Offshore Migratory Corridors and Aerial Photogrammetric Body Length Comparisons of Southbound Gray Whales, *Eschrichtius robustus*, in the Southern California Bight, 1988–1990

JAMES L. SUMICH and IVAN T. SHOW

ABSTRACT—*Through most of their annual migration, gray whales,* Eschrichtius robustus, *remain within 10 km of shore, but in the Southern California Bight many individuals migrate much farther from shore. This paper summarizes aerial survey and photogrammetric efforts to determine body lengths and temporal and spatial distributions of migratory gray whales in the southern portion of the Southern California Bight. Aerial surveys were flown along 13 east–west transects between lat. 32°35′N and 33°30′N during the southbound gray whale migratory seasons of 1988–90 in the Southern California Bight. Photogrammetry was used to obtain body length estimates of animals during some of the surveys. A total of 1,878 whales in 675 groups were sighted along 25,440 km of transect distance flown and 217 body lengths were measured. Using position and heading data, three major migratory pathways or corridors in the southern portion of the bight are defined. Those migrating offshore were split almost evenly between two corridors along the west sides of Santa Catalina and San Clemente Islands. These corridors converge on the mainland coast between San Diego and the United States–Mexico border. No whales larger than 11.5 m were photographed within 30 km of the mainland coast, suggesting that smaller, and presumably younger, whales use the coastal migratory corridor through the California Bight.*

Introduction

Gray whale, *Eschrichtius robustus*, migratory distribution encompasses coastal waters in the eastern North Pacific Ocean from the Chukchi Sea in the north (Rugh and Fraker, 1981; Miller et al., 1985) to the periphery of the Gulf of California (Findley and Vidal, 2002). Within this geographical range, gray whales accomplish one of the most extensive annual migrations of any mammal. This 15,000–20,000 km migration covers 50° of latitude and links the summer feeding areas in the Bering and Chukchi Seas with the warmer courting, calving, and assembling grounds along subtropical coastlines of Baja California in winter (Gilmore, 1960; Rice and Wolman, 1971; Sumich, 1986).

The route and timing of the migration of California gray whales were described in general terms by Gilmore (1960) for the southern part of the migration and by Pike (1962) for the northern part, although they both lacked sufficient empirical data to clarify year-to-year or age- and sex-related variations in migratory timing. The general picture of migratory timing was substantially improved by the detailed set of morphometric data obtained from 317 whales collected under Special Scientific Permits issued to the U.S. Bureau of Commercial Fisheries between 1959 and 1969 (Rice and Wolman, 1971). Both south- and north-bound whales were sampled between December 1 and April 10 off the central California coast (lat. 37.5° to 38.0°N).

Shore-based studies of migratory patterns have been conducted at Unimak Pass, Alaska (lat. 55°N) (Rugh, 1984); Newport, Oregon (lat. 45°N) (Herzing and Mate, 1984); California (lat. 37°N) (Reilly et al., 1983); (lat. 36°N) (Poole, 1984); and Laguna San Ignacio (lat. 28°N) (Jones and Swartz, 1984). The results were summarised by Reilly (1984) and Rugh, et al. (2001). Collectively, these studies demonstrate that the migration is best described as multiple annual cycles which exhibit considerable temporal overlap in the same geographic range (Sumich, 1986).

Through most of their migration, gray whales remain in shallow coastal waters, almost always within 10 km of shore (Rice and Wolman, 1971; Reilly et al., 1983; Braham, 1984; Herzing and Mate, 1984; Poole, 1984). However, in the California Bight (lat. 32.5–34.5°N: Fig. 1) with its several large islands extending as much as 100 km south and west of the mainland coast, alternative island-hopping migratory routes are used by gray whales. Rice (1965) and Gilmore[1] reported a few incidental sightings of gray whales as far west as San Clemente Island, but both assumed that such offshore occurrences did not reflect major migratory pathways and that, in the bight, most gray whales continued the nearshore migratory behaviour typical of coastal areas farther north.

Later boat-based surveys west of San Diego by Rice and Wolman (1971) generated estimates of a higher percentage (59%) of southbound whales further than 9.3 km west of the mainland shore. It is doubtful that these estimates ac-

James L. Sumich was with the Biology Department, Grossmont College, El Cajon, CA 92020. Current address: Hatfield Marine Science Center, Oregon State University, Newport, OR 97365 (e-mail: jim.sumich@gcccd.edu). Ivan T. Show was with Southwest Research Associates, 1604 Calle Plumerias, Encinitas, CA 92024. Current address: Alaska Department of Fish and Game, P.O. Box 115526, Juneau, AK 99811-5526.

