Cascadia Research Collective
a non-profit research organization

HARBOR PORPOISE STUDIES IN THE GULF OF THE FARALLONES

FINAL REPORT FOR CONTRACT NO. CX 8000-8-0001

To:

Gulf of the Farallones
National Marine Sanctuary
National Oceanic & Atmospheric Adm.
Fort Mason Center, Bldg. 201
San Francisco, CA 94123

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EXECUTIVE SUMMARY

We report on research to examine the distribution, abundance, reproduction, mortality, and pollutant levels in harbor porpoise (*phocoena phocoena*) in the Gulf of the Farallones. High mortality of this species in recent years and their elimination from other portions of their range has raised concerns about their status and vulnerability.

Vessel surveys were conducted for harbor porpoise from December 1987 through September 1989 in the Gulf of the Farallones area. Just under 1,000 nm of line-transect surveys were completed. We also conducted calibration experiments and photographic identification of individual harbor porpoise.

Harbor porpoise were predominantly distributed in coastal waters at water depths under 40 m. Highest sighting rates were in the summer and fall. Harbor porpoise were consistently seen just outside San Francisco Bay. In September 1989, the area west of Pt. Reyes had some of the highest harbor porpoise densities seen in the study. The presence of harbor porpoise in this area was variable, however, with few sightings at other times.

Best estimates of harbor porpoise abundance were obtained in the fall of 1988 and 1989 when an estimated 2,100 harbor porpoise were present in the study area. This is considerably higher than estimates reported previously. This difference is more the result of greater effort and the use of different methods than an indication of a change in harbor porpoise population size. We restricted our analysis of population size to only include survey effort in ideal weather conditions (Beaufort sea state of 0 or 1).

Sightings of harbor porpoise made from Oceanic Society nature trips showed a significant increase from 1983 to 1987. These differences remained after the effects of weather were incorporated. These trips only reflect the density of harbor porpoise along the route traveled from San Francisco to the Farallon Islands.

The number of strandings of harbor porpoise reported in the Gulf of the Farallones area has decreased substantially since the high numbers of strandings in 1983 and 1984. This appears to reflect a decline in incidental mortality of harbor porpoise in set nets as a result of protective measures adopted starting in 1984. Concentrations of the stable chlorinated hydrocarbon contaminants PCBs, DDT, and HCB were found in blubber tissues of stranded harbor porpoise from the Gulf of the Farallones. These concentrations, though high in comparison to most animals, were within the range found in harbor porpoise and other coastal small cetaceans in other regions. Contaminant ratios provide an indication of the interchange of harbor porpoise between different areas. Ratios determined in harbor porpoise from the Gulf of the Farallones were highly variable and overlapped with those found in harbor porpoise in Monterey Bay and to a lesser degree Oregon.

INTRODUCTION

We report on the results of studies conducted on harbor porpoise in the Gulf of the Farallones region of central California. The Gulf of the Farallones National Marine Sanctuary encompasses the waters surrounding the Farallon Islands, Point Reyes and the coast north to Bodega Head. The research was funded as part of the sanctuary's goals to promote research and obtain information necessary to manage and protect its resources.

The overall goal of the research was to understand better the population size and biology of harbor porpoise in the Gulf of the Farallones National Marine Sanctuary, Cordell Bank, and vicinity. Specific objectives were as follows:

1) Determine the population size of harbor porpoise in the Gulf of the Farallones and Cordell Bank areas.

2) Determine how harbor porpoise distribution in the study area is related to location, depth, and other oceanographic features.

3) Determine if seasonal movements of harbor porpoise occur in the study area.

4) Examine year to year changes in occurrence of harbor porpoise.

5) Evaluate the potential impacts of pollutants on harbor porpoise.

6) Examine aspects of reproduction and food habits of harbor porpoise in the study area.

7) Evaluate the effectiveness of vessel survey methods.

BACKGROUND

The harbor porpoise is the second most commonly sighted small cetacean from Año Nuevo to Bodega Bay (Huber *et al.* 1982, Szczepaniak and Webber 1985a). It is also the most frequently stranded cetacean in this area (Schonewald and Szczepaniak 1981).

Several studies of harbor porpoise populations in the Gulf of the Farallones have been conducted, but all were limited in scope. Sightings and strandings in this region were reported in the mid-1800s (Gill 1865, Scammon 1874). Brownell (1964) and Fiscus and Niggol (1965) reported observations of harbor porpoise in the early 1960s. From 1971 through 1979, the Point Reyes Bird Observatory, while on route to and from the Farallon Islands, recorded sightings of harbor porpoise (Huber *et al.* 1982). LaBarr and Ainley (1985) reported sightings and depth distribution of harbor porpoise from cruises in and around the Gulf of the Farallones from April to June of 1985. Aerial surveys for marine mammals were conducted from 1980 to 1983 along the coast of central and northern California including the Farallon region (Dohl *et al.* 1983). Additional aerial surveys were conducted in August and September 1984 in the Gulf of the Farallones (Dohl 1984). Oliver (1986) reported results of aerial surveys along the coast of California, Oregon, and Washington, including the Gulf of the Farallones. Webber and Cooper (1983) report sightings of harbor porpoise near Cordell Bank in Autumn 1981-82. Barlow (1988) and Barlow *et al.* (1988) recently reported the results of vessel and aerial surveys and population estimates of harbor porpoise along the coasts of California, Oregon, and Washington. Szczepaniak and Webber (1985a) reported sightings of harbor porpoise from Oceanic Society trips to the Farallon Islands. In the fall of 1986, preliminary vessel line-transect surveys were conducted in this area by personnel from this project under contract to National Park Service (Szczepaniak 1988).

