Cascadia Research Collective

a non-profit research organization

BIOLOGY OF BLUE WHALES IN THE GULF OF THE FARALLONES AND ADJACENT AREAS OF CALIFORNIA

Final Report for Order No. 43ABNC803245

To:

Gulf of the Farallones National Marine Sanctuary
National Oceanic and Atmospheric Administration
Fort Mason Center, Bldg. 201
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EXECUTIVE SUMMARY

Blue whale populations have been depleted as a result of commercial whaling conducted up to 1966. Blue whales were hunted in the Gulf of the Farallones from whaling stations operating out of San Francisco Bay. There has been little evidence to document the recovery of blue whales in the North Pacific since the end of whaling. Frequent sightings of blue whales in the Gulf of the Farallones, California since the early 1980s, and the results of this study, indicate the Gulf of the Farallones has become one of the major areas of concentration for blue whales on the west coast.

We studied blue whales in the Gulf of the Farallones (including coastal waters north to off Bodega head) from July to November of 1986 to 1988. Levels and type of survey effort were similar among years with a total of 1,457 hours of vessel surveys and 88 hours of aerial surveys conducted over the three-year period. Individual blue whales were identified from photographs using the pigmentation patterns on both sides of the whale near the dorsal fin. Blue whales were also identified outside the Gulf of the Farallones with the help of other researchers and naturalists who contributed photographs to our catalogue. The lengths of 39 blue whales were measured using aerial photogrammetry.

Increasing numbers of blue whales were seen in aerial and vessel surveys from 1986 to 1988. The distribution and timing of blue whale sightings from 1986 to 1988 were somewhat variable among years. Peak numbers were generally present in August to early October. The water depth of blue whale sightings varied significantly by year, with blue whales occurring in deepest water in 1987. Blue whales were significantly associated with concentrations of marine birds, primarily Cassin's Auklets and phalaropes.

There were significant differences in the lengths of blue whales measured in 1987 and 1988, average lengths were 20.5 (67 feet) and 21.8 meters (72 feet), respectively. This difference may reflect a segregation of animals by age class as has been documented in feeding areas of other baleen whales. The majority of the whales measured fell between the anticipated lengths of sexual and physical maturity. Few calves were seen during the research but this may have been as a result of calves having already been weaned prior to their arrival in the Gulf of the Farallones.

A total of 179 individual blue whales were photographically identified in the Gulf of the Farallones from 1986 to 1988. Most individuals were identified in 1988 (101) and 1987 (75). In both years more than 50% of these individuals were seen on only one day. In 1986, when 35 whales were

identified, most whales were seen on more than one day. Fifteen percent of the identified whales were seen in more than one year and five individuals (3%) were seen in all three years.

Movement of blue whales between the Gulf of the Farallones and other locations to the north and south was documented through photographic matches of identified whales. In 1987 and 1988, five and three individuals, respectively, were seen in both Monterey Bay and the Gulf of the Farallones; all but one of these whales travelled from Monterey Bay in August to the Gulf of the Farallones in late August and September. A large number of blue whales were seen north of the Gulf of the Farallones near Point Arena in middle to late October 1988 and half of the animals identified (n=17) were seen in the Gulf of the Farallones in September or October.

Blue whales in the Gulf of the Farallones migrate from the west coast of Baja and the Sea of Cortez, Mexico. We identified blue whales from these areas using photographs provided by other researchers and whales catalogued by Mingan Island Cetacean Study. Nine blue whales seen in the Gulf of the Farallones have been matched to these areas. For example, three blue whales identified in March and April of 1988 off Baja, Mexico were seen in August or September 1988 in the Gulf of the Farallones or Monterey Bay.

Estimates of the number of blue whales occurring in the Gulf of the Farallones were possible from individual identification data and from aerial line-transect flights. A single line-transect flight conducted on 26 September 1988 provided area-dependent estimates of 160 and 250 animals in the study area, the highest numbers that we obtained. Mark-recapture estimates for 1988, despite the violation of a number of assumptions, yielded similar estimates of about 200 animals, depending on the time period and sides of the whale used in these calculations. Population estimates for 1986 and 1987 indicated lower numbers of blue whales than in 1988.

The high number of blue whales using the Gulf of the Farallones indicates it is an important area for this endangered species. The dramatic increase in numbers of blue whales that has occurred in the last seven years is extremely encouraging. If this increase continues the Gulf of the Farallones could become the single most important feeding area for the remnant blue whale population in the North Pacific.

INTRODUCTION

Blue whale (Balaenoptera musculus) populations were heavily depleted in the modern era of commercial whaling and were not protected until 1966 (Tonnessen and Johnsen 1982, Gambell 1976, 1979, Guiland 1972). Commercial whaling for blue whales in the eastern North Pacific occurred near the Aleutian Islands and in the Gulf of Alaska (Reeves et al. 1985, Brueggeman et al. 1985), off British Columbia (Pike 1962, Pike and MacAskie 1968), along the coast of California (Tonnessen and Johnsen 1982, Rice 1963a, 1963b, 1974), and off Baja California, Mexico (Rice 1966). The North Pacific blue whale population was estimated at 1,600 (NMFS 1987, Gambell 1976) based on extrapolations from sightings made by Japanese whale scouting trips in the 1960s and early 1970s (Wada 1973, Omura and Ohsumi 1974). The movements and stock identity of blue whales in the North Pacific are not well understood (Mizroch et al. 1984). The recent development of individual photoidentification of a number of whale species (Katona et al. 1979, Payne et al. 1983, Bigg 1982), including blue whales (Sears 1987, Sears et al. 1987, Calambokidis et al. 1987a, 1987b), provides a valuable tool for examining movements and stocks of blue whales.

Sightings of blue whales in the Gulf of the Farallones, California, in the 1980s have been reported (Huber et al. 1982, Dohl et al. 1983, 1984, Webber and Cooper 1983, Szczepaniak and Webber 1985, Rondeau 1987). These sightings represented an apparent increase from the few reports of blue whale sightings in this region in the 1970s. Large numbers of blue whales were also seen off Monterey Bay in 1986 (Schoenherr 1988).

Partly because of its significance to marine mammals, the Gulf of the Farallones National Marine Sanctuary was designated in 1981. The sanctuary covers 948 square nautical miles, including waters surrounding the Farallon Islands, off Pt. Reyes, and Bodega Bay, California (NOAA 1987). National marine sanctuaries are areas designated by the federal government for protection because of their significant natural and cultural resources. Goals for marine sanctuaries include promoting resource protection, education, and research.

We examined the distribution, abundance, behavior, and movements of blue whales in the Gulf of the Farallones region from 1986 to 1988. Our goal was to provide baseline information on blue whales that would assist in their management and protection in the marine sanctuary. The work was funded by the National Marine Sanctuary Program of NOAA and was conducted in conjunction with a three year study of humpback whales in the same region (Cubbage et al. 1987, Calambokidis et al. 1988b, Calambokidis et al. 1989).

METHODS

Aerial and vessel surveys were conducted in the vicinity of the Gulf of the Farallones from July to October 1986 to 1988 (Figure 1). The study area included all of the Gulf of the Farallones National Marine Sanctuary plus the area surrounding Cordell Bank and offshore from Bodega Bay. This area encompassed the waters from the shore to the shelf break from 37° 30' N to 38° 30' N.

Vessel Surveys

Vessels were used to examine blue whale distribution and relative abundance and to photograph individual whales. Vessel effort was concentrated in areas of highest humpback and blue whale concentrations. Vessels generally operated out of Bodega Bay. Vessel coverage by year is shown in Figure 2.

Three types of vessels were used in the study: 1) Noctilio, a 44' motor sailer, 2) Shachi, a 19' Boston Whaler, and 3) 14-16' inflatable boats. Tracks of all dedicated surveys are shown in Figure 1; effort is summarized in Table 1. Total hours of vessel effort were 513 hr in 1986, 460 hr in 1987, and 484 hr in 1988. In 1986, our effort was conducted in a 7-week period from 23 July to 15 Sept; the 1987 surveys were conducted in two three-week sessions between 17 Aug-4 Sept and 25 Sept-17 Oct; the 1988 surveys were conducted in two three-week sessions 19 Aug-5 Sept and 21 Sept-17 Oct, as well as a short late season effort from 27 Oct-2 Nov. Data collected on other vessels included one dedicated survey conducted by Farallon Research Associates under sub-contract to Cascadia and six surveys on larger vessels with Cascadia personnel.

A number of other researchers, naturalists, and nature trip operators provided information used in our study (see Acknowledgments). Under a subcontract, Farallon Research Associates photographed and recorded sightings of blue whales during Oceanic Society nature trips to the Farallon Islands in 1986 and 1987 (not in 1988). Cruises were conducted on 34 days between 7 June and 26 Oct 1986 and 53 days between 6 June and 8 November 1987. They primarily covered the area around the Farallon Islands and between the islands and San Francisco Bay.

Data collection

Effort data recorded the movement of each vessel and the study conditions. Time, position, depth, and presence of ships, boats, and birds in the area were recorded every 15 or 30 minutes, depending on vessel;

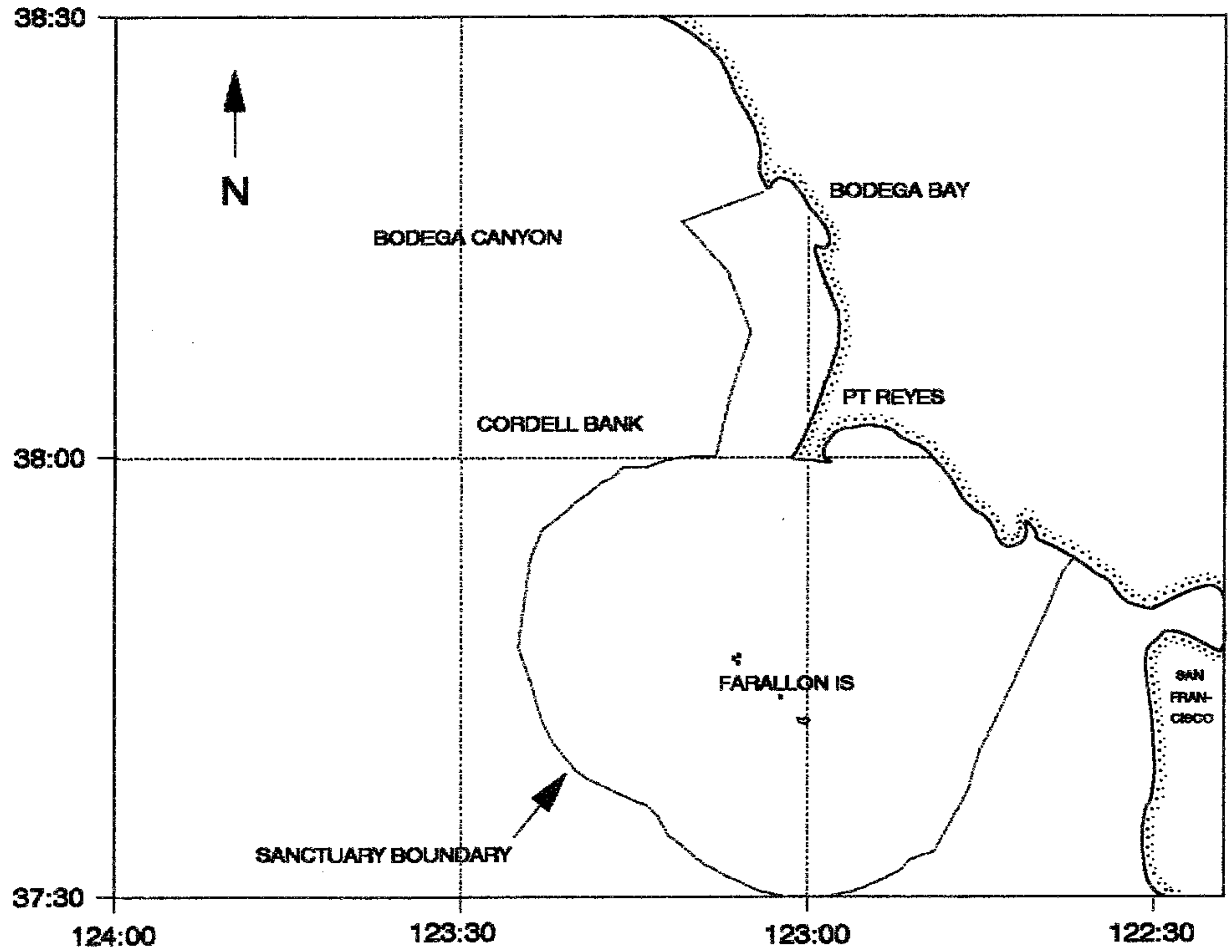

Figure 1. Study area off central California showing the Gulf of the Farallones National Marine Sanctuary and surrounding areas.

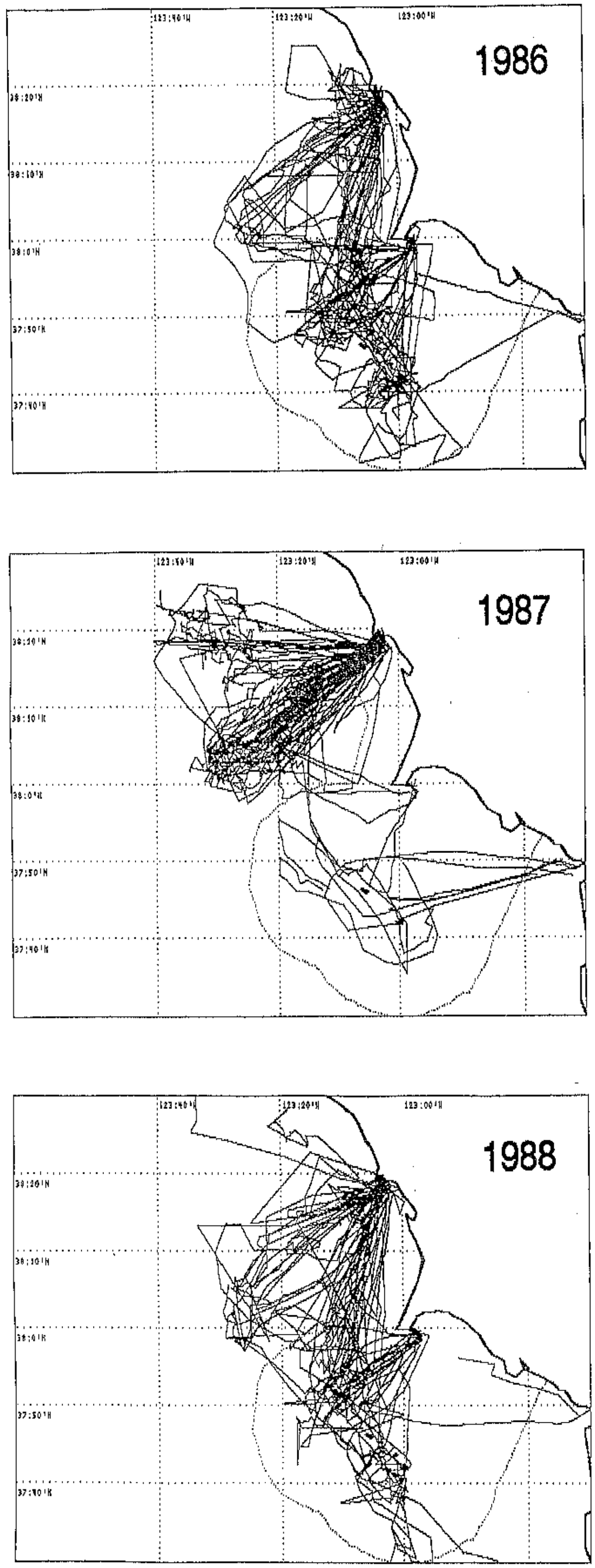

Figure 2. Tracklines of vessel surveys in 1986–1988.