[1]Gilmore, R. San Diego Museum of Natural History, San Diego, Calif., 1979, personal commun.

curately reflect actual distributions of southbound whales because they were calculated using an assumed continuous distribution of whales across an offshore migratory front nearly 200 km wide. Additionally, these surveys were made about 2 weeks after the peak of the migration and may not have included a representative sample of all age groups and sexes.

Results of previous aerial surveys of gray whales in the California Bight indicate that a substantial, but undefined, portion of the population migrates south well offshore at least to the United States–Mexico border. Leatherwood (1974) reported approximately equal encounter rates with gray whales 80–160 km offshore as for 0–80 km offshore. No adjustment was reported for distances from island shorelines or for varying survey effort through the migratory season. Between 1980 and 1983, monthly flights made over much of the California Bight (Dohl et al.[2]) indicated that gray whales migrated throughout the bight, with about 24% using a mainland coastal migratory route. In a study in the Santa Barbara Channel in 1980–81, Leatherwood[3] noted that south-bound gray whales passed the west and east sides of San Miguel Island in approximately even numbers. Their study did not extend to the southern portion of the bight. Incidental sightings of gray whales were noted during aerial surveys of portions of the bight made during 1980–85 (Oliver and Jackson[4]) to investigate abundance of pinnipeds and small odontocetes and most gray whale sightings occurred in the vicinity of Santa Catalina Island. Limited aerial surveys for south-bound gray whales in the northern Channel Islands were conducted in 1986 (Jones and Swartz[5]), but these surveys did not extend into the southern half of the bight. Anecdotal reports by whalewatching boat operators south of Los Angeles (e.g. H. Helling[6]) also suggest a substantial decline during the 1980's in the numbers and group sizes of southbound gray whales accessible to half-day whalewatching boats migrating through nearshore mainland coastal waters.

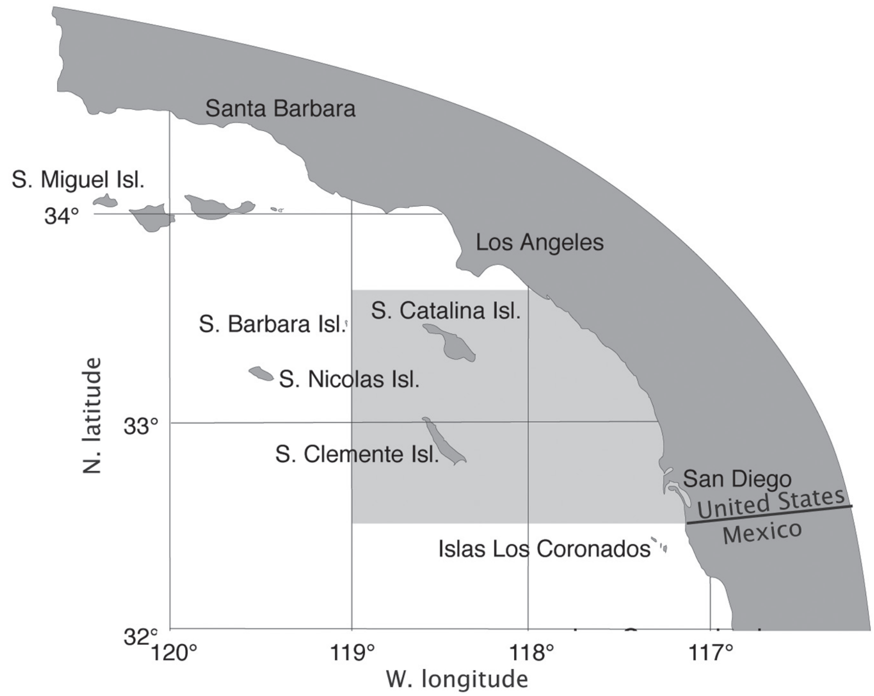

Figure 1.—The California Bight showing major geographic features and islands. Study area is shaded.

This paper reports on results of three years (1988–90) of aerial surveys of southbound gray whales in the southern portion of the California Bight. The purpose was to determine the spatial and temporal distribution of migratory gray whales in the southern portion of the California Bight. A particular emphasis of this study was to detect and define migratory corridors and to compare the numbers, timing, and body size distributions of southbound gray whales migrating near the mainland coast with those of animals migrating near Santa Catalina and San Clemente Islands, located about 40 and 80 km, respectively, west of the southern California coastline.

Methods

Aerial Surveys

Aerial transects were flown during the southbound gray whale migratory seasons of 1987–88 through 1989–90 (referred to here as 1988, 1989, and 1990 seasons) over much of the southern portion of the California Bight (Fig. 1). High-wing, single-engine aircraft (i.e. Cessna[7] 172 or 182L) were

[2]Dohl, T. P., R. C. Guess, M. L. Duman, and R. C. Helm. 1984. Cetaceans of central and northern California, 1980–1983: Status, abundance, and distribution. Prep. for Pacific OCS Region, Minerals Management Service. OCS Study MMS 84-0045, 284 p.