These previous surveys have provided neither a good population estimate nor a clear picture of harbor porpoise distribution by location, season, or depth in the study area. Estimates by Dohl *et al.* (1983) were extremely low and did not use a correction factor for the high proportion of animals probably missed by aerial surveys. Population estimates by Barlow (1988) represented the first good effort to estimate the harbor porpoise population size along the west coast of the U.S., but due to limited number of surveys, the study does not provide a good estimate of porpoise in the Gulf of the Farallones. The vessel surveys conducted in the fall of 1986 (Szczepaniak 1988) represented the most thorough census effort to date, but did not provide coverage in all seasons and did not survey all the waters of the Marine Sanctuary.

Concern over the status of harbor porpoise populations along central California intensified in the mid-1980s. An increase in harbor porpoise strandings since 1982 along the coast of California coincided with an increase in gill-net activity. An annual kill of 166-193 animals was estimated for the San Francisco region alone (Diamond and Hanan 1986, Hanan *et al.* 1986).

Harbor porpoise populations have been eliminated or dramatically reduced in other regions including Puget Sound (Calambokidis *et al.* 1984, 1985), the Baltic Sea (Otterlind 1976), the Wadden Sea (Wolff 1981), San Francisco Bay (Leatherwood and Reeves 1986), and portions of the east coast of North America (Prescott and Fiorelli 1980). Causes of these declines have not been identified, but agents that have been suggested include entanglement in fishing gear, pollution, and disturbance from vessel traffic.

The high harbor porpoise kill in central Californian waters, the historical precedent of regional extirpation, and the lack of baseline data to detect population trends created the urgent need for more study of harbor porpoise. Four harbor porpoise surveys along the coasts of Washington, Oregon, and California were conducted by the Southwest Fisheries Center (NMFS)(Barlow 1988). The estimate of harbor porpoise abundance in the San Francisco region was very low due to, in part, the poor weather encountered and the small amount of suitable habitat in the region surveyed (Barlow 1988). Recent studies indicate a larger population probably resides in the San Francisco region (Szczepaniak 1988). This research was response to the need for more data on harbor porpoise population trends, distribution, and natural history.

METHODS

Boat Surveys

Boat-based surveys were the principal method used to examine population abundance, seasonal occurrence, and distribution by location and depth. Boat surveys were reported to be superior to aerial surveys because harbor porpoise were often missed by standard aerial surveys (Kraus *et al*. 1983, Barlow 1988). Line-transect methods have been employed extensively to determine cetacean abundance and have been used recently with harbor porpoise (Barlow 1988, Barlow *et al*. 1988, Dohl *et al*. 1983, Szczepaniak 1988, Polacheck 1989, Calambokidis 1990).

Vessel effort is shown in Table 1. Each month we attempted to survey the entire study area, which required two days of vessel effort to complete. Poor weather forced the cancellation of many surveys; 28 scheduled surveys were canceled before just before leaving port because of changes in weather conditions. This was because of the strict weather requirements we set for the study to insure the maximum success of the surveys, as well some unseasonably poor weather that occurred during the study.

Survey design

Areas of greater than 60 fathoms were excluded from sampling because systematic coverage of these areas would require a large amount of effort and sightings of harbor porpoise unlikely in these areas (Dohl *et al*. 1983, Barlow 1988, LaBarr and Ainley 1985). Areas deeper than 60 fathoms were examined opportunistically during surveys by Cascadia Research for humpback whales and Farallones Research Associates in their research aboard Oceanic Society nature trips.

The study area was divided into four survey blocks that each extended from the shore out to 60 fathoms (Figure 1). Transect lines ran east to west through each block (Figure 2). Sample transects were selected randomly by block for each survey. Starting in September 1988, the survey lines were truncated to include only the more coastal half of the blocks. This was done because all but one sighting had been made in that area and the truncation allowed us to double the number of lines completed during each survey. Transect lines were changed each survey (month) so that most areas inside each block had an equal chance of being surveyed throughout the study. Analysis of sightings by block provided information about broad areas of harbor porpoise abundance as well as categories of preferred habitat in the National Marine Sanctuary.

The saw-tooth line-transect survey design, which has gained popularity in recent years (Cooke 1985, 1986), was used for a single survey at the end of the study to sample the areas of highest harbor porpoise density. This type of survey make efficient use of vessel time; we sampled the region in both directions traveling on criss-crossing transect lines.

Table 1. Harbor porpoise vessel surveys conducted in the Gulf of the Farallones. Surveys that were cancelled before leaving port are not noted.

