal ice, lower overall food availability and El Niño and La Niña phenomena probably contributed to the mass mortalities, the emaciated whales and low calf production observed in Mexican waters, and all along the distribution range of gray whales (Le Boeuf *et al.*, 2000; Jones, M.L. and Swartz, 2002; Perryman *et al.*, 2002).

Mortality in passive fishing gear

Norris and Prescott (1961) documented the first gray whale taken in fishing gear. The whale was caught in April 1959 off the Palos Verdes Peninsula, California in a gillnet used for

Table 7

Gray whales stranded on the Mexican coast during the winter season of 2000. For key see Table 1.

		BA	BM	SDC	LSI	LOL	C	Total	%
Age class	Adults	0	10	2	34	34	48	128	62
	Yearlings	0	1	0		7	0	8	4
	Calves	1	5	0		1	19	26	12
	Unknown	0	3	1			41	45	22
	Total	**1**	**19**	**3**	**34**	**42**	**108**	**207**	**100**
Sex	Males	0	11	1	27	16	23	78	38
	Females	1	7	1	6	24	0	39	19
	Unknown	0	1	1	1	2	85	90	43
	Total	**1**	**19**	**3**	**34**	**42**	**108**	**207**	**100**

white sea bass (*Cynoscion nobilis*). Brownell (1971) reported four additional dead gray whales from California fisheries in the 1960s. Heyning and Lewis (1990) reported two dead gray whales and 61 more entangled gray whales during the 1980s in California fisheries. Forty of these 61 whales were observed alive but many of them were entangled in fishing gear and their survival was questionable in many cases. Most entangled whales were three years of age or younger. During the 1990s, two gray whales were observed dead in the offshore driftnet fishery off California (J. Carretta, pers. comm.). Thus, the minimum incidental bycatch in California fisheries is 48 whales over the past 43 years.

In Mexico, there have been six documented incidents of gray whales entangled in passive fishing gear. Two sub-adults (11-12m) were caught in a large nylon rope and steel chain in Playa Palmira, close to San Jose del Cabo at the southern end of Baja California Peninsula: one in 1989 and the other in 2000. Both whales were released by local fishermen, divers and scientists with at least superficial injuries to the rostrum and mouth. Two calves were observed dragging a buoy and line entangled around their peduncle: one in Santo Domingo Channel in 1992 and the other in Laguna San Ignacio in 1999. One gray whale, probably a yearling (10-11m) was caught by a 'curvinera' gillnet in Bahia de Ballenas, 15 miles NW of Laguna San Ignacio mouth. This whale was released by students of the UABCS after four days of entanglement with injuries to the peduncle. Finally, the only documented fatal incident was a calf found dead in a gillnet used, apparently illegally, for sea turtles in Laguna San Ignacio in 1996.

Angliss *et al.* (2001) reported additional human-caused mortality in fishing gear in Alaska, British Columbia and Washington but the data are very limited. Data on gray whales taken in other parts of their range (Russia) are not available.

Ship strikes

Gray whales are more vulnerable to being struck by ships because of their near-shore migration route (Laist *et al.*, 2001). Five deaths are known to have been caused by ship strikes in Californian waters between 1993 and 1998 and one in Alaskan waters in 1997 (Angliss *et al.*, 2001). It is believed that many ship strikes and subsequent mortality go unreported because the whale may not die when hit and may not strand when dead. According to fishermen in Santo Domingo Channel, a gray whale died during the 2002 season after being struck by a small, fast vessel.

During the winter season, when the whales are inside the lagoons, small fiberglass fishing boats (pangas) occasionally hit whales transiting to the fishing areas outside the lagoons. There are no records of strikes by large ships on gray whales in Mexican waters, but based on the photo-ID catalogue of the UABCS, at least 2% of the whales ($n = 1{,}600$) have injuries (scars) presumably produced by impact with a large keel or a propeller.

Escalera Naútica (Nautical steps)

Currently, in waters of the Baja California Peninsula, gray whales are relatively undisturbed due to the near absence of military exercises, coastal development and industries. However, this will change if the 'Nautical Steps' tourist development proceeds as proposed by Mexico's Bureau of Tourism. The project consists of a mega-development that would be distributed on more than 2,500 miles of coast. It is aimed at luring the 1.6 million boat owners in California and other nearby US states into a new system of harbours, wharves, hotels, restaurants, airports and airstrips. Marinas of the Nautical Steps network would link ports beginning in Ensenada, just south of San Diego, to marinas located along the entire western and eastern coasts of the Baja Peninsula. No more than 120 miles apart, some of the marinas would be built along the coasts of Sonora and Sinaloa states, which face Baja across the Gulf of California, on the mainland coast of Mexico. Only five such marinas or harbours currently exist; others would be expanded or built in new areas. If Nautical Steps is not carefully planned to be a low-impact development it could pose a major risk to gray whales and other large cetaceans in the area.