[3]Leatherwood, J. S. Hubbs-Sea World Research Institute, San Diego, Calif., 1979, personal commun.

[4]Oliver, C. W., and T. D. Jackson. 1987. Occurrence and distribution of marine mammals at sea from aerial surveys conducted along the U.S. west coast between December 15, 1980 and December 17, 1985. U. S. Dep. Commer., NOAA, NMFS, SWFC Admin. Rep. LJ-87-19, 189 p.

[5]Jones, M. L., and S. L. Swartz. 1987. Radiotelemetric study and aerial census of gray whales during their southward migration in the Channel Islands National Marine Sanctuary, January 1986. *In* Final Report to National Marine Mammal Laboratory. NMFS, Seattle, p. 97. Prep. for U.S. Dep. Commer. NOAA Sanctuary Program, No. 50-ABNF-6-00067.

[6]Helling, H. San Diego, Calif., 1990, personal commun.

[7]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Table 1.—Summary of survey flight results.

Distance Year	No. of flown (km)	No. of surveys	No. of sights	No. of whales	Mean group size	No. of sights/survey	whales/ 100 km flown
1987–88	7,422	25	231	642	2.78	9.2	8.6
1988–89	11,597	34	356	1,007	2.83	10.5	8.7
1990	6,421	19	88	229	2.60	4.6	3.6

Table 2.—Means and standard deviations of nearshore and offshore group sizes of gray whales in the California Bight.

Area	No. of groups	Mean	s.d.
Nearshore	143	2.51	1.14
Offshore	532	2.89	2.17
Combined	675	2.79	2.12

Table 3.—Summary of photogrammetric effort, sample size of measured lengths, and mean and standard deviations of lengths for 1989 and 1990.

Year	Distance flown (km)	No. of film frames	No. of whales measured	L(m)	
				Mean	s.d.
1898	733	92	154	11.1	0.8
1990	527	48	60	11.3	0.9

used with an observer on each side and a data recorder in the co-pilot position. Preferred flight altitude was 1,000 ft (305 m), but other altitudes were used when dictated by military, air traffic, or weather restrictions. Time, number of animals, Loran C position and compass heading, barometric altimeter reading, sea state, visibility, and behavioral notes for each sighting were recorded manually. Survey efforts were discontinued when visibility declined to less than 10 km or sea surface conditions exceeded Beaufort 3.

Survey effort for the 1988 and 1989 migratory seasons involved several flights per week from early December to late January or early February. In 1990, surveys began in early January and continued to 20 February to include the early portion of the phase A northbound migration (Poole, 1984). Thirteen equally spaced east–west transects 5′ of latitude apart were included. The transects lay between lat. 32°35′ and lat. 33°30′N. Each transect extended from the mainland coast westward to long. 119°W. Within the constraints necessary to avoid resighting the same whales, the order and spacing in which the transects were flown was randomized, although subsequent surveys of each transect was started from the same point. At least two transects were flown on each day, one westbound and one eastbound. Observations were continued on the N–S segments between transect legs.

The study area was divided into approximately 240 discrete 5′ lat. by 5′ long. blocks, and the number of kilometers flown in each grid block was determined. The map position of each whale group sighted was plotted and its heading was extended as a 7 km long line of travel, equivalent to approximately one hour of migratory travel time, to indicate relative density distribution of whales across the bight and to delineate migratory pathways within the bight.

Photogrammetry

On 10, 14, and 18 January 1989 and on 8, 9, and 12 January 1990, the aerial surveys north of 33°45′ were combined with photogrammetry (Perryman and Lynn, 2002) to obtain estimates of body lengths. Vertical aerial photographs were taken through a camera port installed in the side cargo hatch of the Cessna 182L. When animals surfaced to blow, photographs were taken with a Pentax 60×45 mm still camera equipped with a motor drive and vertical bubble level and a calibrated 208 mm lens. The camera was hand-held using a shutter speed of 1/1000 sec to reduce vibration and motion blur. Time, Loran C position, and barometric altimeter readings for each film frame were recorded manually. The camera-aircraft altimeter system was calibrated by photographing the 14.2 m wide west end of the Scripps Institution of Oceanography pier (corrected for its height of 10.1 m above mean lower low tide level). As the maximum vertical range of local tides at the shoreline is less than 1% of our flight altitude and diminishes in deeper water, no corrections for tidal variations were made.