Date	Block	Survey Line/Position Latitude	Longitude Start	Longitude End	Status/Survey type
17 Oct 87	-	37 49.7	122 35.2		photo-identification survey
18 Oct 87	-	37 49.9	122 36.5		photo-identification survey
20 Dec 87	2	37 49.5	122 36.5	123 15.2	completed line
	1	37 41.5	123 05.0	122 33.1	completed line
21 Jan 88	2	37 47.5	122 31.7	122 48.5	line aborted partway
	1	37 39.5			line cancelled
24 Jan 88	3	37 56.5	122 46.3	123 19.9	completed line
	4	38 03.5	123 28.9	122 59.8	completed line
01 Feb 88	1	37 39.5	122 32.1	122 39.6	completed line
	2	37 47.5			line cancelled
04 Feb 88	2	37 50.5	122 33.6	123 18.0	completed line
	1	37 42.5	123 06.3	122 30.9	completed line
25 Feb 88	4	38 06.5	122 58.3	123 30.0	completed line
	3	37 58.5	123 26.8	122 48.9	completed line
18 Apr 88	2	37 46.5	122 31.3	123 15.0	completed line
	1	37 38.5	123 03.9	122 41.6	completed line
25 Apr 88	4	38 02.5	122 59.6	123 30.0	completed line
	3	37 54.5	123 19.8	122 44.6	completed line
09 May 88	4	38 00.5	123 30.0	122 51.5	completed line
	3	37 52.5	122 37.7	123 20.0	completed line
11 May 88	1	37 36.5	122 30.3	123 00.1	completed line
	2	37 44.5	123 10.1	122 36.9	completed line
09 Jun 88	1	37 42.5	122 30.3	123 08.1	completed line
	2	37 50.5	123 18.0	122 32.7	completed line
24 Aug 88	3	37 58.5	122 48.7	123 27.0	completed line
	4	38 06.5	123 30.0	122 58.1	completed line
14 Sep 88	2	37 49.5	122 31.6	122 54.0	completed line
	2	37 48.5	122 54.0	122 31.0	completed line
	1	37 41.5	122 30.2	122 44.1	completed line
	1	37 40.5	122 43.8	122 30.3	completed line

continued

Table 1. continued

23 Sep 88	3	37 56.5	122 47.1	123 10.1	completed line
	4	38 05.5	123 09.6	122 58.0	completed line
	4	38 04.5	122 58.8	123 10.0	completed line
	3	37 57.5	123 09.7	122 50.5	completed line
01 Oct 88	-	38 14.6	123 08.0		photo-identification survey
14 Oct 88	2	37 44.5	123 31.6	122 46.0	aborted partway
14 Oct 88	-	north of Point Bonita			calibration survey
26 Oct 88	3	37 52.5	122 42.1	123 10.1	completed line
	4	38 06.5	123 10.0	123 00.0	completed line
	4	38 00.5	123 00.6	123 05.0	completed line
	3	37 58.5	123 04.9	122 50.1	completed line
29 Oct 88	2	37 50.5	122 35.0	123 00.0	completed line
	1	37 37.5	122 47.0	122 30.0	completed line
	1	37 42.5	122 30.3	122 49.1	completed line
	2	37 44.5	122 50.0	122 41.5	line aborted partway
06 Sep 89	1	37 38.5			line cancelled
	1	37 38.5			line cancelled
	2	37 46.5			line cancelled
	2	37 47.5			line cancelled
08 Sep 89	4	38 03.5	122 59.3	123 10.0	completed line
	4	38 02.5	123 09.9	122 59.6	completed line
	3	37 55.5	123 09.9	122 46.1	completed line
	3	37 54.5	122 44.1	123 10.0	completed line
14 Sep 89	1	37 38.5	122 29.6	122 48.3	completed line
	1	37 39.5	122 47.6	122 29.5	completed line
	2	37 46.5	122 30.7	122 53.1	completed line
	2	37 47.5	122 53.0	122 32.0	completed line
14 Sep 89	-	38 03.4	123 04.7		photo-identification survey
		38 02.8	123 10.5		
15 Sep 89	-	off Point Reyes			calibration survey
20 Sep 89	-	off Point Reyes			calibration survey
29 Sep 89[a]	2	37 49.7 122 35.2 to 37 51.6 122 44.1			completed line
	2	37 51.7 122 44.1 to 37 51.3 122 34.3			completed line
	2	37 51.3 122 34.3 to 37 48.9 122 43.8			completed line
	2	37 49.0 122 44.0 to 37 46.6 122 30.5			completed line
	2	37 46.6 122 30.5 to 37 45.5 122 37.2			completed line
	2	37 45.5 122 37.5 to 37 46.6 122 44.3			completed line
	2	37 46.6 122 44.3 to 37 46.5 122 32.5			completed line

[a]survey used saw-tooth survey lines (see Methods)