Table 1. Summary of dedicated vessel effort in 1986-1988 in the Gulf of the Farallones.

Vessel	Operating dates Start	End	Effort Days	Hours	Description
1986					
Zodiac	27 July	15 Sept	24	114	14' inflatable
Shachi	23 July	2 Sept	15	69	19' Boston Whaler
Noctilio	23 July	15 Sept	32	330	44' motor sailer
Total	23 July	15 Sept	-	513	
1987					
Zodiac	17 Aug	17 Oct	20	145	
Shachi	18 Aug	11 Oct	15	100	
Noctilio	18 Aug	14 Oct	19	184	
Other*	23 Jul	10 Oct	4		
Total	17 Aug	17 Oct	-	460	
1988					
Achilles	20 Aug	2 Nov	28	174	16' inflatable
Kupe	22 Aug	12 Oct	13	79	16' inflatable
Noctilio	19 Aug	6 Oct	22	208	
Other*	11 Oct	13 Oct	3	23	
Total	19 Aug	2 Nov	-	484	

* Data collected by Cascadia personnel on board other research or charter vessels.

weather conditions (visibility, cloud cover, Beaufort, swell height, and overall observation quality) were recorded every hour. These data allowed tests of trends in water depth of sightings, association with birds (examined in 1986 and 1987), and relative density of sightings by area. All sightings of marine mammals were recorded. Additional data were collected in 1987 and 1988 during each closing (when whales were approached and followed to photograph). Closing data included: start and end times of closing effort, locations, depths, number of whales, number and species of birds within 300 m of the whales at the beginning of the closing, roll and frame numbers shot for each photographer, and behavioral data.

Photographic Identification

Photographic procedures

To identify individual blue whales we photographed the side of the body near the dorsal fin and the flukes. Blue whales were approached slowly and followed through several dive sequences; usually, the whales could be approached without disturbance. When possible, right and left sides and flukes of each individual were photographed. We used motor-advance 35mm cameras with lenses from 180mm f2.8 to 300mm f4.5, and Kodak Tri-X or Ilford HP-5 black and white film. Shutter speeds were 1/1000 or faster when lighting conditions permitted. Film was exposed at ISO rating of 1000, and development times were adjusted accordingly using Edwal FG7 1:1 with 9% sodium sulfite. Selected prints were custom enlarged on Kodak RC paper for comparison matching.

Color negative and slide film were used to photograph blue whales on a few occasions. Most of the photographs received from other researchers were also on color slides (see below). Slides were copied with a duplicator onto black and white negative film then custom printed onto Kodak or Ilford RC paper.

Photographs from other areas

Other researchers and naturalists who have taken blue whale photographs off the coast of California and Mexico, provided copies of these photographs for use in our catalogue. Table 2 lists these contributors and their affiliations, up to the time of this report. Blue whale photographs were also compared with those collected by R. Sears, Mingan Island Cetacean Study, from the Sea of Cortez and other areas. Results of these comparisons will be reported elsewhere but are summarized briefly in this report.

Table 2. Names of researchers, naturalists, and photographers, including those who worked on this study, who contributed photographs that have been incorporated into the blue whale catalogue.

Affiliation	Photographer	
Cascadia Research Collective and Center for Whale Research	K. Balcomb L. Barry S. Bartok P. Bloedel D. Bockus	J. Calambokidis D. Claridge J. Cubbage G. Steiger N. Wadsworth
Farallon Research Associates	C. Ewald P. Jones B. Keener	I. Szczepaniak M. Webber
Long Marine Laboratory	D. Goley S. Kruse	J. Ostman R. Wells
Moss Landing Marine Laboratory	N. Black V. Dollarhide T. Jefferson T. Kieckhefer	C. Strong C. Tanner B. Tershy B. Wursig
Other contributors:	B. Agler C. Alvarez A. Brady R. Branson H. Clarke B. Elliot M. Ezikial L. Findley P. Folkens G. Friedrichsen R.D. Harris Hopkins-Lions T. Johnson J. Law	S. Leatherwood M. Lippsmeyer F. Nicklin D. Patten R. Pittman D. Robertson H. Rondeau D. Shearwater R. Stallcup J. Stern R. Storro-Patterson S. Swartz M. Weinrich

Matching and cataloguing

Whales were identified primarily by mottling and scarring patterns on the back near the dorsal fin. We only compared photographs with the dorsal fin visible because it provided an essential reference point. Fluke markings and dorsal fin shape were used to confirm the identity of some individuals.

Individual blue whales were catalogued from photographs taken during our research in 1986-88 and from photographs provided by other researchers. Matches were determined by comparing all good quality photographs (see below) of the right and left sides and flukes of whales. After all photographs had been matched, individual whales were assigned a catalogue number.

The quality of each print selected for matching was coded from A to C as follows:

A) excellent photographs, properly exposed, in focus, taken perpendicular to the whale and at close range with the back of the whale well out of the water. These photographs provide complete confidence in determining a match or non-match with a similar quality photograph;
B) good photographs not meeting all the criteria of A photographs but still suitable for cataloguing and matching;
C) marginal photographs not generally suitable as catalogue photographs but still containing some information that might allow them to be matched with another photograph.

Database

A computerized database was developed of all blue whales identified in this study or from photographs provided by others. Each database record summarized the information for each sighting of an identified individual including: date, time, location, ID number, vessel, sighting number, other individuals in group, geographic region, part of the body matched (right, left, or fluke) and the quality of the photographs.

Mark-recapture Estimates

Mark-recapture estimates were made using the Bailey modification of the Peterson estimate and the Jolly-Seber estimate as described in Hammond (1986) and Seber (1982).

Aerial Surveys

Aerial surveys were conducted primarily to search large portions of the study area in order to direct vessels to concentrations of humpback and blue whales for subsequent vessel-based photoidentification work. Transect surveys were conducted to provide a census estimate of blue whales in the study area. In addition, blue whales were measured with photogrammetry techniques to determine the approximate age-class of animals found in the Farallones area.

Surveys were generally flown in a Cessna 172, a single-engine high-winged aircraft. A crew of three (1 pilot, 2 observers) flew most surveys. The left aft observer searched for whales and recorded data; right front observer searched for whales and directed the flight. The pilot/biologist also searched for whales. A portable LORAN was used to record positions.

Flight time for aerial survey effort was 37 hr in 1986, 26 hr in 1987, and 24 hr in 1988; surveys were conducted from July through Oct in 1986 and Aug through Oct in 1987-88 (Table 3). One survey was conducted before the study season on 13 May 1986. Survey tracklines flown by year are shown in Figure 3.

Line-transect population estimates

Blue whale population sizes were examined using the line-transect population estimates from aerial survey data. Line-transect surveys were flown along latitude lines every four latitude minutes (nm). Distances of blue whales from the transect line were determined based on aircraft altitude and downward angle to the sighting (measured with an inclinometer) as the aircraft passed abeam of the sighting location. The largest sample of blue whale sightings, from the 1988 survey, was used to model a sighting probability curve based on distance from the transect line (Figure 4). The equations used for the density calculations were taken from Burnham et al. (1980). Variances and confidence limits were calculated for the estimates of density of whales as described by Burnham et al. (1980) based on the assumption of a binomial distribution for n. These calculations are discussed in more detail in Burnham et al. (1980, p. 63).

Models of the sighting curve, required for the line-transect estimates, were made separately from the 1987 and 1988 sighting distributions using the Fourier series models described in Burnham et al. (1980). These models generally appeared to provide a good fit to the observed sighting distributions. Two Fourier series models were used to estimate the density of whales in the 1988 survey (Figure 4). A two-term model provided a

Table 3. Aerial surveys flown 1986-1988.

Date	Start time	Landing time	Elapsed time	Completed?	Survey description
1986					
05/13	0855	0934	0:39	No	Severe fog and high winds
07/22	1302	1349	0:47	No	Fog and low ceiling
08/01	1418	1733	3:15	Yes	South study area
08/14	1303	1649	3:46	Yes	North study area
08/28	1209	1553	3:44	Yes	North study area
09/06	1440	1524	0:44	No	Fog and high wind
09/09	1037	1427	3:50	Yes	Reconnaissance and photogrammetry
09/10	1140	1753	5:29	Yes	Reconnaissance and photogrammetry
09/11	1052	1126	0:34	No	Heavy fog
09/12	1600	1905	3:05	Yes	North study area
09/16	1525	1839	3:14	Yes	Line-transect survey
10/21	1339	1432	0:53	No	Fog, low ceiling
10/23	1147	1639	4:52	Yes	Fair conditions
10/24	1230	1443	2:13	Yes	South study area
Total			37:05		
1987					
08/21	1217	1830	6:13	Yes	Line-transect survey
08/22	1332	1628	2:56	Yes	Line-transect calibration
08/31	1353	1655	3:02	Yes	Reconnaissance and photogrammetry
09/07	1122	1506	3:44	Yes	Reconnaissance and photogrammetry
09/27	1205	1250	0:45	No	Mechanical problems
10/05	1445	1818	3:33	Yes	Reconnaissance and photogrammetry
10/09	1154	1517	3:23	Yes	South study area
10/13	1433	1704	2:31	Yes	Reconnaissance and photogrammetry
Total			26:07		
1988					
08/19	1301	1355	0:54	No	Heavy fog
08/23	1205	1303	0:58	No	Heavy fog
08/24	1238	1544	3:06	Yes	Reconnaissance and photogrammetry
09/25	1218	1633	4:15	Yes	Reconnaissance and photogrammetry
09/26	1108	1610	4:39	No	Line-transect survey
09/29	1000	1300	3:00	Yes	Reconnaissance
10/08	0946	1256	3:10	Yes	Reconnaissance
10/14	1028	1608	4:36	Yes	Reconnaissance and porpoise research
Total			24:38		

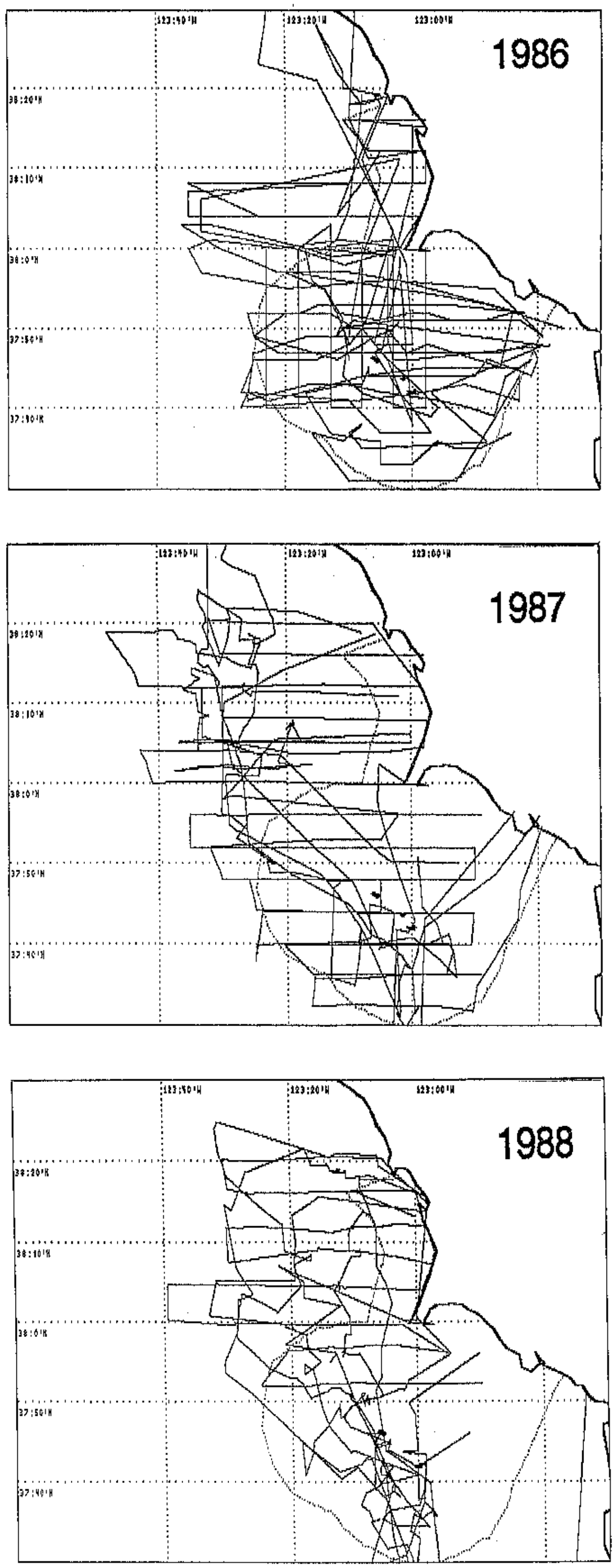

Figure 3. Tracklines of aerial surveys in 1986-1988.