Whale images were projected from the film negatives on a 23× magnifier calibrated with a microscope stage micrometer, and the magnified image was measured to the nearest millimeter (equivalent to about 1% of adult body length). Body length was measured only if both the fluke notch and rostrum tip were clearly visible. These film image body lengths were converted to actual body length (L) values with:

$$L, m = (\text{altitude, m}) \times (\text{length of film image, mm}) / (\text{lens focal length, mm})$$

Results

Aerial Surveys

The survey effort is summarized by year in Table 1. A total of 1,878 southbound whales in 675 groups were sighted along 25,440 km of transect distance flown. The distribution of survey effort, in km flown for each year, is shown in 5′×5′ grids in Figure 2. The positions and headings of each whale group sighted are shown by year in Figure 3. Three principal migratory corridors are apparent, an inshore corridor near the mainland coast and two farther offshore associated with the west sides of Santa Catalina and San Clemente Islands.

Temporal changes in sighting rates (whales/km) for each of the survey years are summarized in Table 1 and shown in Figure 4. Sharp mid January peaks are obvious for 1988 and 1989, with a broader, ill-defined January peak in 1990.

There were no significant group size differences for different survey years (ANOVA $F = 1.117$, $p = 0.33$). In Table 2, group sizes of whales migrating within 30 km of the mainland are compared with those migrating farther offshore. Group sizes in the offshore migratory paths were more variable and were slightly, but significantly, larger than those near shore ($t = 1.647$, $p = 0.04$).

Photogrammetry

For 5 of the 6 photogrammetric surveys, altimeter calibration correction factors were obtained (mean = 1.021, CV = 4.2%) and applied. The mean correction factor was applied to whale images obtained on the sixth, uncalibrated flight.

Table 3 summarizes the photogrammetric effort and the number of images of sufficient quality for length determinations. The 1989 images included a 4.0–4.5 m long neonate and another 9.5–10.0 m animal with missing flukes. Both are excluded from further analysis, as were two neonates (L = 4.0–4.5 m) photographed in 1990.

Frequency distributions of body lengths for both years are shown in Figure 5. Calculated lengths ranged from 8.4 to 13.2 m (mean = 11.2 m) in 1989 and from 9.7 to 12.5 m (mean=10.9 m) in 1990. Mean body lengths differed only slightly between 1989 and 1990 (t = 1.97, p = 0.045). Comparisons of body length with date are not presented, as all photogrammetric surveys were conducted within short time spans; 8 days for 1989 and 4 days for 1990.

Body lengths as functions of distance offshore are shown in Figure 6. No whales longer than 11.5 m were photographed within 30 km of the mainland, and the 2-year combined overall distribution of these nearshore body lengths was significantly different than those farther offshore (K/S max. diff = 3.52, p = 0.027).

Discussion

Gray whales observed migrating south through the bight exhibited similar year-to-year patterns of positions and headings during this study (Fig. 3), with the smallest portion of these whales using what Rice (1965) referred to as "the major inshore migration route." The results of this study delineate two additional major corridors, one each along the west side of Santa Catalina Island (40–50 km offshore) and San Clemente Island (80–90 km offshore). We cannot address the question of where the offshore departure from the coastal pathway occurs north of our study area. But, after clearing the southern ends of Santa Catalina and San Clemente Islands, these southbound whales veer southeast to merge with the inshore corridor between La Jolla and the United States–Mexico border, where most whales presumably continue south near the mainland Mexican coast.