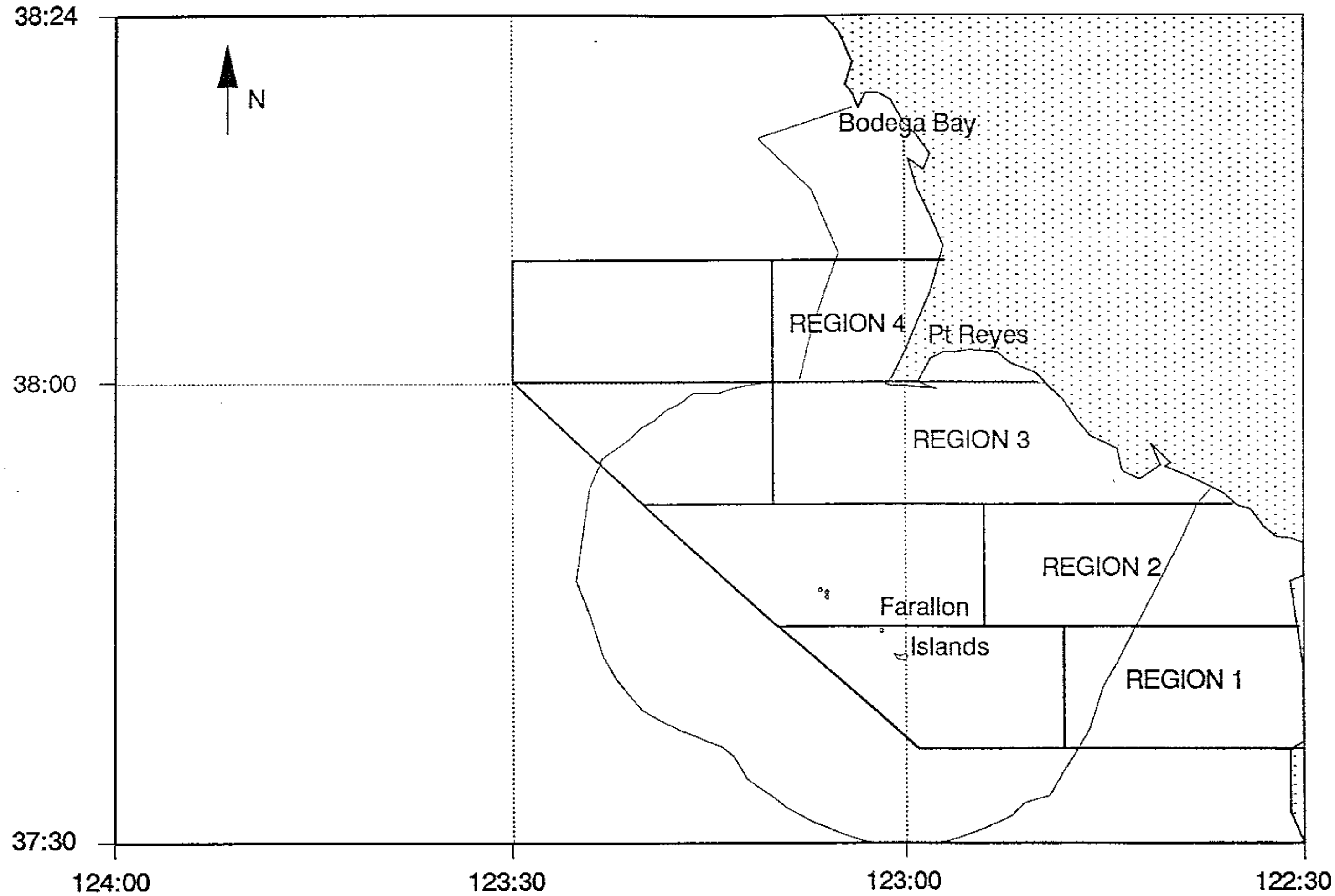

Figure 1. Study area showing regions used. Offshore portions of blocks were not surveyed after initial surveys revealed no harbor porpoise.

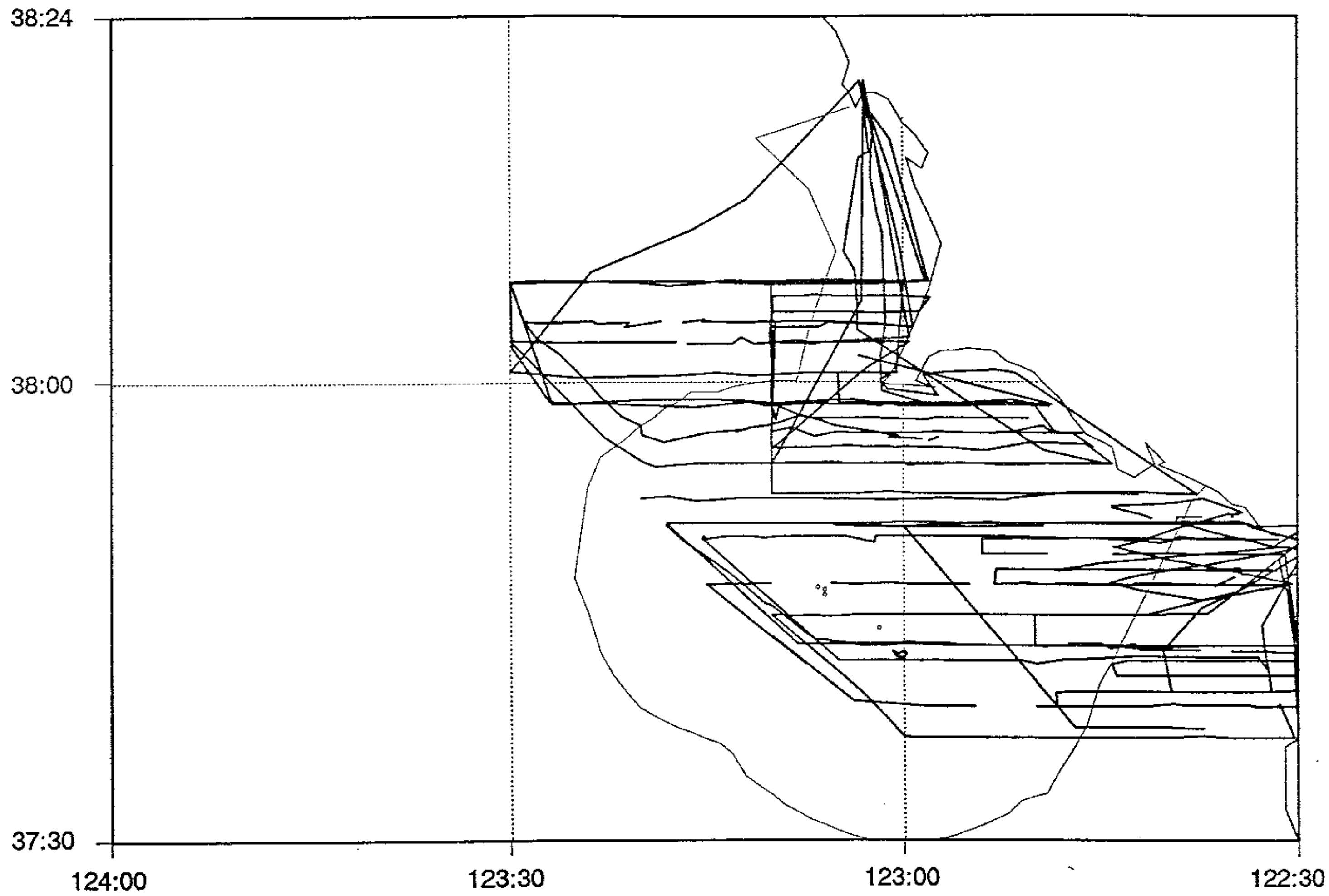

Figure 2. Vessel effort during entire study. Does not include calibration surveys. Only east-west lines were on effort and used in the relative abundance and density calculations.