Major potential threats include: (1) increased whalewatching activities along the Baja California coast and outside the breeding lagoons; (2) increased noise associated with vessel traffic as much man-made noise in the ocean occurs in the lower frequency range and at high levels, which could interfere with or mask gray whale' sounds and possibly damage their hearing (Jones and Swartz, 2002); and (3) pollution from vessels and fuel stations, marinas, golf courses and hotels.

Whalewatching

Gilmore (1976b), who directed the first long-range marine mammal tourist ventures into Baja California waters in 1970, stated that the 'entry of man with his industrial or recreational activities into the calving and courting lagoons… could have only an adverse effect on the reproduction and survival of the newborn… the damage, if any as of now, has not been measured'.

Gard (1974), the first investigator to study the effects of human activities on the whales in the lagoons, concluded that the most serious threat was posed by San Diego-based excursion boats arriving to observe and photograph the whales. Rice (1975, in Reeves, 1977), claimed that 'considerable harassment is caused by commercial cruise boats which take people into the calving lagoons to see the whales'. He regarded this kind of activity, together with industrial development, as the 'greatest threat' to the whale population.

Kenyon (1973, in Reeves, 1977) described the observed effects on gray whales of close approach by outboard skiffs, but he, like Gard (1974), was unable to demonstrate unequivocally that such disturbances actually harmed the whales. 'It is unknown', he admitted, 'what effect this continued large-scale disturbance may have on the habits, behaviour, and population size of the gray whale. Certainly the effect is not beneficial'. Villa-Ramírez (1975), who was on the same cruise as Kenyon, wrote that 'the hundreds of tourists who want to view whales closely in the lagoons force the animals to seek other quiet areas far from their normal routes'.

Jones *et al.* (1994) noted that the primary, more frequent sources of potential human disturbance to the gray whales in Laguna San Ignacio from 1977 to 1982 were local fishing cooperatives inside the lagoon, US commercial whalewatching excursions (both ocean-going and overland groups) and scientific researchers. During the course of their study, they found no statistically significant evidence to substantiate the contention that whalewatching had a detrimental effect on the demography of gray whales in Laguna San Ignacio. They concluded that as of 1982, whalewatching activity in the lagoon did not seem to pose a serious threat to gray whales, but its potential for becoming a problem should be acknowledged. Urbán *et al.* (1997) detected a decrease in whale density in Laguna San Ignacio compared to earlier studies by Jones and Swartz (1984) and suggested that this variation was due to natural modification in timing and movements of the whales in response to changes in environmental factors or human activities such as whalewatching (Urbán and Gómez-Gallardo, 2000). Mosig (1998) reported an inverse relation between the average number of whalewatching boats and the average number of gray whales in Laguna San Ignacio in the winter of 1997, but she was not able to demonstrate a direct effect of the vessels on the whales. Heckel *et al.* (2001) found significant differences in both speed and direction of the transit of migrant gray whales with and without presence of whalewatching boats in Bahia de Todos Santos, Baja California.

Noise disturbance

The number of gray whales occupying Laguna San Ignacio declined in 1984 following a series of noise playback studies within the lagoon, but numbers appeared to return to previous levels the following year when no playback studies were conducted (Jones *et al.*, 1994). Other playback studies during the gray whales' migration past central California documented avoidance and disruption of their migration (Malme *et al.*, 1983; 1984). Many of the sounds produced by Outer Continental Shelf (OCS) activities of the Minerals and Management Service, USA, are within the frequency range of sounds produced by and, thus, probably heard by the California gray whale. The acoustical pulses used in seismic surveys off California are generated by air-guns or water-guns. If seismic-generated sound waves exceed the 'background' noise, they could interfere with gray whale communication or disturb behaviour. In controlled experiments, gray whales have exhibited startle responses, avoidance reactions, and other behavioral changes when exposed to seismic pulses at sound levels corresponding to a distance of 2-3 miles from an air-gun setup off the California coast. In recent biological opinions issued for OCS activities, the National Marine Fisheries Service, the Federal agency responsible for protecting the gray whale, has concluded that geophysical seismic activities may create a stressful situation for gray whales, but are not likely to inhibit their migration. In experiments conducted off central California, migrating gray whales have been exposed to underwater playbacks of drill-ship, semi-submersible, drilling platform and production platform sounds. Avoidance reactions to all sounds were observed at levels corresponding to distances of about 1,000m from a drill-ship and only 4-22m from the other three sources (Minerals Management Service, 2002). Limited observations also suggest that stationary industrial continuous noise results in less dramatic reactions by cetaceans than to moving sources of sound, particularly from ships (Richardson *et al.*, 1995).