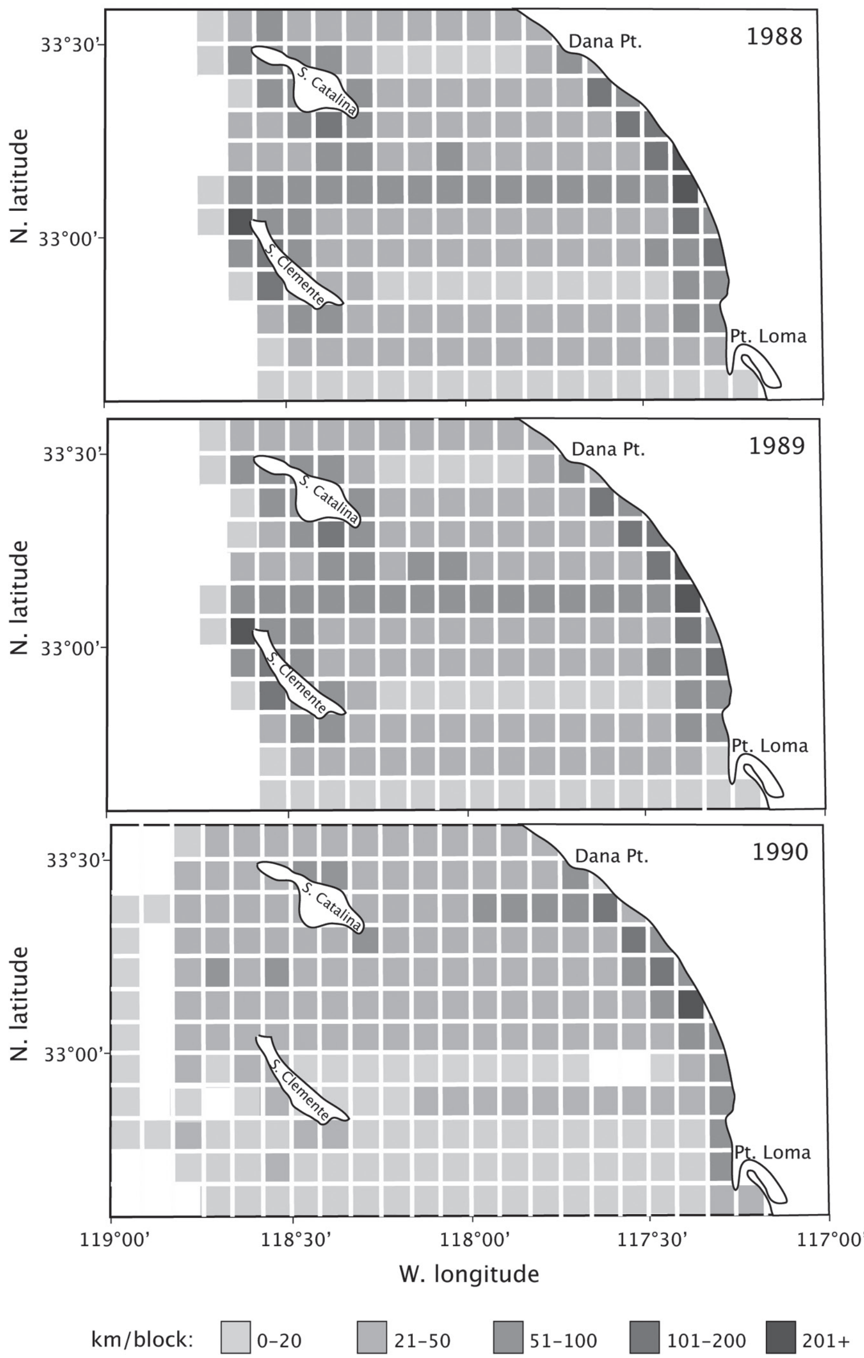

Figure 2.—Cumulative numbers of survey kilometers flown in 5′×5′ blocks (10 km×10 km): 1988–90.

Body length values were compared to those reported by Rice and Wolman (1971) and by Sumich et al. (2001) to estimate maturity. Rice and Wolman (1971) found that the median length at puberty was approximately 11.4 m (11.1 m for males and 11.7 m for fe-