Vessels

To effectively conduct line-transect surveys for harbor porpoise in the Gulf of the Farallones, we used four survey vessels out of either San Francisco Bay (Sausalito) or Bodega Bay (Table 2). We required vessels to be at least 30 ft long and equipped with marine radios and LORAN; they needed to have a high platform for observations (flying bridge) and were available with short notice.

Observers

Three observers were employed on vessel surveys (in addition to the skipper and crew). Two observers scanned alternately with naked eye and 7x binoculars abeam of the vessel (perpendicular to the transect line) from straight ahead to 90° to port or starboard; the middle observer scanned the transect line ahead with unaided eye and served as the data recorder. Observers rotated positions during the survey to reduce fatigue; they also rested during off-transect time (between the end of one transect line and the start of the next).

Distance estimation

Distance to sighting, bearing to sighting, and perpendicular sighting distance (distance from the transect line) were determined with the aid of Fujinon reticle and compass binoculars that measured angle of sightings below the horizon and magnetic bearing to the sighting. Vertical angle was calculated based on 0.285° per reticle tick-mark (estimated to 0.1 ticks) between the horizon and the sighting. An adjustment of 0.06° (based on the height above the water) was added to reflect the angle between the observed horizon and true vertical. The height of the observers' eyes above the water line was measured for each individual while in their typical posture. Distance was calculated as follows:

$$\text{distance} = \text{height} * \text{cotan (vertical angle)}$$

When distances were less than 100 m, observer-estimated distance was used instead of the above methods because of our subjective impression that these were more accurate. The rapid relative movement of the vessel at these close distances made reticle-calculated distance subject to error if there was a delay between the time of the sighting and the calculation of reticle tick-marks.

Sighting distance off the transect line was calculated using the bearing to the sighting, vessel heading, and distance to the sighting. Vessel heading was the course between waypoints. Angle off the transect line was determined as the difference between the bearing to the sighting and the vessel heading. Distance off the transect line was calculated as follows:

$$\text{perpendicular sighting dist.} = \text{dist.} * \sin(\text{angle off transect line})$$

Table 2. Vessels used during transect surveys.

Vessel	Length/Type	Bridge Ht	Port
Bounty	42′ Grand Banks	2.8 m	Sausalito
Kumbaya	42′ Grand Banks	2.8 m	Sausalito
Mystique	32′ Grand Banks	2.4 m	Sausalito
Susan K	42′ Grand Banks	2.8 m	Bodega Bay

Data recording

All effort, weather and sea conditions, and sighting data were recorded during surveys. Effort and position readings were made at least every 30 min as well as at the start and stop of transect lines or when weather conditions, observers, or vessel course changed. More detailed information was recorded for all sightings of marine mammals including harbor porpoise. Data were transferred from data sheets to DBASE III+. Error checking for reasonable values and plotting of all positions were used to find and check potential errors in computer entry.

Density calculations

Density and abundance calculations were made following the methods described by Burnham *et al.* (1980). Line-transect calculations were conducted excluding all effort and sightings during sea state conditions worse than Beaufort 1. As explained in the results, effort in poorer sea states yielded dramatically lower sighting rates and resulted in few harbor porpoise sightings. A truncation point of 750 m was used in the calculation which resulted in the exclusion of three sightings. A model of the sighting frequency versus perpendicular distance off the track-line was fitted with the Fourier Series using formulas given in Burnham *et al.* (1980). Initial models were also made using sighting data already grouped by distance interval with the program TRANSECT. The choice of the grouping interval, however, resulted in differences in the calculation of f(0) and the calculation that used ungrouped data contained in Burnham *et al.* (1980) was used to provide a good fit (Figure 3).

Variances for the density estimates were computed by estimating the variance of f(0) and the variance for number of sightings (Burnham *et al.* 1980). We estimated the variance for the number of sightings using replicate lines conducted during the same season using the following formula:

$$Var(n) = L * \frac{sum(l_i[n_i/l_i - n/L])}{R - 1}$$

Where: l_i and L are the replicate and total transect lengths
n_i and n are the replicate and total number of sightings
R is the number of replicate lines in the sample

The variance of D was calculated as follows:

$$Var(D) = D^2 * [cv(n)^2 + cv(f(0))^2]$$

Where cv(n) and cv(f(0)) are the coefficient of variation for the number of sightings and f(0), respectively.