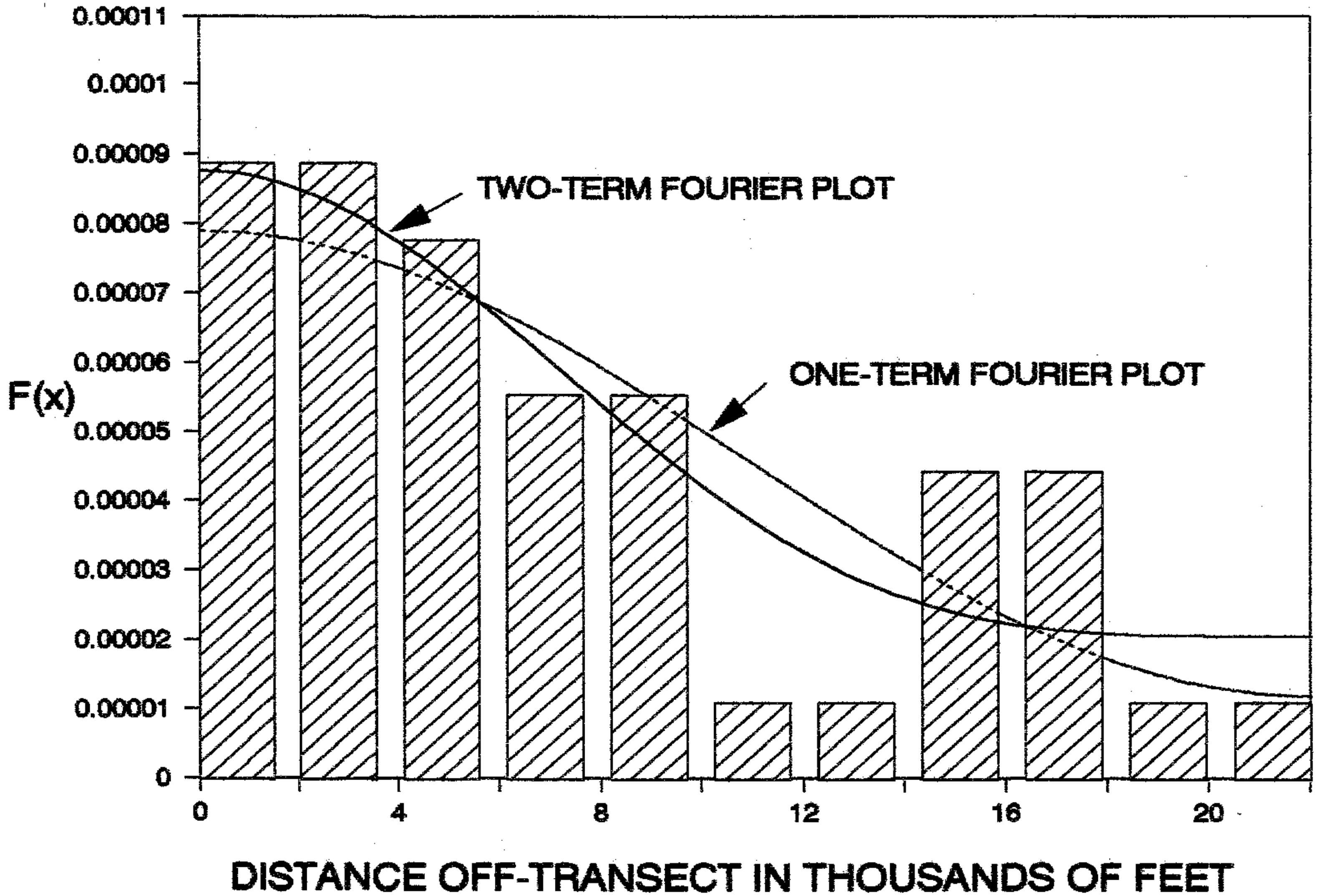

Figure 4. Sighting probability curves from aerial survey line-transects in 1988. Bars show the observed distribution of sightings based on distance off transect. Lines show fitted one and two-term Fourier series plots.

better fit to the observed sighting distribution than the one-term model but at the expense of a larger variance.

We estimated a correction factor for animals missed because they were underwater. One assumption of typical line-transect estimates is that all animals on the transect line are seen and that sighting probability decreases only in relation to distance off the transect line. This assumption is not true for cetaceans because animals underwater, even directly on the transect line, would be missed. Therefore, a correction for the proportion of blue whales underwater is required. A precise calculation of this correction factor was not possible with existing data, however, we were able to estimate this value. We identified 19 cases where the location of a group of blue whales within 1.5 nm of the transect line was known from data independent of the pass along the line. This was based on sightings made from an adjacent transect line, except in two cases where we surveyed the same line four times to aid in calibrating the surveys. The correction factor for submerged animals was calculated by dividing the number of groups seen (out of the total of 19 known to be present) by the sum of the probabilities of seeing each group (based on the distance off the transect and the sighting curve). The estimate of the proportion of groups seen compared to that predicted from the sighting curve alone was 0.43. This indicates 57% of the blue whale groups would be missed even if they were on the transect line, likely because they were underwater during the period they would have been in view of the survey aircraft. This factor was then used to adjust the line transect density estimates.

Photogrammetry

Whales were photographed from the air and measured with photogrammetric techniques to discern length and general age-class of animals residing in the study area. Vertical photographs were taken with a hand-held 35mm Nikon FE equipped with a 105mm or 200mm fixed focal length lens and color slide film. Photo scale was derived from focal length of the lens and barometric altitude.

Images of whales were measured with a stereo dissecting microscope (15x) equipped with an ocular reticle calibrated with a stage micrometer that allowed measurements to the nearest 0.04mm.

The equation used to measure whales was:

$$\text{whale size} = \text{image size (calibrated scale)}$$

$$\text{calibrated scale} = (\text{altitude}/\text{NFL})(C1)+C2$$

where NFL is the nominal focal length of the lens and C1 and C2 are correction factors based on a regression of true scale to altimeter-based scale. True scale was determined using vertical photographs of known-sized objects near the whales. The average scale of the photographs was about 1:800. The precision of whale length measurements was evaluated using five whales that were photographed and measured more than once. The repeat measurements averaged 0.8% difference; the mean difference in whale length was 17 cm (n=5, s.d.=15).

Forty-four acceptable quality images of 39 whales were measured. Whale images were graded according to observed whale flex and resolution of the image. Flex was graded from 1 to 5 with 1 being straight and 5 unacceptable. Clarity and resolution of the snout and flukes were also graded from 1 to 5 with 1 being clear and 5 being unusable.

RESULTS

Distribution and Relative Abundance

During vessel surveys in three study seasons (1986-1988), over 500 sightings of 943 blue whales were recorded (Table 4). Concurrent aerial surveys recorded an additional 237 sightings of 372 blue whales (Table 4). The locations and frequency of these sightings provided insight into blue whale occurrence in the study area. Aerial sighting rates and locations are representative of overall distribution and abundance because there was consistent coverage of the entire study region each year. Vessel sighting data, even when corrected for effort, may be biased by differences in the locations surveyed during a specific time period.

Annual changes in relative abundance 1986-1988

Blue whale numbers increased dramatically in the study area during the three years of research (Table 4). Three measures of blue whale abundance showed an increase: 1) number and rate of blue whale sightings from vessels, 2) number and rate of blue whale sightings from aircraft, and 3) number of animals identified in each of the three years. Despite a small decrease in aerial survey coverage each year, the number of blue whales seen increased from 51 animals in 1986 to 216 in 1988. The effort-corrected sighting rate showed a 600% increase over the three-year period. Sightings from vessel surveys also increased, but the 1987 to 1988 increase was not as great as the increase found through aerial surveys. Because of the more consistent and broader coverage of aerial surveys, the increase seen from aerial surveys is more representative of the entire study area.

Changes in abundance in previous years

The increase in blue whale numbers seen from 1986 to 1988 appears to be the continuation of an increase that began in the late 1970s or early 1980s. Sightings of blue whales in the vicinity of Southeast Farallon Island were uncommon in the 1970s. From 1970 to 1980 only one sighting of a blue whale was reported by biologists working on the Farallon Islands (Ainley et al. 1977, 1978, Huber et al. 1979, 1980, 1981). Frequent sightings of blue whales were made beginning in 1981 and continuing through 1983 (Huber et al. 1982, 1983, 1985, 1986). The most blue whales seen during this period was 10 sightings of 22 whales between 20 June and 30 October 1982. Sightings of blue whales offshore from the Gulf of the Farallones in 1979 (Smith et al. 1986) suggest that whales were in the region prior to the 1981 Farallon Island sightings, but were farther offshore.

Table 4. Summary of effort and blue whale sightings in 1986-1988 in the Gulf of the Farallones.

Year	Effort		Blue whale sightings		
	Days	Hours	Sightings	Whales	Num./hr.
Dedicated vessels					
1986	71	513	96	196	0.38
1987	58	460	209	338	0.73
1988	76	484	234	409	0.85
Total	205	1457	539	943	0.65
Aerial surveys					
1986	9[a]	33.5[a]	27	51	1.5
1987	7	25.4	75	105	4.1
1988	6	22.8	135	216	9.5
Total	22	81.7	237	372	4.6

[a]Number and hours of aerial surveys includes flights of greater than 1 hour. Hours includes transit time.

Other sources of data also support the hypothesis that numbers of blue whales have increased in the early 1980s. Frequent sightings of blue whales in the early 1980s in the Gulf of the Farallones and Cordell Bank area were reported by naturalists aboard nature trips (Webber and Cooper 1983, Szczepaniak and Weber 1985, Rondeau 1987). These sightings were of fewer whales than seen in 1986 to 1988. Monthly aerial surveys of the central and northern California coast from 1980 to 1983 also revealed an increase in blue whale numbers in the Gulf of the Farallones region during this period (Dohl et al. 1983, Dohl 1984). No sightings in this area were made in 1980, three sightings in 1981, and eight sightings in 1982 and 1983 (Dohl 1984, and estimated from figures in Dohl et al. 1983).

Data from Oceanic Society nature trips (collected by Farallon Research Associates) indicate blue whale occurrence increased again in 1986 (Figure 5). The number of blue whales seen in 1986 was about 10 times higher than the sighting rate from 1983 to 1985. Contrary to our findings, the sighting frequency of blue whales from nature trips declined in 1987. This decrease, however, was consistent with our observations of a distribution farther north and offshore in 1987, areas generally not surveyed by the nature trips. The increased number of blue whales we observed for 1986 to 1988 should be viewed in the context of these earlier increases.

<u>Reasons for increased numbers of blue whales</u>

The reason for the dramatic increase in blue whale occurrence in the Gulf of the Farallones is not clear. However, the most plausible hypothesis is an increase in the blue whale population in conjunction with a shift in distribution to more coastal waters. More information on the occurrence of blue whales in other parts of the eastern North Pacific will be needed to fully explain the reasons behind the changes observed in the Gulf of the Farallones.

Blue whale populations would be expected to increase because they have not been hunted in the North Pacific since 1966. An increase in overall population size, however, could not solely be responsible for the observed increases because of the relatively low net recruitment rate of large cetaceans. Other than the observations in central California, there has been little other evidence of an increase in blue whale populations in the North Pacific. Sightings of blue whales from Japanese whale scouting expeditions showed no increase from 1965 to 1978 (Wada 1979, 1980). The population of blue whales may be increasing but it would have to be at a slow rate. Such a slow increase could be one factor responsible for the changes observed in the Gulf of the Farallones, if it occurred in conjunction with a shift in the distribution of blue whales.

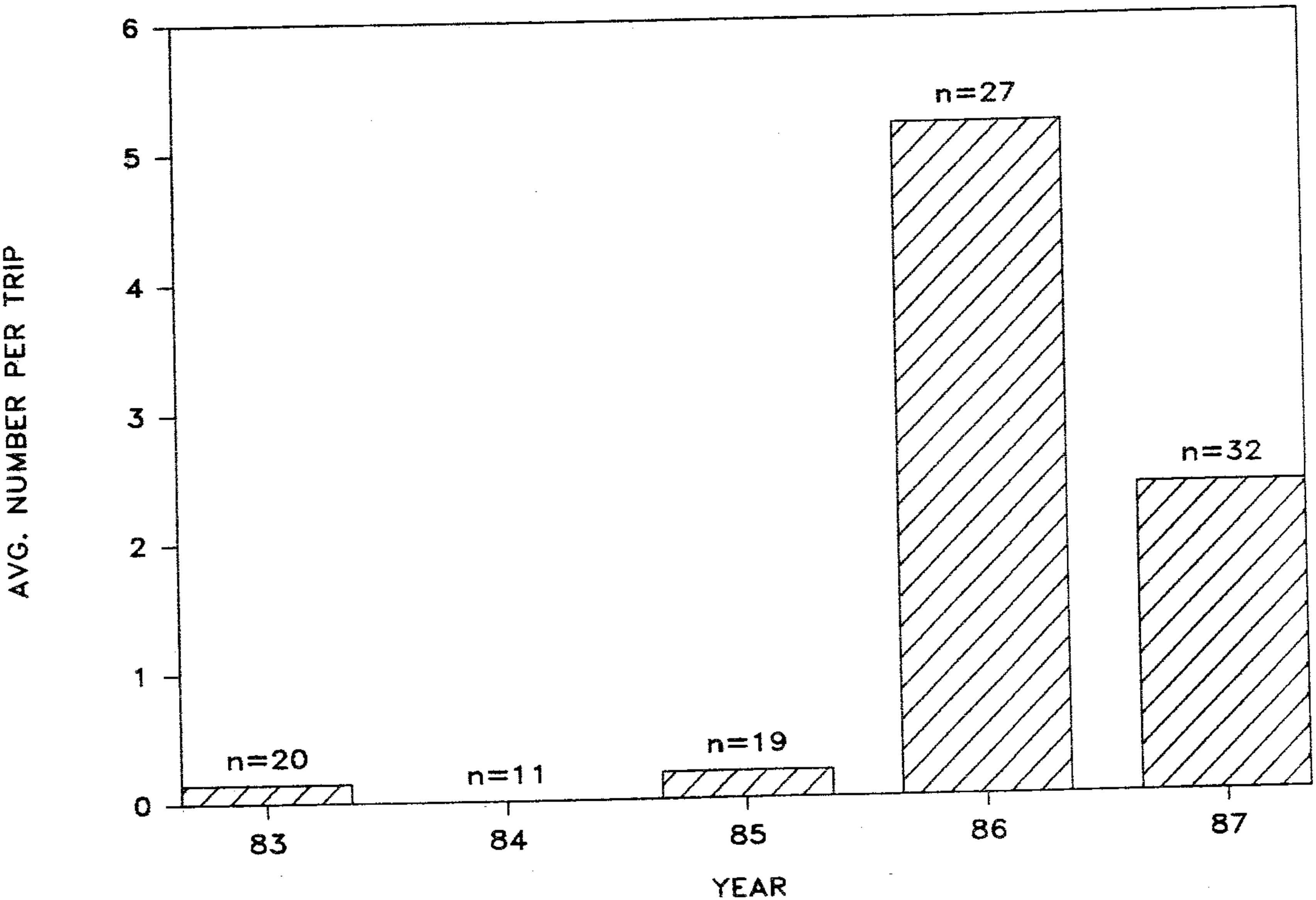

Figure 5. Average number of blue whales seen per day aboard Oceanic Society nature trips to the Farallon Islands by year for 1983 to 1987. Data provided by Farallon Research Associates.

Blue whales along the California coast may have shifted from offshore to more coastal waters in recent years. Blue whales in the North Pacific often occur far offshore (Wade and Friedrichsen 1979, Wada 1980). Dohl et al. (1983) reported a decrease in the depth at which blue whales were seen from 1980 to 1982. These sightings still were farther offshore than we have observed in recent years. Smith et al. (1986) reported sighting blue whales in 1979 offshore from the Farallon Islands at a time when blue whales were not being seen in the vicinity of the islands. Recent anecdotal reports from fishermen have indicated blue whales still are seen far offshore. A shift to more coastal waters could be in response to higher prey availability in coastal waters or a shift in prey selection (see Feeding Behavior and Prey).