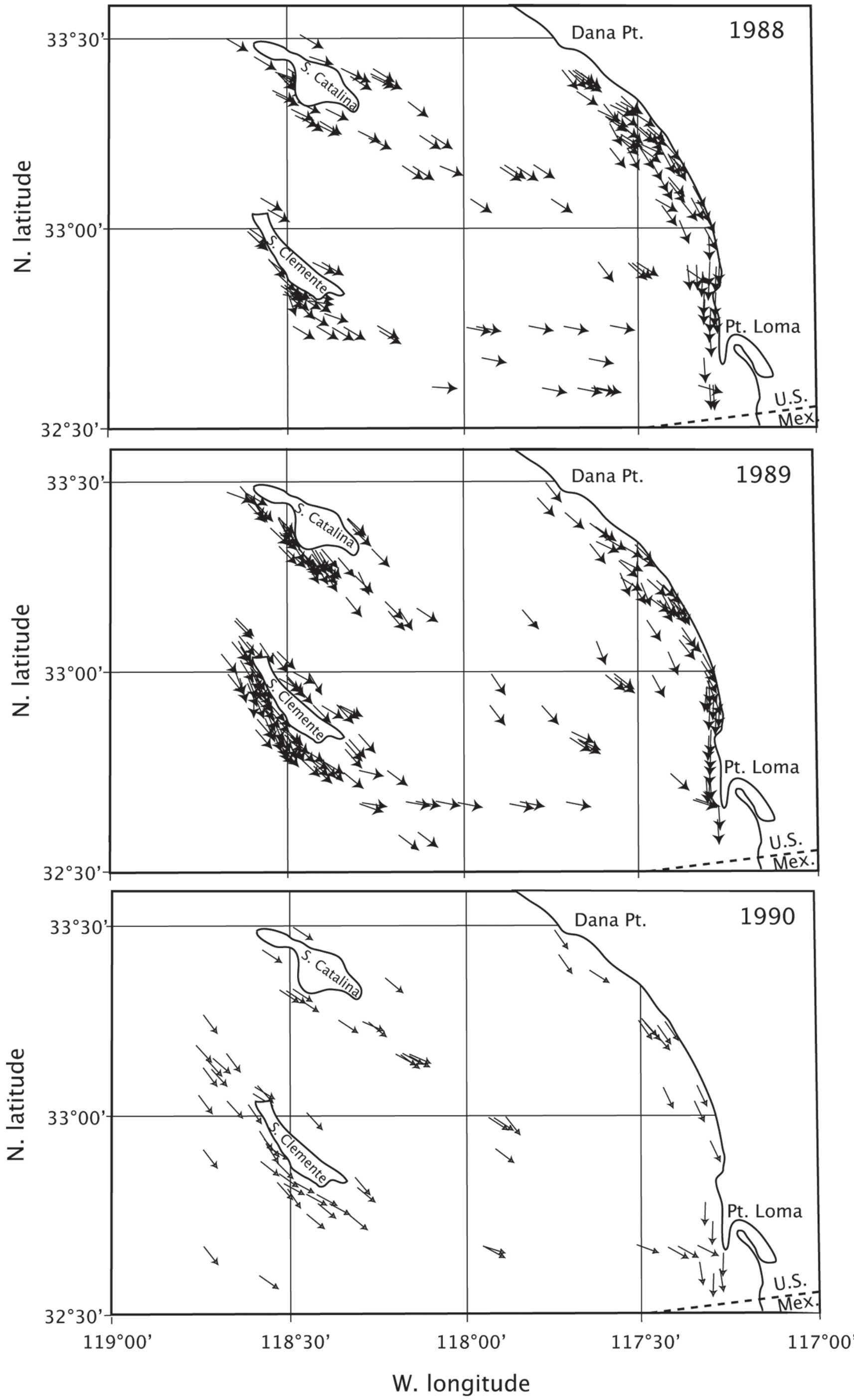

Figure 3.—Positions (bases of arrows) and headings of gray whale groups sighted: 1988–90.

males). All whales larger than 11.5 m were photographed only at distances greater than 30 km from the mainland coast, while smaller whales were photographed in all three migratory corridors.

Our results suggest an offshore preference by larger, presumably older whales, leaving fewer and apparently younger whales to use the mainland corridor through the California Bight. These data also indicate an almost complete absence throughout the bight of whales with body lengths expected for year-old animals (8–8.5 m; Sumich et al., 2001) and only slightly more apparent 2-year-old animals (9–10 m). Our result may underestimate their relative abundance, as these small whales typically swim alone, likely making them more difficult to detect. However, to avoid underestimating the total size of this population, future shore-based census efforts must determine if representative numbers of these young age classes do indeed migrate south past counting stations.

The migratory corridors shown in Figure 4 have been both consistent and persistent during the 3 years of this study. Those migrating offshore were split between the Santa Catalina and San Clemente corridors, with substantial year-to-year variability. This inter-annual variability in the numbers of whales using each corridor could lead to large variations in the results of single shore-based census efforts elsewhere in the bight.

Within the past 100,000 years, gray whales must have ranged widely in coastal waters of both the North Pacific and North Atlantic Oceans. During the Last Glacial Maximum (LGM, 18,000 years B.P.), sea level was about 150 m below its present stand (Imbrie et al., 1983). With sea level lower and all the islands of the bight substantially larger, migrating gray whales most likely skirted the west sides of these islands and avoided the coastal mainland of the bight until they were clear of Santa Catalina and San Clemente Island.

In general terms, the two offshore migratory corridors described in this paper reflect the expected migratory pathways for gray whales during the LGM. It is tempting to speculate that these whales currently use the offshore corridors to avoid human-induced changes in environmental conditions within the bight, yet no evidence currently exists to support or to deny such speculation. Rather, the offshore migratory corridors described here may have been used by varying portions of the gray whale population at least since the LGM.