Group size estimates were calculated separately for each abundance estimate because group sizes varied significantly among

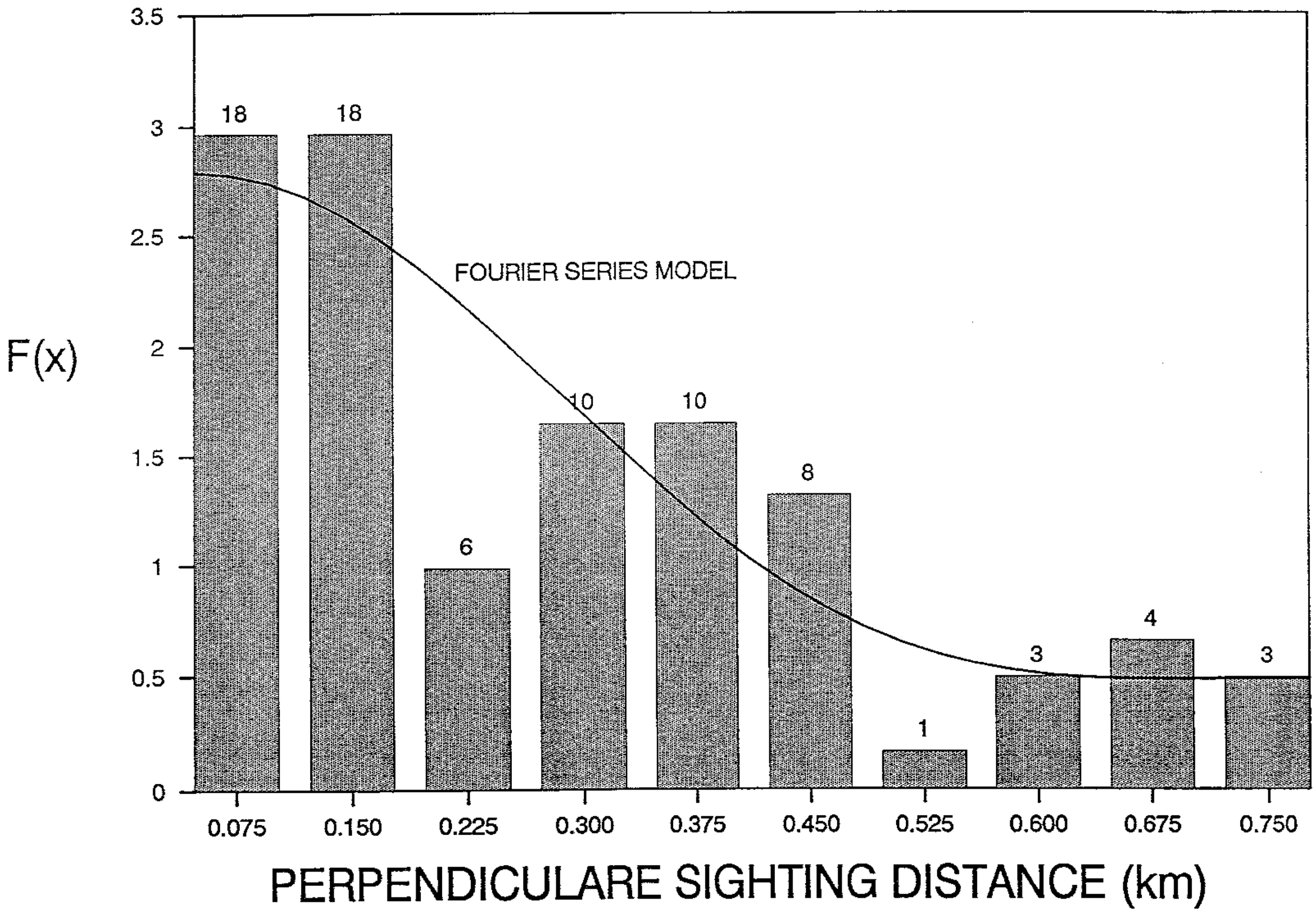

Figure 3. Sightings of harbor porpoise by perpendicular sighting distance and the Fourier Series model used to calculate the probability density function. Numbers above bars are the number of sightings.

seasons (see Results). Group size estimates included all harbor porpoise sightings made from vessels on and off effort. Group sizes were assumed to be measured without error and no variance was added to the abundance estimate for this element. There was probably some error in groups size estimation, but this was presumed to be small.

Survey coverage of offshore areas was terminated in September 1988 in order to double of the coverage of inshore areas. This improved survey coverage of the high density areas. Because only a single sighting had been made in the offshore area, we did not consider this area in the density and abundance estimates. Including these areas for the time periods they were surveyed would not alter the abundance estimates because: 1) the density would have been cut in half and 2) area would have been doubled.

Calibration of boat surveys for animals missed

Line-transect methods rely on the assumption that all animals on the transect line are detected by the observers and sighting probability only decreases with distance off the transect. This is clearly not the case with marine mammals that elude detection because they can spend considerable time underwater. Three approaches were used to evaluate the proportion of harbor porpoise groups on the transect line that would likely not be detected: 1) we examined the correction factors developed in other line-transect surveys of harbor porpoise, 2) we developed a simulation model of the surfacing behavior of harbor porpoise using breath rates reported in the literature and examined the sighting probability given our vessel speed and distances of detection, and 3) conducted comparative land and aerial calibrations of the vessel surveys to obtain data on the observers' ability to detect harbor porpoise.

During calibration surveys, a group of independent observers (on land or above in a plane) tracked groups of porpoise and directed the survey vessel to pass through the same area to examine the groups seen or unseen by vessel observers. Vessel transects were conducted using methods identical to surveys. Aerial-based calibration was completed successfully on one day. Two observers and the pilot in a single-engine high-wing aircraft (Cessna 172) circled over areas of anticipated high harbor porpoise density while the vessel waited nearby. After circling an area, aerial observers directed the vessel by radio through the area. There was no noticeable disturbance to the harbor porpoise caused by the aircraft.