We found no evidence of areas where blue whales numbers have decreased concurrently with the increase in the Gulf of the Farallones. High concentrations of blue whales were not seen in any other coastal regions of California in 1980 to 1983 (Dohl et al. 1983, Dohl 1984). Blue whale occurrence in some other areas along the California coast including Monterey Bay, Point Arena, and the Channel Islands, has appeared to increase in recent years. It is possible, though unlikely, that blue whales have shifted their distribution from northern or southern areas outside California. Large numbers of blue whales occur into the summer months off the west coast of Baja, Mexico (Scammon 1874, Rice 1966) but little is known of any recent changes in their abundance. Similarly, little is known of the present status of blue whales off British Columbia and in the Gulf of Alaska, areas where they were formerly hunted.

The increase in blue whale numbers in the Gulf of the Farallones appears to be more than a temporary phenomenon. Blue whales were hunted in the past in this region (Rice 1963a, 1974). Blue whale sightings have now increased over an 8-year period. The increase in blue whales in the Gulf of the Farallones follows an increase in numbers of humpback whales seen in this area beginning in the late 1970s (Dohl et al. 1983) that has continued through 1988 (Calambokidis et al. 1988a). It seems likely, though not certain, that the large number of blue whales visiting the Gulf of the Farallones will continue or increase in future years.

<u>Seasonal patterns of relative abundance</u>

Blue whales were generally present in the study area during the entire period we conducted dedicated vessel surveys (July to October), though the number of whales appeared to be highest in August and September (Figure 6). The seasonal pattern of blue whale abundance varied somewhat between years. Numbers of blue whales in 1986 increased in late July and August

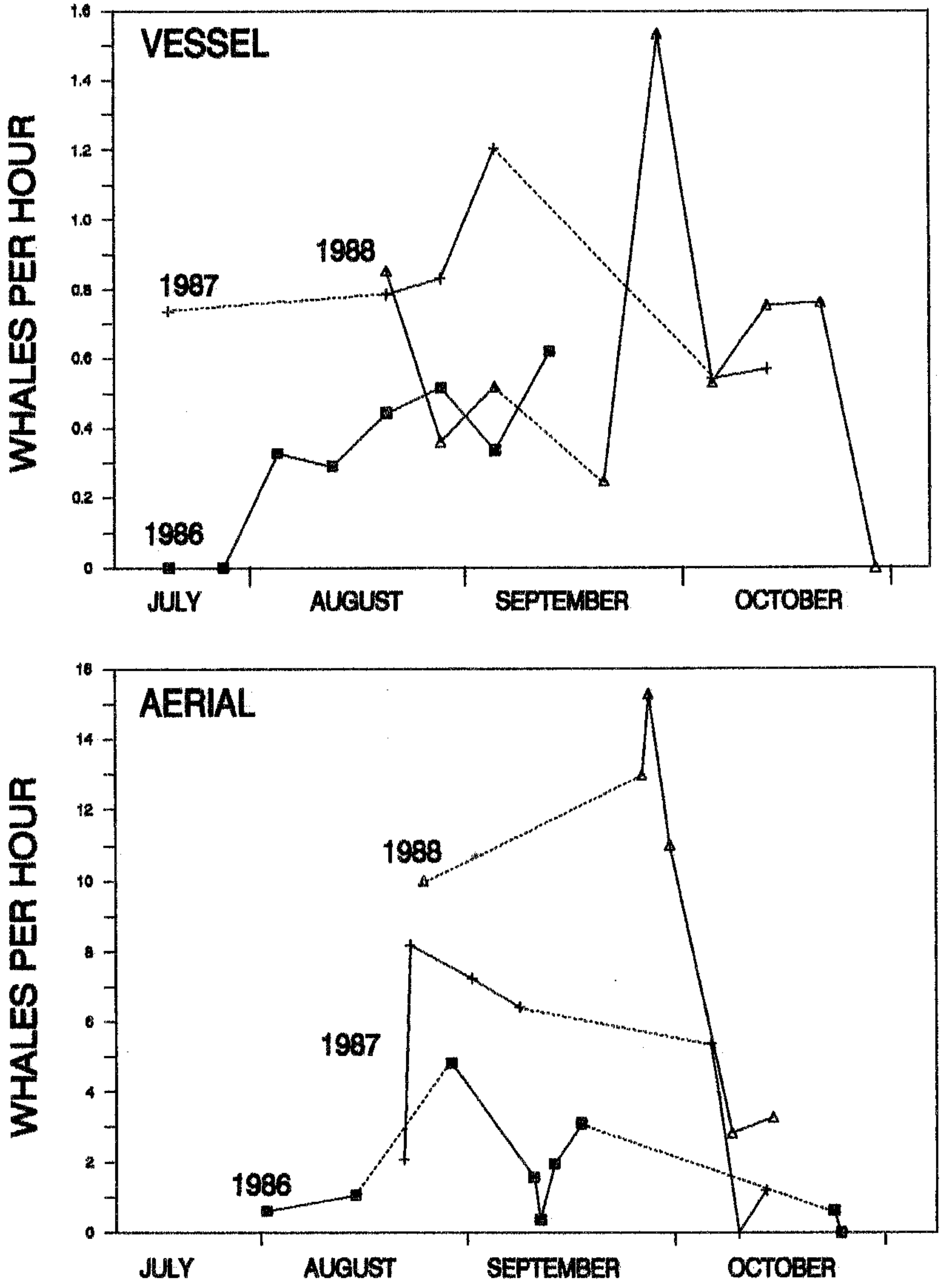

Figure 6. The number of blue whales seen per hour of effort in 1986-1988. Vessel data show sighting rates by week; aerial survey data show sighting rates by survey.

with highest numbers seen in late August and September. In 1987, the peak sighting frequency also occurred in late August and September. In 1988, however, the peak occurred in late September. In all three years the sighting rate decreased in October. The decline in blue whale numbers in the study area in October appeared to coincide with large numbers of blue whales reported in neighboring areas. In 1986, large numbers of blue whales were seen in Monterey Bay starting in October (Schoenherr 1988) and, in 1988, we saw concentrations of blue whales off Point Arena in October. The movement of blue whales between these regions has been demonstrated using animals identified in both regions (see Individual Identification).

Seasonal sighting frequencies of blue whales during Oceanic Society nature trips (gathered by Farallon Research Associates) for 1983 to 1987 were generally similar to our findings (Figure 7). Blue whales were seen during all six months of nature trip operations (June to November) with the highest sighting rates in August to October. In 1986, the highest numbers were seen in late September and early October, while in 1987 the highest number of sightings was in late July and early August. The differences in seasonal abundance between the nature trips and our surveys probably reflect the smaller geographic region covered by the nature trips.

Recent sightings of blue whales in late 1988 and early 1989 indicate some animals may occur in the study area almost any time of year. These reports have come from nature trips by the Oceanic Society, Whale Center, and an aerial whale watching business operated by Bob Lamar. Sightings of one to three blue whales have been made during most months from December 1988 through April 1989. These sightings are unusual because most blue whales would be expected to be farther south off Mexico and central America during this period.

<u>Seasonal and annual changes in blue whale distribution</u>

Blue whale distribution in the study area was different among years as well as among months. Locations of vessel sightings of blue whales were different among years (Figure 8), though this difference is magnified by our tendency to have more vessel effort in locations where we found concentrations of blue and humpback whales. Because of fairly consistent coverage among years and months (August to October), aerial surveys provide a less biased basis for comparison of distribution over time (Figure 9). This information, supplemented by the vessel sightings, provides a good picture of blue whale distribution in the study area.

In 1986, blue whales were widely distributed over a broad portion of the study area, though several areas of higher concentrations were

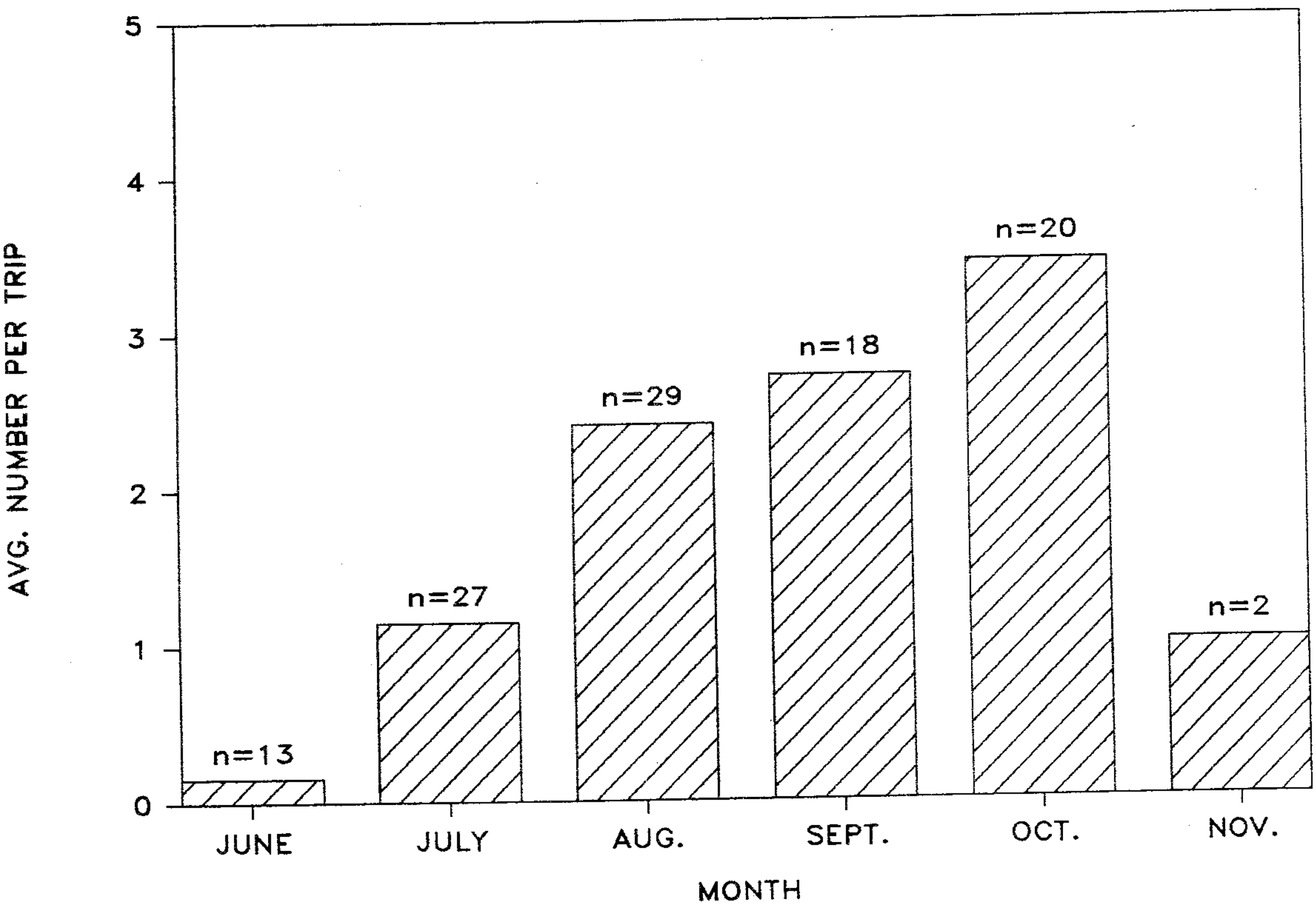

Figure 7. Average number of blue whales seen per trip from Oceanic Society nature trips to the Farallon Islands by month between 1983 and 1987. Data were provided by Farallon Research Associates.

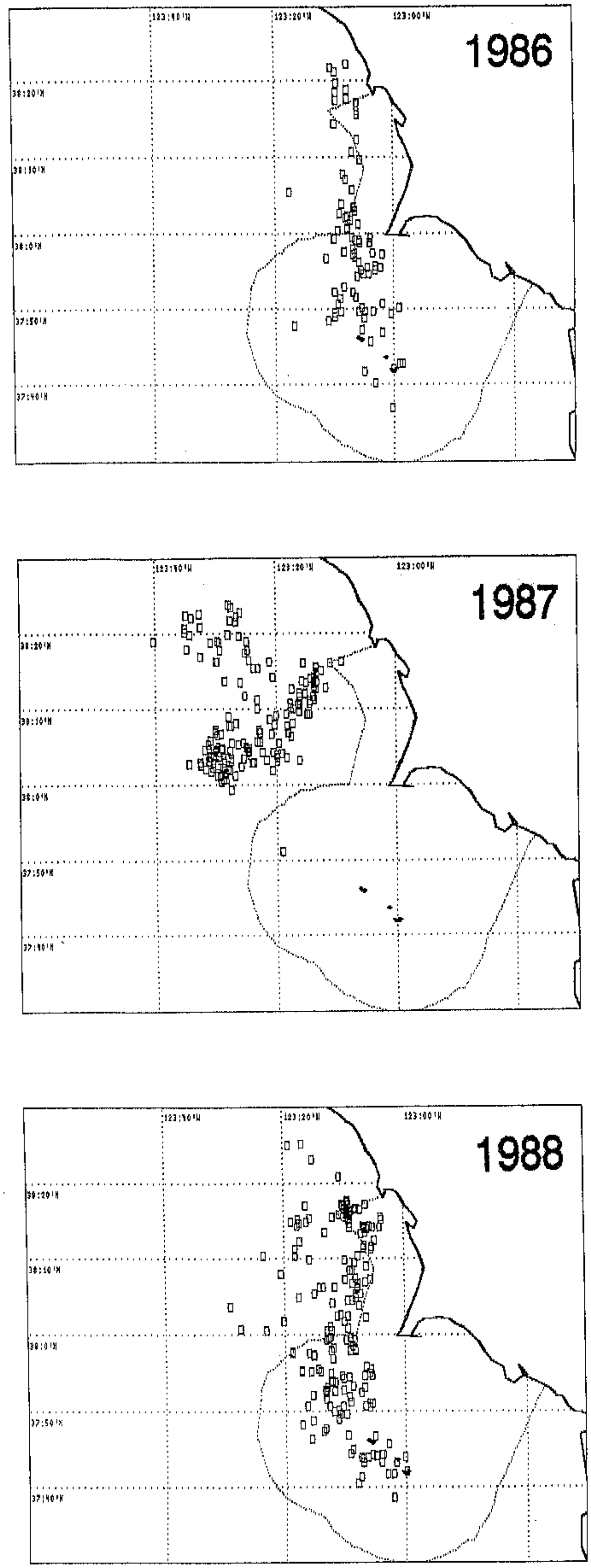

Figure 8. Locations of blue whale sightings made from dedicated vessels in 1986 to 1988.