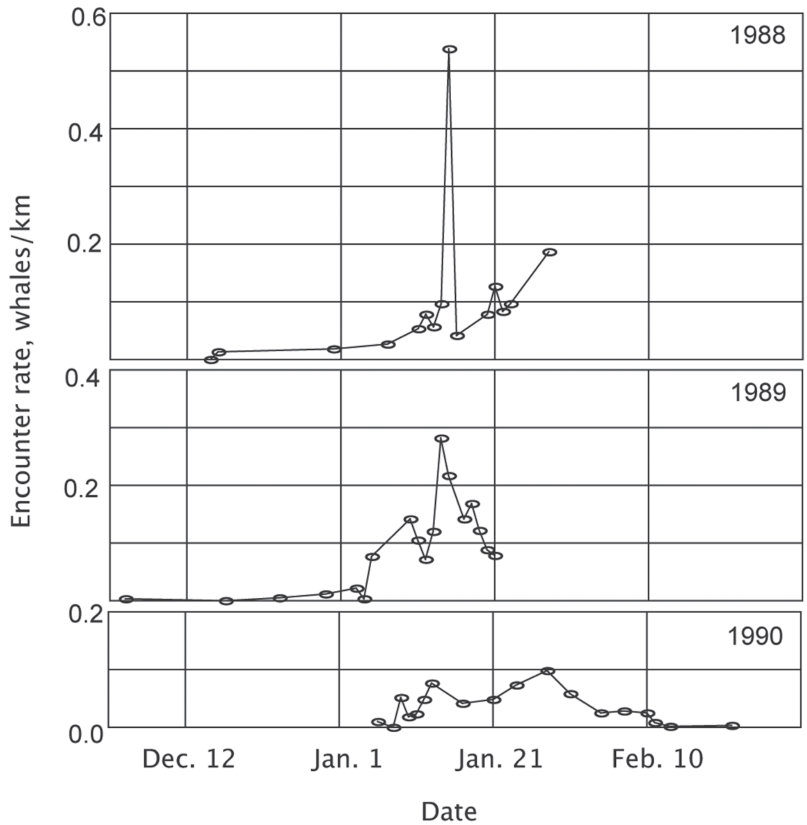

Figure 4.—Temporal changes in encounter rates of whales. When multiple surveys were flown on the same day, the results were combined for single daily values.

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Literature Cited

Braham, H. W. 1984. Distribution and migration of gray whales in Alaska. *In* M. L. Jones, S. L. Swartz, and S. Leatherwood (Editors), The gray whale, *Eschrichtius robustus*, p. 249–266. Acad. Press, Inc., Orlando, Fla.

Findley, L., and O. Vidal. 2002. Gray whale, *Eschrichtius robustus*, at calving sites in the Gulf of California, México. J. Cet. Res. Manage. 4:27–40.

Gilmore, R. M. 1960. A census of the California gray whale. U.S. Fish. Wildl. Serv. Spec. Sci. Rep. Fish. 342, 30 p.

Herzing, D. L., and B. R. Mate. 1984. Gray whale migrations along the Oregon coast, 1978–1981. *In* M. L. Jones, S. L. Swartz, and S. Leatherwood (Editors), The gray whale, *Eschrichtius robustus*, p. 289–307. Acad. Press, Inc., Orlando, Fla.

Imbrie, J., A. McIntyre, and T. C. Moore. 1983. The ocean around North America at the last glacial maximum. *In* S. C. Porter (Editor), Vol. 1. Late quaternary environments of the United States, p. 230–236. Univ. of Minn. Press, Minneapolis, Minn.

Jones, M. L., and S. L. Swartz. 1984. Demography and phenology of gray whales and evaluation of whale-watching activities in Laguna San Ignacio, Baja California Sur, Mexico. *In* M. L. Jones, S. L. Swartz, and S. Leatherwood (Editors), The gray whale, *Eschrichtius robustus*, p. 289–307. Acad. Press, Inc., Orlando, Fla.

Leatherwood, J. S. 1974. Aerial observations of migrating gray whales, *Eschrichtius robustus*, off southern California, 1969–72. Mar. Fish. Rev. 36(4):45–49.

Miller, R. V., J. H. Johnson, and N. V. Doroshenko. 1985. Gray whales (*Eschrichtius robustus*) in the western Chukchi and East Siberian Seas. Arctic 38(1):58–60.

Perryman, W. L., and M. S. Lynn. 2002. Evaluation of nutritive condition and reproductive status of migrating gray whales (*Eschrichtius robustus*) based on analysis of photogrammetric data. J. Cet. Res. Manage. 4(2):155–164.