LNG (Liquid natural gas) facilities

Five different energy consortiums have announced plans to build Liquefied Natural Gas (LNG) terminals at different locations along the northern Baja California coast. Sempra Energy and partner CMS Energy plan to build a $400-million (US) terminal about 75km (probably on Punta Salsipuedes) from the US-Mexico border. Another project with El Paso Corp., Royal Dutch/Shell, Chevron Texaco Corp and Marathon Oil Co. plans to build a terminal at Rosarito (Playas de Tijuana). The other three consortiums are: Marathon Oil, Chevron Texaco and El Paso Corporation and Conoco Phillips. These projects plan to re-gasify the super-cooled liquid gas and pipe it to California and other destinations in Mexico. The Sempra project will include a pier of a 300m or more from shore. Both projects hope to be operational around 2005 (Kraul, 2001a; b). Huge reservoirs of natural oil exist in the Tarija Province of Bolivia. The plan is to extract the gas and pipe it to a Pacific port, liquefy the gas and transport it by ship to the Mexican LNG terminals (Anon., 2002). First, however, Bolivia needs to find a port in either Peru or Chile.

The Sempra project, if established at Punta Salsipuedes, would be at an important point of the gray whale migration, especially for northbound females with their calves that pass very close to this prominent point of land.

FUTURE RESEARCH AND MONITORING NEEDS

Proportion of population utilising the breeding lagoons

The surveys conducted in the lagoons and coastal areas of Baja California during the winter breeding season have involved aerial and vessel-based counts to obtain an index of the density of gray whales. At best, these counts indicate the beginning, peak and end of the breeding season. To determine the relative importance of the coastal and lagoon areas as breeding habitats, it is necessary to determine the estimate of the population that congregates in these breeding habitats each winter, and the proportion of those that utilise specific areas. This will require the integration of the survey results with estimates of residency within specific lagoons, and the 'turn-over rates' or rate of exchange of whales in those sites. In addition, the timing and duration of the winter breeding season needs to be better documented. Previous surveys have not documented the arrival of the first gray whales in Baja California, or the departure of the last whales in the spring. Future surveys should begin early and continue for a sufficient time to document the 'tails' of the winter occupation of the lagoons by whales.

Photographic identification

To address residency times and inter-lagoon movements, individual reproductive rates, and fidelity to specific areas, photographic identification programmes should continue in all areas that gray whales congregate during the winter. The photographs provide a permanent record that contributes to numerous research objectives, including the identification of specific components of the population in other portions of their range (e.g. Northwest summer residents, Bering Sea feeding aggregations, etc.).

Radio telemetry

Radio tagging, both VHF and satellite-based, have great potential to improve understanding of gray whale migration paths, rates of travel, and yearly variation in the migration timing and residency in the breeding lagoons and coastal areas of Baja California. These data are valuable for addressing questions of the effects of seasonal variation in reproductive behaviour that may be the result of changes in environmental conditions.

Genetic research

Genetic research conducted in recent years suggests that groups of related gray whales preferentially use specific breeding lagoons for calving. Such a structure within the population could have implications for its resilience to perturbations from natural climate changes, or from disturbance by human activities (e.g. oil spills). Additional genetic sampling of gray whales in all the principal lagoon areas should be undertaken to increase the size of the genetic data base for this population. Larger samples will support statistically meaningful analyses and provide the basis for conclusions concerning population sub-structure.

Calf production

Calf counts during the northbound migration vary considerably from counts in the breeding lagoons. There is a reported loss of about 30% of the calves between the breeding lagoons and central California (Swartz, 1986). This needs to be investigated. An independent count of northward migrating mother-calf pairs in northern Baja California should be considered. This would allow comparisons with the counts from central California. An appropriate site for land surveys would need to be identified in northern Baja California.

Whalewatching

Assessments of long-term effects of whalewatching are aimed at measuring changes in population parameters, physical condition of individuals and habituation or tolerance (IFAW *et al.*, 1995). The population parameters that can be monitored in conjunction with whalewatching programmes and used to assess the long-term status of whale stocks could include:

(1) Those related to the behaviour of photo-identified whales such as: residency times, philopatry and fecundity/ calving rates.
(2) Those related to behaviour of the whales with or without the presence of tourist boats versus land based platforms.
(3) Those related to genetic studies using skin samples from living and stranded dead whales, including research on genetic diversity and relatedness.
(4) Mortality including the counting, measuring and determining the sex of dead whales found in the lagoons.

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