Land observations were conducted on two days from the lighthouse on Point Reyes. This site at 300-400 ft elevation provided a view of an area where harbor porpoise had been sighted. Land-based calibration were based on roughly the same procedures as the aerial-based calibration. Harbor porpoise positions were measured from shore with a surveyor's theotolite. Once animals were seen, tracked, and counted, the survey vessel was radioed to pass through the area using census techniques identical to the surveys. Harbor porpoise numbers and behavior were monitored from shore.

Another method used to estimate the probability of porpoise that would be seen on the transect line was with a basic computer simulation model that we developed. The premise for this model was that a group of harbor porpoise on the transect line and at the surface when the vessel passes has a probability of 1 of being seen, while a group of harbor porpoise only at the surface when the vessel is more than 500 m away has a probability of 0 of being seen. The relationship between sightability and distance was assumed to be linear between these distances. Our data on sighting distance from the vessel were not adequate to test this assumption or to develop an alternate model of sightability. Vessel speed was set at 9 knots, as was the case in our surveys.

Harbor porpoise surfacing rates were modeled for the simulation using the pooled breath rate data compiled by Barlow *et al.* (1988) that indicated a mean surface time of 30 s (n=52, SE=1.95) and a mean dive time of 95.8 s (n=52, SE=5.32); these dive times were drawn from a number of sources including Taylor and Dawson (1984). Similar to Barlow *et al.* (1988), we assumed that porpoise surfacing patterns consisted of a series of short dive intervals during which the animals were visible at or near the surface, followed by a longer dive during which the animals were no longer visible. This is consistent with "Pattern B" surfacing behavior reported by Watson (1976) and Watson and Gaskin (1983) to be the most common and reflects feeding or milling behavior. The actual timing of the surfacing pattern of groups was generated by assuming the dive and surface durations were normally distributed around the mean with a standard deviation calculated from Barlow *et al.* (1988). Dive and surface times were randomly selected based on this distribution of times. The model simulated 500 vessel passes of a group of harbor porpoise on the transect line.

Photo-identification

Photo-identification procedures have helped to track individual animals of many species of cetaceans. Because the quick surfacing pattern (1 second rolls) and their small size, harbor porpoise are difficult to photograph; they must be in close range to recognize and photograph markings. However, researchers have identified and tracked harbor porpoise successfully in other areas (Watson 1976, Flaherty and Stark 1982, Taylor and Dawson 1981, Calambokidis and Steiger 1982).

Harbor porpoise were photographed using a 35 mm camera with a 300mm lens and high speed Ilford black-and-white film pushed to 1000 or 1600 ASA. This allowed us to photograph at a high shutter speed (1/1000 of a second). Custom processed negatives and prints were examined to identify any individual markings.

Use of data from opportunistic platforms

We examined data on harbor porpoise sightings made by Farallon Research Associates during the natural history trips made from 1983 to 1987 in the Gulf of the Farallones by the Oceanic Society. An average of 35 trips per year were made from 1983 to 1987. One of the primary objectives of the analysis of data from other sources was to examine annual in harbor porpoise occurrence in the study area.

Routes taken from San Francisco Bay out to the Farallon Islands and back during each nature trip did vary greatly. Data from nature trips were used only if the usual route was taken and experienced observers were aboard. We treated each outgoing and incoming passage as a separate sample of the nearshore waters off San Francisco Bay. Each trip, therefore, generated two samples. Information on the number of sightings, number of animals, and group size were coded for each trip leg along with weather data (predominant sea state, visibility/precipitation, swell height), number of observers, and tidal state (including tide state, tide height and time to nearest high and low tides). Data from 382 samples (191 round-trips) were analyzed, however, 32 of these had incomplete sighting data and were excluded from most of the analyses. Other data entries were excluded from particular analyses when information was not available.

Statistical analysis of the historical nature trip data was conducted using SYSTAT (Wilkinson 1988). The goal of the statistical tests was to identify observer and weather-related factors responsible for variations in porpoise sightings and to incorporate these into a model to test whether sighting frequencies changed from 1983 to 1987. Multiple linear regression and step-wise linear regression were used to simultaneously test for the influence of multiple factors. In regression analyses, sea state, year, and swell height were treated as continuous variables. Analysis of Variance and Analysis of Covariance were conducted using year as a categorical factor.

Sightings of harbor porpoise were also examined from vessel and aerial surveys conducted by Cascadia Research in their humpback whale research. This research was conducted in the Gulf of the Farallones from August to October of 1986 to 1988 (Calambokidis *et al*. 1989a, 1989b) and in September and October 1989.

Reproduction

Observations of calves accompanied by mothers were recorded during dedicated vessel surveys and observations from opportunistic sources. During the first few months of life, calves can be easily discerned from juvenile animals. The number of calves seen as a percentage of all porpoise seen in September and October (months when most calves were seen) were used to examine calf abundance. The number and proportion of calf sightings in each block were examined to identify critical habitat or preferred areas.

Examination of strandings and collection of tissues

Stranded animals provide valuable information not available from the examination of live animals. An active marine mammal stranding network exists in the San Francisco region. At the beginning of the study, an intensive effort was made to notify all involved of our special interest in harbor porpoise. All stranding reports were referred through the Department of Ornithology and Mammalogy of the California Academy of Sciences (CAS). In addition to responding to reports, beach walk surveys were made to search for stranded animals (Table 3).

When a stranded animal was recovered, a complete set of external body measurements was recorded. Necropsies were conducted when possible, either at CAS or in the field. A blubber sample was taken for contaminant analysis. Information on some strandings were obtained through the cooperation of other participants in the Stranding Network. Robert Jones provided information on the identification of stomach contents of harbor porpoise that he examined. Ray Dieter provided information and blubber samples from stranded harbor porpoise he examined during the study.