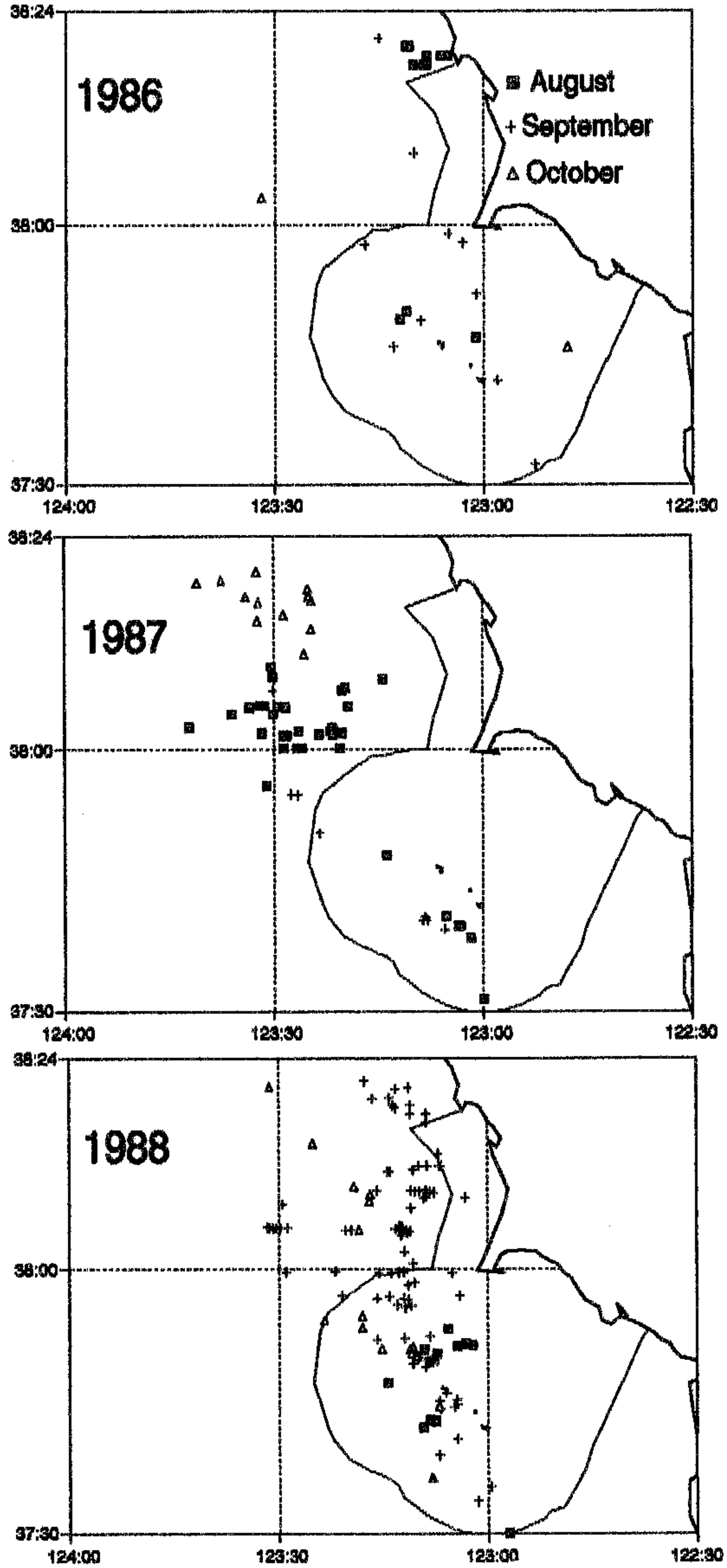

Figure 9. Locations of blue whale sightings from aerial surveys in 1986 to 1988. The month of each sighting is indicated by symbols.

observed. Blue whales in early to mid-August were seen principally in the vicinity of the Farallon Islands and within a 10-mile radius of Pt. Reyes. In late August, blue whale distribution shifted northward with a high density of animals found just off Bodega Head. Sightings in September and October were spread over a wide area.

In 1987, blue whale distribution was more clustered by month and farther offshore than in 1986. Blue whale sightings in August and early September were concentrated in the vicinity of Cordell Bank with a smaller number of sightings near the Farallon Islands. In late September and October, however, very few blue whales were seen in these areas and almost all the sightings were farther north in the vicinity of Bodega Canyon.

Although high densities of blue whales were seen in numerous regions in 1988, there was a general northward shift in distribution from August to October. Sightings in August were mostly south of Pt. Reyes with the highest concentrations between the North Farallon Island and Pt. Reyes. Concentrations of blue whales also were observed just south of the sanctuary boundary on 26 August. In late September, blue whales were abundant throughout the study region. October sightings did not reveal clear areas of concentration within the study area, however, sightings from surveys north of the study area in middle and late October revealed high concentrations of blue whales just south of Point Arena (30 nm north of the study area).

Water depth association

Blue whale sightings tended to be associated with certain water depths. There were significant differences in the average water depth for blue whale sightings (made from the two vessels that recorded depth) among years (ANOVA, $p<0.001$). Average depth of blue whale sightings was shallowest in 1986 (mean=280 feet, n=78, s.d.= 46) and deepest in 1987 (mean=478 feet, n=132, s.d. 190); average depth in 1988 was 378 feet (n=99, s.d.=96).

The distribution of whale sightings by depth deviated significantly from those expected based on effort for all years (chi-square, $p<0.001$ in all three years). Sightings per unit effort are shown by depth class in Figure 10. In 1986, sightings were more clustered than in 1987 or 1988. Fifty-nine percent of blue whale sightings (where depth was measured) in 1986 were made at 250 to 300 feet while only 25% of the vessel effort occurred at this depth; no whales were seen at water depths deeper than 500 feet or shallower than 150 feet. Blue whale sightings in 1987 were spread over a broad range of depths from 150 to over 1,000 feet; depths of 300 to

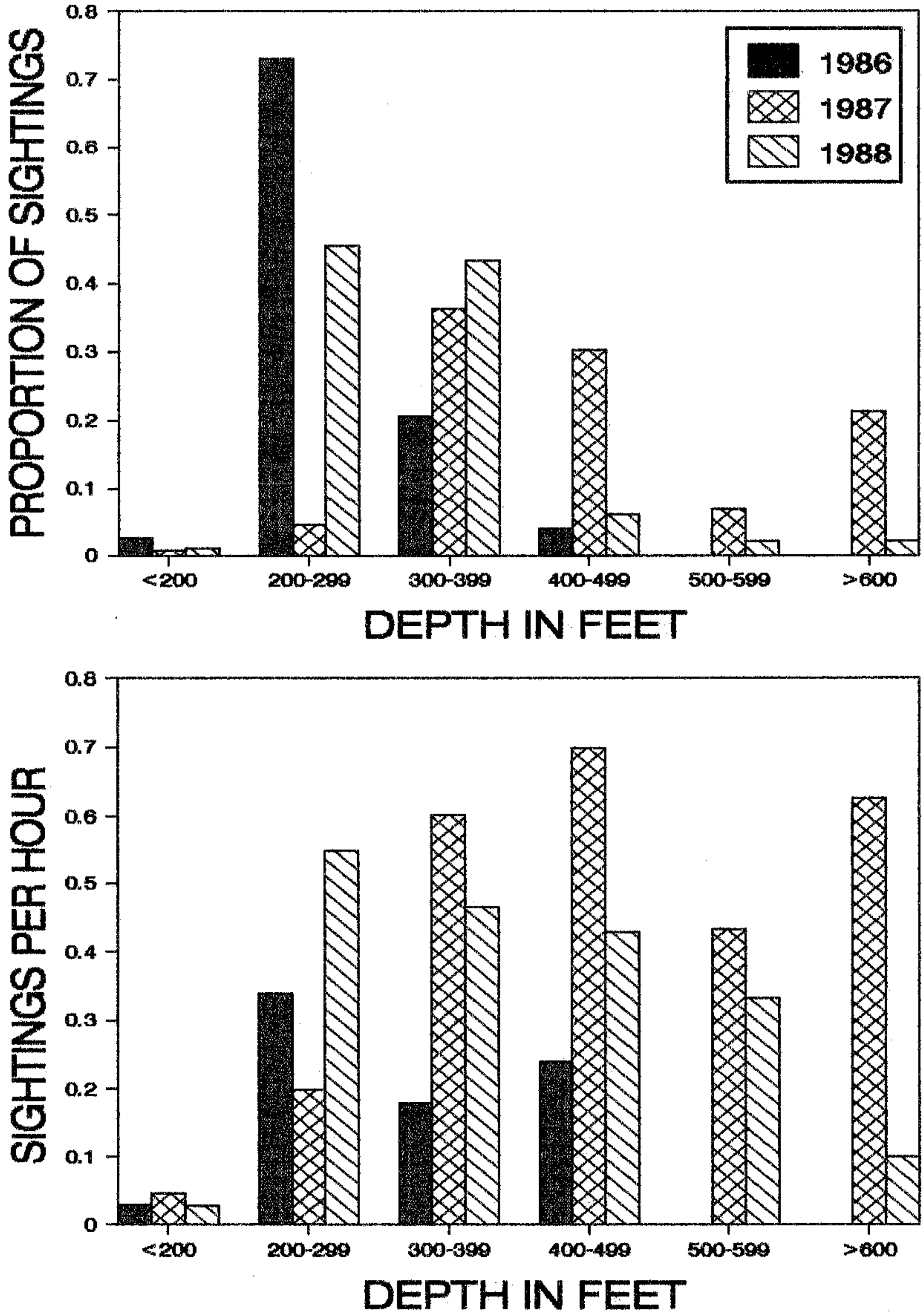

Figure 10. Vessel sightings of blue whales by depth shown as (top) the proportion of all sightings and as (bottom) effort-corrected sightings per hour by depth.

450 feet were most common, accounting for 58% of the sightings (45% of vessel effort was spent at these depths). Sightings in 1988 were clustered at depths of 250 to 400 feet (80% of sightings compared to 59% of effort).

Feeding Behavior and Association with Other Species

Feeding behavior and prey

Blue whales were observed feeding or milling during 51% of our behavioral observations in 1987 and 1988. Table 5 lists the behavior observed during blue whale approaches (n=231). Feeding at the surface was seen in 16% of the observations. More feeding behavior was observed in 1988 (57%) than in 1987 (42%).

When surface feeding was observed, blue whales were seen lunging with the lower jaw and throat pleats breaking the surface, or swimming on their sides just at the surface with open mouths and side of the fluke visible above the surface of the water. On 2 September 1988, euphausiids (that appeared to be *Thysanoesa spinifera*) were seen in dense swarms at the surface where five groups of blue whales were surface feeding.

Annual and seasonal changes in blue whale distribution are likely the result of changes in prey availability or selection. Blue whales feed almost exclusively on euphausiids (Nemoto 1959). Relationships between the distribution of whales and that of prey has been previously established (Nemoto 1959, Payne et al. 1986). Blue whales seen in surveys along the California coast in 1979 were associated with waters characterized by more homogeneous medium levels of chlorophyll (Smith et al. 1986). Chlorophyl is an indicator of productivity and would likely reflect euphausiid abundance.

Three blue whale prey species have been identified in the eastern North Pacific, including the Gulf of the Farallones. Rice (1977) reported euphausiids in the stomachs of blue whales caught by whalers operating from San Francisco Bay; 95% of the blue whales with food in their stomachs contained *Euphausia pacifica* and 5% contained *Thysanoesa spinifera*. Three blue whale fecal samples collected in the Gulf of the Farallones in 1986 all contained *T. spinifera* (C. Ewald, pers. comm.). Schoenherr (1988) provided convincing evidence that blue whales off Monterey Bay in the fall of 1986 were primarily feeding on dense swarms of *T. spinifera*. Stomachs of two blue whales caught off British Columbia contained only *T. spinifera* (Pike 1950). Blue whales also occasionally feed on pelagic red crab, *Pleuroncodes planipes*, an anomuran crustacean that often is seen in dense surface swarms off the west coast of Baja, Mexico (Rice 1966, 1974).

Table 5. Primary and secondary behavior observed as a proportion of times whales were approached for photo-identification in 1987 (n=93) and 1988 (n= 138) and in both years combined.

Behavior	Primary			Secondary		
	1987	1988	Total	1987	1988	Total
Milling	.26	.35	.32	.05	.08	.07
Feeding	.04	.12	.09	.01	.02	.02
Surface/lunge feed	.03	.06	.05	.08	.14	.12
Slow travel	.34	.19	.25	.03	.05	.04
Fast travel	.16	.11	.13	.01	.04	.03
Stationary	.02	.01	.01	–	–	–
Group affiliation	–	–	–	.04	.05	.05
Group disaffiliation	–	–	–	.09	.07	.08

Blue whale selection of T. spinifera and E. pacifica or changes in the abundance or distribution of these prey may be responsible for the variations in blue whale distribution. Ainley et al. (1987) reported that Cassin's auklets in the Gulf of the Farallones switched between predominantly feeding on T. spinifera and E. pacifica on different years apparently in response to water temperature. Evidence in recent years, discussed above, suggests blue whales in the Gulf of the Farallones have been feeding predominantly on T. spinifera. This neretic euphausiid species tends to concentrate closer to shore than E. pacifica and has been abundant in the Gulf of the Farallones region in recent years (S. Smith, pers. comm., Smith and Adams 1988).

Oceanographic conditions are the ultimate factors responsible for variations in productivity. Interannual variations in zooplankton productivity along the California coast is influenced by two related factors: surface water temperature (Colebrook 1977) and large-scale variations in the flow of the California Current (Chelton et al. 1982). The California Current, responsible for the high productivity in this region, is highly variable and consists of intense meandering current filaments intermingled with mesoscale-eddies (Mooers and Robinson 1984). Wind-forced coastal upwelling of nutrient-rich deep water has an influence on local zooplankton biomass but plays a relatively minor role on a large scale (Chelton et al. 1982). The abundance of T. spinifera preyed on by blue whales off Monterey Bay in fall 1986, however, appeared to be related to a prolonged upwelling period that persisted through November 1986 in this area (Schoenherr 1988).

Association with birds

Sightings of blue whales were significantly associated with concentrations of birds on the water in 1987 but not 1986. The presence of birds was noted at regular intervals during all effort in 1986 and 1987 (not 1988) and was used to determine the "expected" number of birds. The number of birds seen when blue whales were observed was significantly different than "expected" in 1987 (chi-square, $p<0.05$), primarily because of the high number of sightings with more than 20 birds. This association was not significant ($p>0.05$) in 1986, probably because of the limited number of sightings of blue whales ($n=45$ for sightings where bird data were recorded).