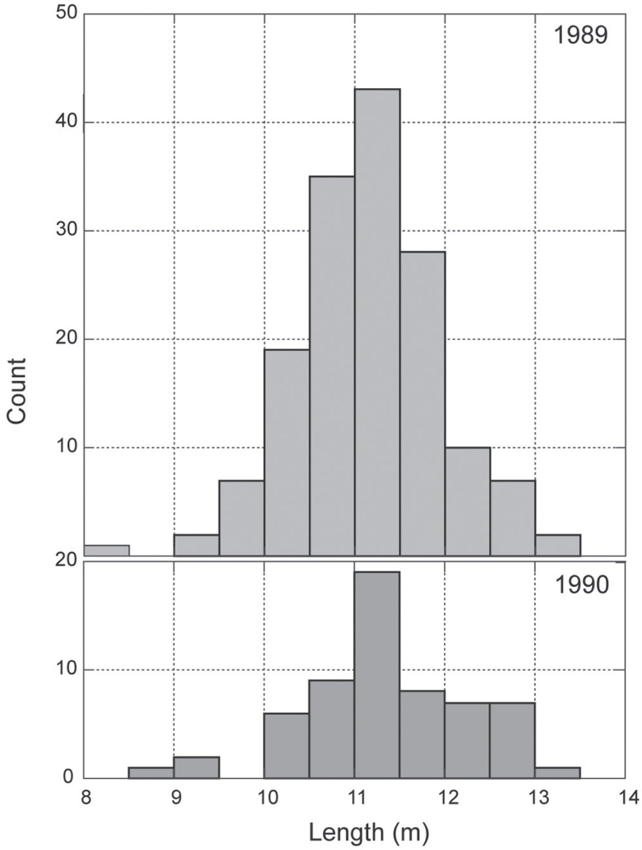

Figure 5.—Frequency distribution of photogrammetrically derived gray whale length classes for 1989 (top) and 1990 (bottom).

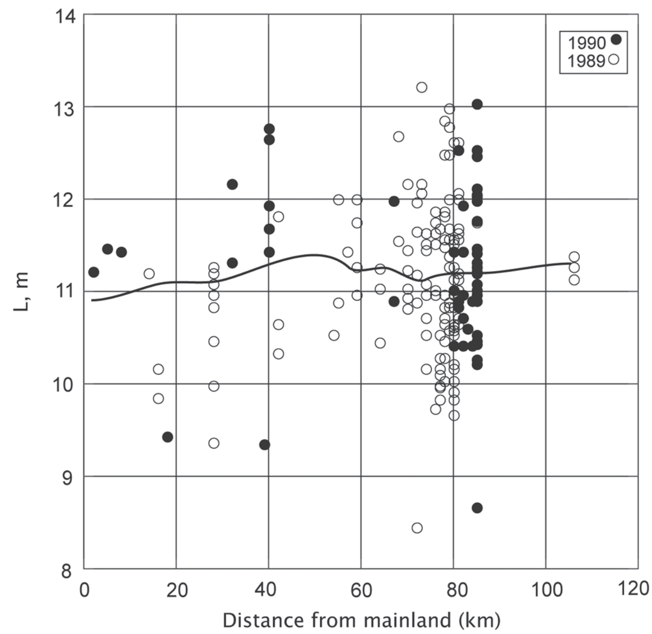

Figure 6.—Distribution of photogrammetrically derived gray whale lengths with distance west of the mainland shore, with loess curve fit for both years combined (tension = 66).

Pike, G. C. 1962. Migration and feeding of the gray whale (*Eschrichtius gibbosus*). J. Fish. Res. Board Can. 19(5):815–38.

Poole, M. M. 1984. Migration corridors of gray whales along the central California coast, 1980–1982. *In* M. L. Jones, S. L. Swartz, and S. Leatherwood (Editors), The gray whale, *Eschrichtius robustus*, p. 389–407. Acad. Press, Inc., Orlando, Fla.

Reilly, S. B. 1984. Assessing gray whale abundance: a review. *In* M. L. Jones, S. L. Swartz, and S. Leatherwood (Editors), The gray whale, *Eschrichtius robustus*, p. 203–223. Acad. Press, Inc., Orlando, Fla.

________ , D. W. Rice, and A. A. Wolman. 1983. Population assessment of the gray whale, *Eschrichtius robustus*, from California shore censuses, 1967–80. Fish. Bull. 81(2): 267–81.

Rice, D. W. 1965. Offshore southward migration of gray whales off Southern California. J. Mammal. 46(3):504–505.

________ and A. A. Wolman. 1971. The life history and ecology of the gray whale (*Eschrichtius robustus*). Am. Soc. Mammal., Spec. Publ. 3, 142 p.

Rugh, D. J. 1984. Census of gray whales at Unimak Pass, Alaska, November–December 1977–1979. *In* M. L. Jones, S. L. Swartz, and S. Leatherwood (Editors), The gray whale, *Eschrichtius robustus*, p. 225–248. Acad. Press, Inc., Orlando, Fla.

________ and M. A. Fraker. 1981. Gray whale, *Eschrichtius robustus*, sightings in Eastern Beaufort Sea. Arctic 34(2):186–187.

________ , K. E. W. Shelden, and A. Schulman-Janiger. 2001. Timing of the gray whale southbound migration. J. Cet. Res. Manage. 3:31–39.

Sumich, J. L. 1986. Latitudinal distribution, calf growth and metabolism, and reproductive energetics of gray whales, *Eschrichtius robustus*. Ph.D. Thesis, Oreg. State Univ., 216 p.

________ , T. Goff, and W. L. Perryman. 2001. Growth of two captive gray whale calves. Aquat. Mammal. 27:231–233.