The most common birds present near blue whales were alcids (primarily Cassin's Auklets, Ptychoramphus aleuticus) and phalaropes (presumably Red Phalaropes, Phalaropus fulicaria, or Red-necked Phalaropes, P. lobatus). The species of birds associated with blue whales were recorded in 1987 and

1988. Birds were present within 300 m of 72% of the blue whales approached in 1987 (n=93) and 65% in 1988 (n=138). Alcids were present during 40% of the approaches in 1987 and 37% in 1988. Phalaropes were present during 27% of the approaches in both 1987 and 1988, and were seen in the most dense concentrations (average of 38 and 77 phalaropes seen within 300 m of the boat in 1987 and 1988 respectively). Other birds seen in over 10% of the blue whale approaches included gulls (1987 and 1988) and shearwaters (1987 only).

Cassin's Auklets and phalaropes feed primarily on zooplankton. Studies in the area of the Farallon Islands showed both species feeding on euphausiids, most notably E. pacifica and T. spinifera (Manuwal 1974, Briggs et al. 1984, Briggs and Chu 1987, Ainley et al. 1987). Calambokidis et al. (1988a, 1989) reported the same association between the presence of humpback whales and Cassin's Auklets and phalaropes in the Gulf of the Farallones; other studies have reported the association of feeding humpback whales with alcids (Webber and Cooper 1983, Hoffman et al. 1981).

Interactions with other marine mammals

Interactions between blue whales and other marine mammal species were seen. Interspecific groupings of blue whales and a fin whale were seen on one occasion. The two species swam in close association and were feeding as a group. An individually identified whale, suspected to be a sei whale, has been seen on numerous occasions in all three years traveling in association with blue whales. We are uncertain whether this individual is a sei or fin whale; experienced researchers disagreed on the species determination. California sea lions and Dall's porpoise were seen swimming in the wake or around the head of blue whales as they surfaced. It was not unusual to observe blue whales and humpback whales feeding closely in the same region, however, no cooperative behavior was observed between these species.

Age and Size Classes of Blue Whales

Lengths of blue whales

The average length of a blue whale in the Gulf of the Farallones, determined through aerial photogrammetry, was 21.2 m (n=39, s.d.=1.21). The length distribution of whales measured is shown in Figure 11. Whale lengths ranged from 18.9 m to 23.2 m. Whales measured in 1988 were significantly longer than in 1987 (t-test, F=8.53, t=3.97, $p<0.001$). The average length of blue whales measured in 1986 was 21.7 m (n=3, s.d.=0.81), in 1987, 20.5 m (n=18, s.d.=1.2), and in 1988, 21.8 m (n=18, s.d.=0.82).

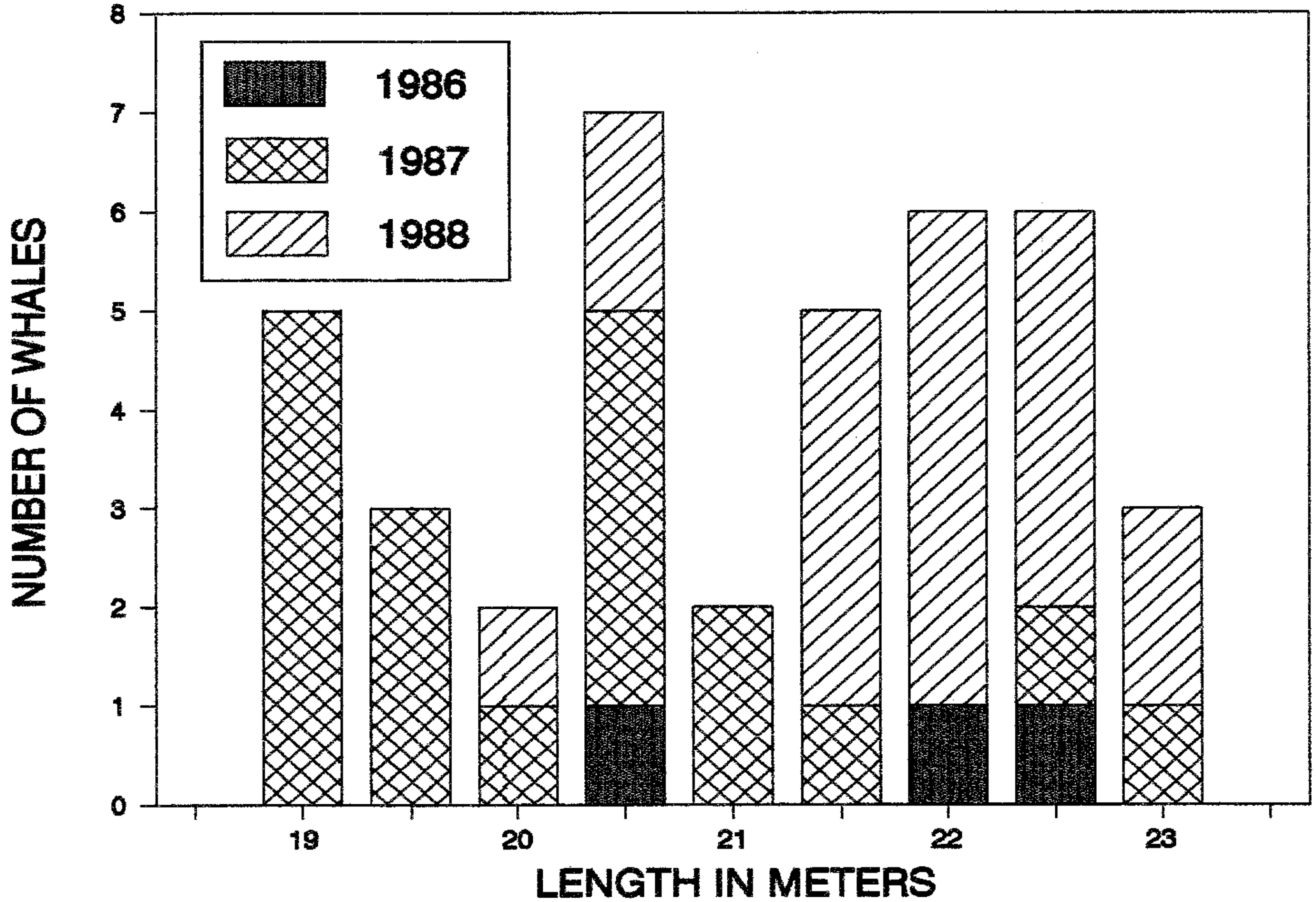

Figure 11. Length (in meters) of the 39 blue whales measured through aerial photogrammetry in the Gulf of the Farallones in 1986 (n=3), 1987 (n=18) and 1988 (n=18).

There were no significant differences in the lengths of whales photographed by survey flight within each year (ANOVA, $p>0.05$); there was no correlation between length of whales photographed and days into the season (linear regression, $p>0.05$).

The difference in blue whale lengths between 1987 and 1988 is surprising and may reflect segregation of whales by age class on the feeding grounds. Segregation by size could confound the measurement of a representative sample of the population. Age class segregation on feeding grounds has been reported for other large mysticetes (Cubbage and Calambokidis 1987). Whaling statistics showed that timing of migration of large balaenopterid species, including blue whales, varied by age class and reproductive condition (Pike 1962, Mackintosh and Wheeler 1929). Additionally, Mackintosh and Wheeler (1929) reported that the high proportion of immature blue whales taken in one region off the Falkland Islands was due to age class segregation rather than excessive hunting. Growth of individual whales visiting the Gulf of the Farallones could account for some of the differences between years.

Age classes of blue whales off California between 1980 and 1982 reported by Dohl et al. (1983) differed from the age classes represented in this study. They reported only 3 of 66 blue whales were sub-adults (one was reported as a calf), however, no information was given on how age was determined.

Blue whale lengths measured in the Gulf of the Farallones were smaller than lengths of blue whales taken by North Pacific whalers in the 1900s. Blue whales taken off Coal Harbor, British Columbia between 1948-59 averaged 22.2 m (n=125, s.d. 1.85) in length (calculated from Pike 1962); blue whales taken off Akutan, Alaska, averaged 22.9 m (n=424, s.d.=1.66)(calculated from Reeves et al. 1985). Information on stock discreteness of blue whales in the North Pacific is not clear. Lengths from whaling data and whale lengths measured through photogrammetry may not be directly comparable.

Most blue whales measured in the Gulf of the Farallones were below the length of physical maturity. Determining age classes is difficult because the length of whales at maturity varies by region and by sex. Table 6 summarizes the lengths at sexual and physical maturity determined from whaling data in the eastern North Pacific (Rice 1963a, Pike and MacAskie 1969). By combining the lengths reported and length differences by sex, we determined a range of lengths that best estimate the status of blue whales measured in the Gulf of the Farallones (Table 7). Eighteen percent of the blue whales measured in 1986-88 were sexually immature and an additional 31% were within the range of just reaching sexually maturity (could either

Table 6. Lengths at sexual and physical maturity reported for blue whales reported from whaling stations in the eastern North Pacific.

Length at sexual maturity		Length at physical maturity		
females	males	females	males	Region
21.5	20.5	25.1	24.1	British Columbia[a]
20.4	-	22.5-25	-	California[b]

[a]source: Pike and MacAskie (1969) for whales taken 1948-1967
[b]source: Rice (1963) for whales taken 1956-1962

Table 7. Age classes assigned to the 39 blue whales measured in the Gulf of the Farallones between 1986-88. Ranges of lengths used for age-class designations were determined from whaling data reported by Pike and MacAskie (1969) and Rice (1963) reported in Table 6.

Age-class designation	Length (m)	number(%) measured
Sexually immature	<20	7 (18%)
Length at sexual maturity	20-21.5	12 (31%)
Sexually mature but physically immature	21.5-22.5	16 (41%)
Near the length of physical maturity	22.5-25	4 (10%)
Physically mature	>25	0 (0%)

be sexually mature or immature). Fifty-one percent of the blue whales measured were above the length of sexually maturity but only 10% were near the length of physical maturity. A greater proportion of the blue whales in the Gulf of the Farallones appear to be below the length of sexual and physical maturity than was found at whaling stations in British Columbia (Pike and MacAskie 1969) and Alaska (Brueggeman et al. 1985). Again, potential biases exist and may create error in the comparison of these data.

Occurrence of cows and calves

Few blue whale calves were seen in the Gulf of Farallones. Because calves were probably weaning or were already weaned prior to our observations, they would be difficult to identify. There was only one sighting of a calf in 1986, no sightings in 1987, and four sightings in 1988 (including one seen north of the sanctuary between Bodega Bay and Point Arena). The term "cow" was assigned to an adult blue whale that accompanied a calf. Using photoidentification, the identity of one cow (#101) and two calves (#214 and #251) were determined and other tentative identifications were made (Table 8).

Information on the timing of blue whale calving and breeding in the North Pacific has not been resolved. Reeves et al. (1985), examining whaling data of blue whales taken in Alaskan waters, reported calving probably takes place in October; however, Brueggeman et al. (1985), using the same data, reported that calving probably occurs in November and peaks in December or January. The blue whale calves that we observed in the Gulf of the Farallones between August and October would be expected to be 7-12 months old. Calves nurse for seven months (Mizroch et al. 1984). Little else is known about how long a cow its offspring remain together. Whale #001 and #011 were observed together as a cow/calf pair in 1986; they were sighted together again in 1988, the same season that whale #001 was possibly the mother of whale #231.

From the size class distribution of blue whales in the Gulf of the Farallones, we would expect the number of calves to increase in future years as the large proportion of younger whales begin to reproduce. Blue whale pregnancy rates in Soviet and Alaskan waters were 25%-35% of mature females in the 1950s and 1960s (Ohsumi and Wada 1972).

Table 8. Identification of blue whale cows and calves seen between the Gulf of the Farallones and Point Arena between 1986 and 1988. Tentative identifications are listed with a question mark.

Cow ID	Calf ID	Date obs. as cow/calf
011? or 001?	011? or 001?	15 Aug 86
101	–	1 Sep 88
–	251	2 Sep 88
270?	214	29 Sep 88
001?	231?	28 Oct 88

Individual Identification

Sighting frequency and number of individuals

Blue whales were identified from photographs taken in all three years in the Gulf of the Farallones. A total of 179 different blue whales were identified from the 384 times whales were identified (Table 9). The number of blue whales identified increased each year from 35 in 1986 to 101 individuals in 1988. Two factors were partly responsible for the annual increase in numbers of individuals identified:

1) More effort was expended to identify blue whales each year of the study. This is reflected in part by the increasing number of occasions on which blue whales were identified each year.

2) A greater number of blue whales were present in the study area each year. This is indicated by the decreasing sighting rate of each individual, despite the higher effort, and is consistent with the sighting data reported previously.

There were significant differences among years in the number of different days individual whales were seen within a year (ANOVA, $p<0.001$). Individuals were seen on an average of 2.1 days (n=35, s.d.=1.2) in 1986 compared to 1.6 days (n=75, s.d.=1.1) in 1987 and 1.4 days (n=101, s.d.=0.9) in 1988. The frequency of resightings of individual blue whales was similar in 1987 and 1988; 1986 showed a different pattern (Figure 12). In 1987 and 1988, over 70% of the blue whales identified were seen on only one day and about 10% of the whales were identified on three or more days. The resighting rates were generally higher in 1986, when only 45% of individuals were seen on only one day and more than 30% were seen on three or more days. Despite these general patterns, a single whale was seen the most number of days (7) in both 1987 and 1988.

The differences in resighting patterns among the three years also can be seen in the rate at which new whales first were identified (discovered) in each season (Figure 13). The shallow slope for 1986 indicates an increasing proportion of the whales identified through the year had been seen earlier in the season. This is consistent with a small stable number of blue whales residing in the study area. The steep slope (approaching 45 degrees) for 1988 reflects the small proportion of whales identified previously that season. This is consistent with the larger number of blue whales seen in the study area in 1988. These patterns confirm the successive increase in the number of blue whales in the Gulf of the Farallones from 1986 to 1988.

Table 9. Number of blue whales identified in the Gulf of the Farallones between 1986 and 1988.

Year	Number of times blue whales were identified	Number of different individuals	Average times seen
1986	82	35	2.3
1987	136	75	1.8
1988	166	101	1.6
Total	384	179	2.1

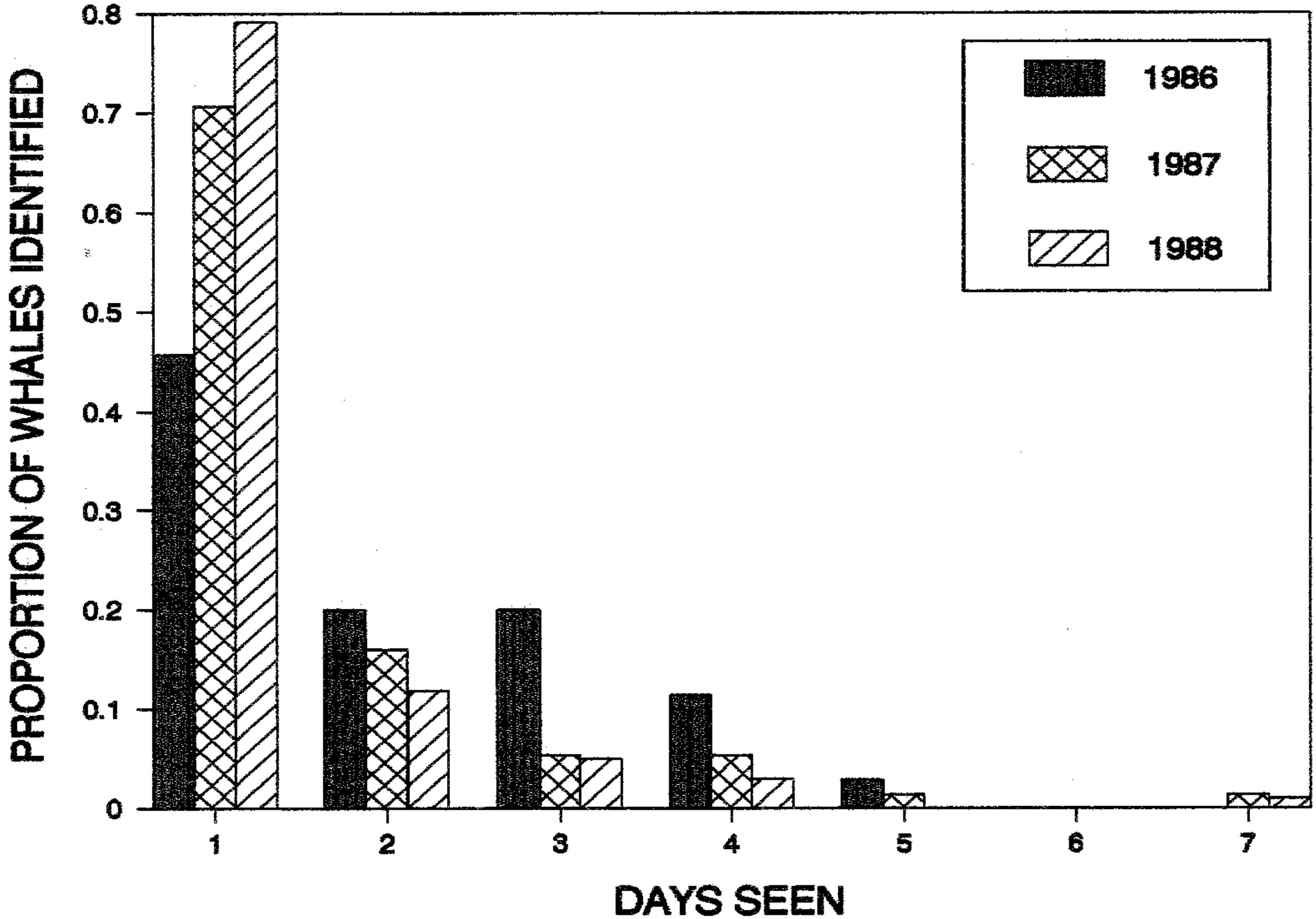

Figure 12. Resighting frequencies of identified blue whales seen for 1986 to 1988.

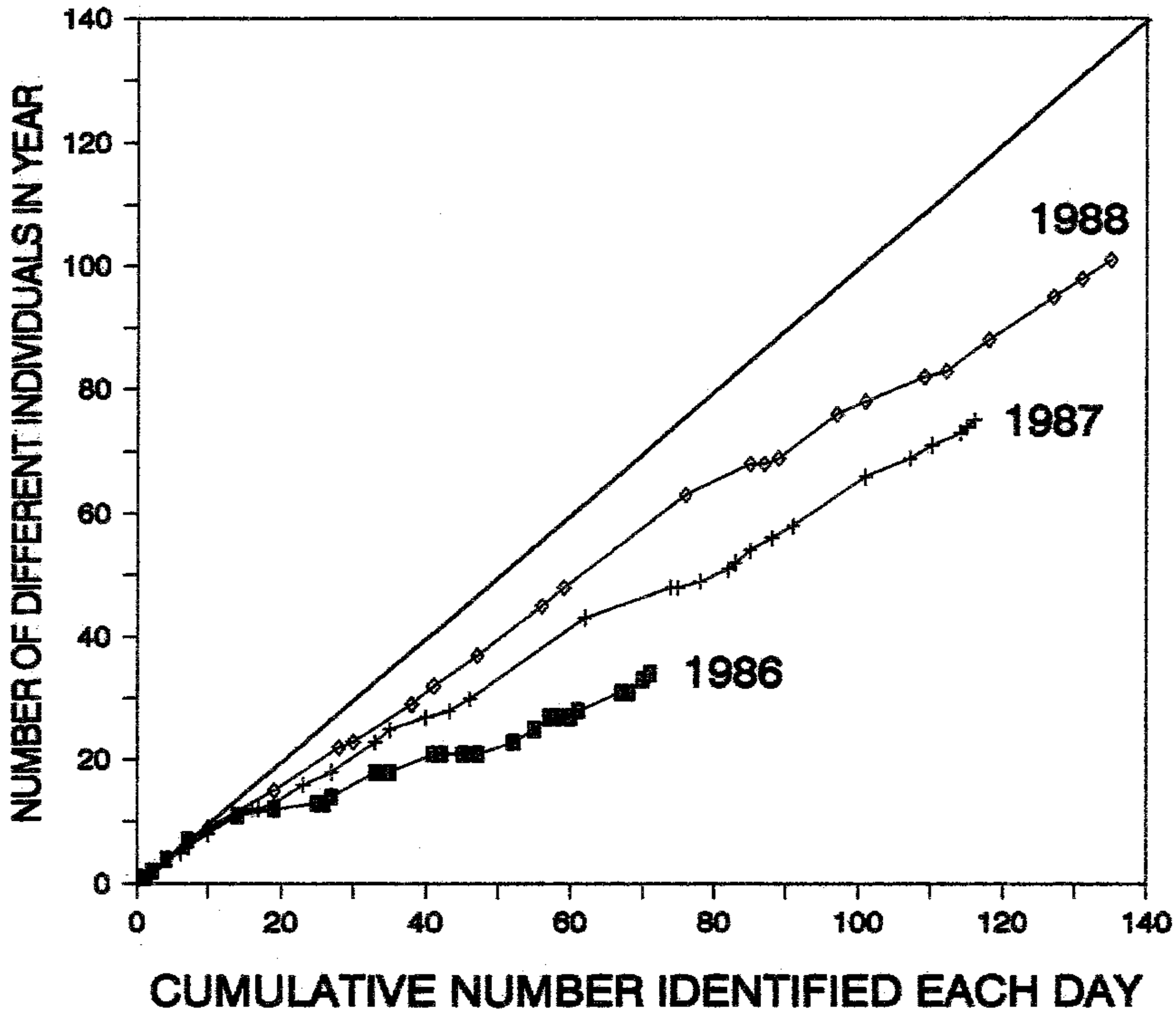

Figure 13. Rate at which new whales were identified, or rate of discovery, in 1986 to 1988. The straight line shows a slope of 1 or the rate expected if all whales were seen on only one day.

Sightings among years

Some individual whales returned to the Gulf of the Farallones on multiple years. Twenty-two of 179 blue whales identified were seen at least two of the three years (1986-88) and five individuals were identified in all three years. More than 10 whales were common to any two years (i.e. 1986 and 1987, 1986 and 1988).

The sighting frequencies of individuals in 1987 and 1988 were higher for individuals that had been seen in a previous year. The average number of times an identified whale was seen in 1988 was significantly higher (t-test, $p<0.001$) for those whales seen in 1986 (n=11, mean=3.0, s.d.=2.9) compared to those not seen in 1986 (n=90, mean=1.5, s.d.=0.88). The same difference (t-test, $p<0.001$) occurred for the 1988 sighting rates for whales that had been seen in 1987 (n=15, mean=2.7, s.d.=2.3) versus those not seen in 1987 (n=86, mean=1.5, s.d.=0.97). The sighting frequency of whales in 1987 that were seen or were not seen in 1986 followed a similar pattern but was not statistically significant (t-test, $p>0.05$). These results suggest that a subgroup of blue whales tend to return and stay longer in the Gulf of the Farallones in multiple years.

Eight blue whales were identified in the Gulf of the Farallones prior to 1986. These whales had been photographed by Connie Ewald and Mark Webber or passengers aboard Oceanic Society nature trips. Two of these eight individuals (seen in 1984 and 1985) were later seen in the Gulf of the Farallones in both 1986 and 1987. A third whale seen in the Gulf of the Farallones in 1983 was later identified in Monterey Bay in 1987.

Movements of individual whales

Movements of two whales (ID# 01 and 27) seen in all three years are shown in Figure 14. Sightings over different years occurred in similar locations relative to the movements which occurred within years. The shifts in locations over years, however, paralleled some of the overall changes in blue whale distribution; for example, the 1987 sightings of these two whales tended to be farther offshore in deeper water. Whale # 01 was seen frequently in the same region between Pt. Reyes and Bodega Head from 21 August to 1 October 1988. The movement patterns shown within the region likely underestimate the locations these individuals traveled. As summarized in following sections, some blue whales traveled from the Gulf of the Farallones to other regions and then returned within the same season.

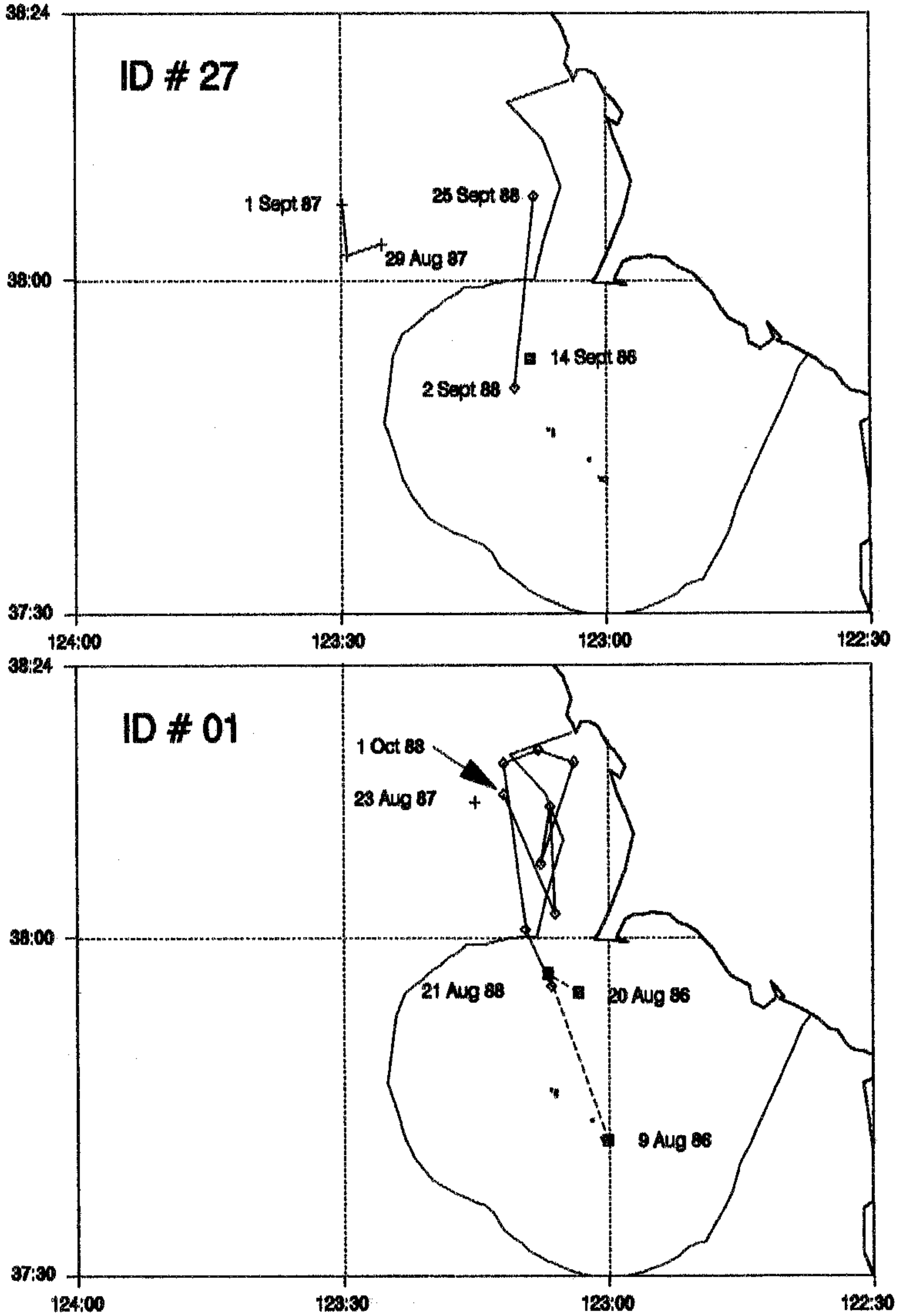

Figure 14. Examples of seasonal and annual movements of individual blue whales that were identified in the Gulf of the Farallones in 1986-1988. Two individuals that were resighted in all three years are shown.

Movements within California

Blue whales identified in the Gulf of the Farallones were also seen off Monterey Bay, more than 60 nm to the south, and Pt. Arena, about 50 nm north of the Gulf of the Farallones (Figure 15). Eighteen identified whales were observed in both Monterey Bay and the Gulf of the Farallones and nine whales were sighted at both Point Arena and Gulf of the Farallones. Many of the matches between Monterey Bay and Gulf of the Farallones span a number of years; one blue whale photographed by Gary Friedrichsen in Monterey Bay in 1975 was identified in the Gulf of the Farallones in 1986, an 11 year interval.

The movement of blue whales between the Gulf of the Farallones and Monterey Bay varied by year. In 1987 and 1988, 5 and 2 blue whales, respectively, were identified in Monterey Bay in August and then seen in late August or early September in the Gulf of the Farallones. Only one individual in 1987 or 1988 followed a reverse course. Three animals moved between these regions in less than 15 days. Two blue whales seen in both areas in 1986 were identified in August and September in Gulf of the Farallones and in mid-October in Monterey Bay (one photograph from Monterey Bay was from the Mingan Island Cetacean Study catalogue and is not shown in Fig. 15). Interchange between these regions may have occurred at other times but was not detected due to lack of effort in Monterey Bay.

Blue whales identified near Point Arena were part of the same group seen earlier in the Gulf of the Farallones. Eight of the 17 blue whales identified in the Point Arena area on 11 and 28 October 1988 had been seen earlier in the year in the Gulf of the Farallones. The matching of almost 50% of the Point Arena whales with the Gulf of the Farallones suggests a fairly cohesive movement of whales north from the study area. The identity of the Point Arena blue whales provides an explanation for the dramatic drop in blue whales sightings in early October in the Gulf of the Farallones.

Despite the movement of blue whales between regions there was a greater tendency for animals to return to the same area in consecutive years than to travel to other regions. We calculated resighting rates to compare the frequency with which whales return to the same region versus move between regions. The inter-year resighting rates for 1986 to 1988 in the Gulf of the Farallones (n=3, mean=0.0031, s.d.=.0011) were very similar to the resighting rates at Monterey Bay (n=3, mean=0.0029, s.d.=0.00098). The resighting rates between the two regions for both the same year and different years (n=9, mean=0.00078, s.d.=0.00043) were significantly lower (t-test, $p<0.001$) than those between years at the same region (n=6,

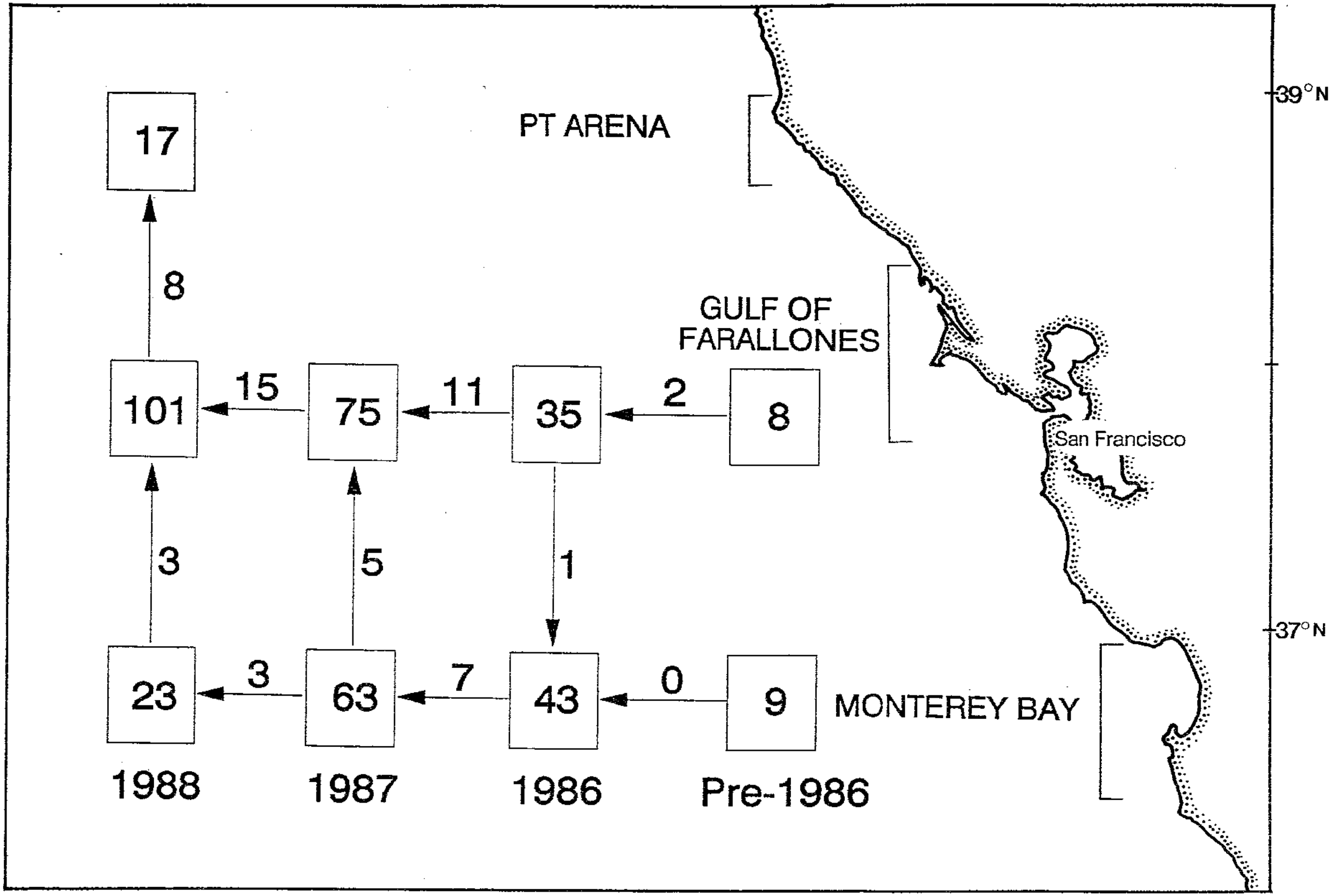

Figure 15. Number of blue whales identified by region and year (shown by the number in the boxes) and the number of matches between regions in the same year and between consecutive years for the same region are shown (with arrows). The direction of the arrow indicates time (e.g. in 1988, blue whales were first seen in the Gulf of the Farallones and later off Point Arena).

mean=0.003, s.d.=0.00094). These results indicate that individual blue whales do not redistribute on feeding areas randomly but instead show some tendency to return to the same region. The relatively low rate of resightings between Monterey Bay and the Gulf of the Farallones suggests that the movement between the regions is by a few individuals rather than a shift by a cohesive group of whales. One exception was the movement of blue whales between the study area and Point Arena in 1988, discussed previously.

Long-range movements

Blue whales identified in the Gulf of the Farallones have been seen in the Sea of Cortez, Mexico and along the west coats of Baja, Mexico in early spring. Nine of the whales identified in the Gulf of the Farallones matched whales photographed in Mexico by people contributing photographs to Cascadia or by members of the Mingan Island Cetacean Study (Sears 1987). In addition to these nine whales, five whales seen in Monterey Bay also matched whales photographed in Mexico.

Some of the resightings between Mexico and California are in the same year and outline the migratory movement of at least a portion of the blue whale population. One whale seen on 17 March 1988 in the Sea of Cortez was identified in the Gulf of the Farallones on 2 September. A second whale seen in late March and early April outside Magdalena Bay along the west coast of Baja was resighted in late September and October in the Gulf of the Farallones. A third whale seen in early April 1988 along the west coast of Baja was identified in Monterey Bay on 12 August.

These results indicate that the blue whales seen in the Gulf of the Farallones and Monterey Bay are all part of a population that shares a common migratory route. Blue whales from this population enter the Sea of Cortez from February to April and feed along the west coast of Baja from March through at least June. Blue whales begin to appear in numbers in the Monterey Bay and the Gulf of the Farallones area in June and July. The resighting data from Monterey Bay to Point Arena indicate blue whales range widely from August to November, and concentrate in different areas at different times depending on the year. The location of the majority of this population from December to February in not clear but the sightings of blue whales during this period off the coast of Central America (Wade and Friedrichsen 1979) may reflect the southern extent of the breeding area for this group. Unfortunately, identification photographs from this area are not yet available to test this hypothesis.

Previous information on the migrations and movements of blue whales along the Mexico and California coast has been limited (Mizroch et al. 1984). Rice (1974) reported on the discovery tagging of 76 blue whales along the California and Baja coasts from 1962 to 1970. Unfortunately, none of these tags were ever recovered. Our results differ from some of the previous speculation on blue whale movements. Rice (1974) suspected blue whales occurring along the Baja coast in early spring migrated north reaching British Columbia in May and then continuing north to the Gulf of Alaska. These animals presumably returned to the California coast in fall prior to their migration to southern waters. Rice (1966) suspected that blue whales along the west coast of Baja from February to July arrived there from California waters.

Population Estimates

Information on the absolute abundance of blue whales in the Gulf of the Farallones region was obtained from aerial survey and individual identification data. We estimated the number of whales present in the study area on a given day from aerial surveys in two ways; the minimum estimate was the total whales seen on each survey and the total single-day estimate was the line-transect calculation from the transect flights. We calculated minimum and total estimates of the number of blue whales over a prolonged period from the photoidentification data. The minimum estimate was the total number identified in any one season and the estimate of the entire population was calculated by mark-recapture. The number of blue whales and their residency patterns in the Gulf of the Farallones changed, sometimes dramatically over the study period, which complicated estimates of overall abundance. These various estimates and their limitations are presented below.

Population estimates from aerial surveys

Population estimates of blue whales from aerial surveys were possible from two line-transect surveys conducted in 1987 and 1988 (Table 10). The most dramatic results were found during the survey on 26 September 1988 when 48 sightings of 72 blue whales were made during coverage of the northern and central portions of the study area. Line-transect calculations yielded an estimate of 167 blue whales in the region surveyed. The southern portion of the study area could not be surveyed because of heavy fog. Blue whales had been seen in the southern portion of the study area, however, during a non-transect aerial survey the previous day. Assuming the observed density of blue whales was similar in the southern portion of the study area (where blue whales had been seen the previous day) the estimate would be 253 blue whales for the entire region.

Table 10. Estimates of blue whale numbers from aerial line-transect surveys.

Date	Region	Numbers seen[1] Groups	Numbers seen[1] Animals	Estimates Number	Estimates 95% C.I.[2]
21 Aug 1987	Bodega to S end Sanctuary 38'24' to 37°36' N	12	14	43	14 - 53
25 Sept 1988	Bodega to S of Pt. Reyes 38°22' to 37°50' N	48	72	167	109 - 224
25 Sept 1988	As above extrapolated to include S to 37°30' N	-	-	253	156 - 350

[1] Number seen likely includes some duplicate animals seen from adjacent survey lines.
[2] Confidence limits are based on variances for the density calculations (see Methods) and do not include variances for group size or the correction for animals underwater.

The number of blue whales estimated during the line-transect survey in 1987 was much lower than 1988; an estimated 42 blue whales were present in the study area on 21 August 1987. This number is also much lower than the number of whales identified in 1977 (75) indicating most of the blue whales were not present in the study area on that day.

Minimum estimates of the number of blue whales in the study area from non-transect aerial surveys were consistent with the line-transect results. The largest number of blue whales seen in any single non-transect aerial survey was on 25 September 1988 when 55 blue whales were seen. This was a 4 hr scouting flight with flight lines far enough apart that duplicate sightings of the same animal were unlikely. Two other non-transect flights in 1988, on 24 August and 29 September, yielded counts of 31 and 33 blue whales, respectively. The largest number of blue whales seen on single non-transect flights in 1987 was on 31 August and 8 September when 22 and 24 blue whales were seen. A maximum of 10 blue whales were seen in any single non-transect survey in 1986.

Population estimates from individual identification

The number of animals identified each year provides a minimum estimate of the number of blue whales that visited the Gulf of the Farallones. This number increased from 35 blue whales in 1986 to 101 in 1988. Inclusion of blue whales identified between Bodega Bay and Pt. Arena raises this number to 110 for 1988. A total of 179 blue whales were identified between 1986 and 1988 (186 with the Point Arena sample). The resighting rates of individual whales show that a majority of the individuals identified in 1987 and 1988 were identified only once. It is therefore likely that other individuals were present but not photographed. The high resighting rate in 1986 indicates a majority of the whales present were identified.

Mark-recapture estimates provide a method for estimating population size from individual identification data (Hammond 1986). A number of the assumptions of these calculations, however, are at least partially violated in our situation:

1) The assumption of a "closed" population needed for many models is clearly violated based on our movement information.

2) The assumption that emigration, should it occur, is permanent, as required for the Jolly-Seber "open" population model, is not true.

3) The existence of a subgroup of whales with a higher sighting frequency and a tendency to return in multiple years indicates the assumption of equal probability of capture is violated to a certain degree.

4) The requirement that all matches are identified is usually true but is violated to some degree because some matches are likely missed.

Open population models such as the Jolly-Seber are more appealing but require a minimum of three samples and are more accurate with additional samples (Seber 1982).

Despite the violation of these mark-recapture assumptions, it is surprising how consistent the results of these estimates were with those found using aerial surveys. Data from 1988 provided the best basis for comparison of aerial survey and mark-recapture estimates; 1986 and 1987 line-transect flights were not completed during periods of maximum blue whale relative abundance. The 1988 line-transect survey was conducted on 26 September during the peak period of blue whale sightings and yielded an estimate of 163 blue whales in the area surveyed and 253 blue whales extrapolated to the entire study area. The Peterson mark-recapture estimate for 1988, using the two 3-week field sessions as the samples, was 181 and 179, based on photographs of left and right sides of the whales, respectively. Similarly, a comparison can be made between individuals in the Gulf of the Farallones through mid-October and those identified off Point Arena (an area to which the Farallon whales shifted) in middle to late October. This estimate yielded surprisingly similar results compared to the sessions mentioned above, 148 and 173, for left and right sides, respectively.

The various mark-recapture estimates were surprisingly similar to the aerial line-transect estimate and indicate about 200 blue whales visited the study area in 1988 with most being present during the late September aerial survey.

Different numbers of whales were estimated using mark-recapture calculations for 1986 and 1987, but these could not be directly compared to line-transect surveys conducted during the peak abundance of blue whales. Mark-recapture estimates for 1986 yielded consistent estimates of 41 to 48 whales depending on how the samples were compared (side of the whale used and division of season). The 1987 estimates, however, were problematic because the season was not easily divided into two periods with comparable samples. The results of these calculations for 1987 were highly variable (130 to 280) and of little value. As an alternate method, we used the

Jolly-Seber "open" population model to calculate the 1987 population size using the resighting data from multiple years. The mark-recapture estimates using the Jolly-Seber (Seber 1982) open population model for 1986 to 1988 yielded an estimate of 136 whales in 1987. Population estimates for the first (1986) and last (1988) years of the sample cannot be calculated with this method.

Our estimates of blue whale numbers off California are the first for this region. Dohl et al. (1983) conducted monthly surveys from 1980 to 1983 for marine mammals along the central and northern California coast and recorded only 40 sightings of blue whales, too few to estimate population size. It is not possible to determine the proportion of the North Pacific blue whale population that occurred in the Gulf of the Farallones because reliable estimates of the entire North Pacific population are not available. The North Pacific population has been reported to be 1,600 (NMFS 1987, Gambell 1976). These estimates, however, are based on very limited sighting data gathered on Japanese scouting trips in the North Pacific in the 1960s and early 1970s (Omura and Ohsumi 1974, Wada 1973). Most of the sighting data came from the eastern, central, and northern portions of the North Pacific with very little effort in California coastal waters. These estimates are of little value because 1) they are based on very small numbers of sightings extrapolated to the entire North Pacific, 2) they were not conducted in a systematic or random manner that is necessary for extrapolation to the entire population, 3) they were determined more than 15 years ago, and 4) they do not appear to cover the range of the California-Mexico blue whale population that we observed.

The Gulf of the Farallones served as a major feeding area for blue whales during this study. Since 1981, blue whales have consistently returned to this area. The number of blue whales estimated in 1988 in the study area represents the largest concentration we are aware of in U.S. waters. If the number of blue whales using the Gulf of the Farallones continues to increase, the sanctuary could easily become the single most important feeding area for blue whales in the North Pacific.

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