Pollutant analysis

Harbor porpoise tissues were analyzed for contaminants to evaluate the discreteness of the harbor porpoise population in the study area and to evaluate the potential impacts of some of these persistent chlorinated hydrocarbons (PCBs, DDT and its homologs, and HCB) on harbor porpoise in the region.

Contaminant analysis were conducted on 5 samples as a part of this study and on additional samples as part of ongoing research with the Southwest Fisheries Center in La Jolla, California. Samples were handled and analyzed as described in previously (Calambokidis *et al.* 1979b, Calambokidis 1986). Briefly, blubber samples were placed in aluminum foil and immediately frozen. Samples were shipped and stored frozen at Cascadia Research. At the time of analysis, a subsample of blubber was taken with a super-clean scalpel and forceps from the interior (unexposed) portion of the blubber sample taken in the field.

Blubber subsamples were digested in acid (BFM solution), extracted with hexane, cleaned-up with concentrated sulfuric acid and injected on a Hewlett-Packard electron-capture gas chromatograph. Contaminants were quantified based on comparison to standards injected throughout the analysis. Analyses were conducted by Cascadia personnel at the Environmental Analysis Laboratory of the Evergreen State College in Olympia, Washington.

Table 3. Number of beach searches conducted to look for porpoise carcasses. Three porpoise were found in June 1987 during walks in the Pacifica and San Francisco regions.

Yr/Month	Pacifica[a]	Daly City[b]	San Fran[c]	San Mateo Co.[d]
1987-Jun	2	-	3	-
Jul	1	1	1	-
Aug	2	-	-	-
Sep	2	1	1	-
Oct	2	-	-	-
Nov	1	-	-	-
Dec	-	-	-	-
1988-Jan	2	-	-	-
Feb	4	1	1	1
Mar	2	-	-	-
Apr	-	1	1	-
May	6	-	-	-
Jun	3	-	-	-
Jul	2	1	1	-
Aug	2	-	-	-
Sep	5	-	-	-
Oct	3	1	1	1
Nov	1	-	-	-
Dec	1	-	-	-
1989-Jan	5	-	-	-
Feb	5	-	-	-
Mar	5	-	-	1
Apr	-	1	1	-
May	3	-	-	1
Jun	2	-	-	-
Jul	3	1	1	-
Aug	2	1	1	-
Sep	1	-	-	-
Oct	-	-	-	-
Nov	2	-	-	-
Dec	1	-	-	-
	--	--	--	--
TOTAL	70	9	12	4

[a] Pacifica-beach was walked between Pedros Pt and Mussel Rk

[b] Daly City-beach was walked between Mussel Rk and Ft Funston

[c] San Francisco-beach was walked between the Cliff House and Ft Funston

[d] San Mateo Co.-beach was scanned from overlooks between Pacifica and Año Nuevo

Data analysis

Effort-corrected sighting frequency were calculated for each transect through a survey block. Sighting frequency were tested against the following factors:

1) Static conditions including location (by survey block) and water depth.

2) Variable conditions that may effect porpoise distribution such as tidal state, time of year, presence of tide rips, and presence of feed.

3) Environmental factors that may affect sightability including Beaufort state, wind speed and direction, swell height, wave height, fog, and presence of glare.

The total effort (in nm) and number of harbor porpoise sightings in each category of the above factors were compared using a sighting rate per nautical mile. Effort for different depth strata were determined after the surveys by plotting vessel locations at regular intervals and determining depth from a NOAA chart.

RESULTS AND DISCUSSION

Harbor porpoise distribution

Harbor porpoise were sighted on 141 occasions during line-transect surveys in the study area (Figure 4). Additional sightings of harbor porpoise were also made off effort between survey lines, during the calibration experiments, and during photo-identification surveys.

All harbor porpoise were seen in waters less than 70 m deep despite coverage in areas extending out to 120 m. Sighting rates were highest in the water depths between 0 and 40 m (Figure 5). All water depths out to 80 m were sampled equivalently except waters less than 10 m deep where it generally was not possible for the vessel to survey safely.

Cascadia Research made incidental sightings of harbor porpoise in conjunction with humpback and blue whale research in the Gulf of the Farallones from 1986 to 1988. Although most of the vessel and aerial effort was concentrated in deeper waters (greater than 100 m), all sightings were made in the shallower coastal waters (Calambokidis *et al*. 1989b).

Harbor porpoise were seen in nearshore areas. From December 1987 to August 1988, vessel transects covered waters out to 60 fathoms that traversed the waters around the Farallon Islands and Cordell Bank. Only one sighting was made in the offshore portion of these transects. Consequently, lines were truncated to include only the more coastal half of the survey blocks; this doubled the number of inshore legs conducted after this time. All figures on sighting rates, densities, and abundance were computed only for the inshore portion of the original study area, except where otherwise noted.

The sighting rate of harbor porpoise was highest in Region 2, the region directly offshore from the entrance to San Francisco Bay, and lowest in Region 3, south of Point Reyes (Figure 6). Differences in sighting rates among regions did not appear to be related to better weather conditions; regional patterns were similar when restricted to only the best sea state conditions (Figure 6).

The distribution of sightings we observed is generally consistent with previous studies. Dohl (1984) conducted aerial surveys for harbor porpoise and other marine mammals in the Gulf of the Farallones in August and September 1983. All but 1 of 33 sightings of harbor porpoise were made within 4 nm of land (Dohl 1984). In vessel surveys in the fall of 1986, Szczepaniak (1988) sighted most harbor porpoise just outside San Francisco Bay where most effort was concentrated. A few sighting were also made in waters further offshore than found in this study.

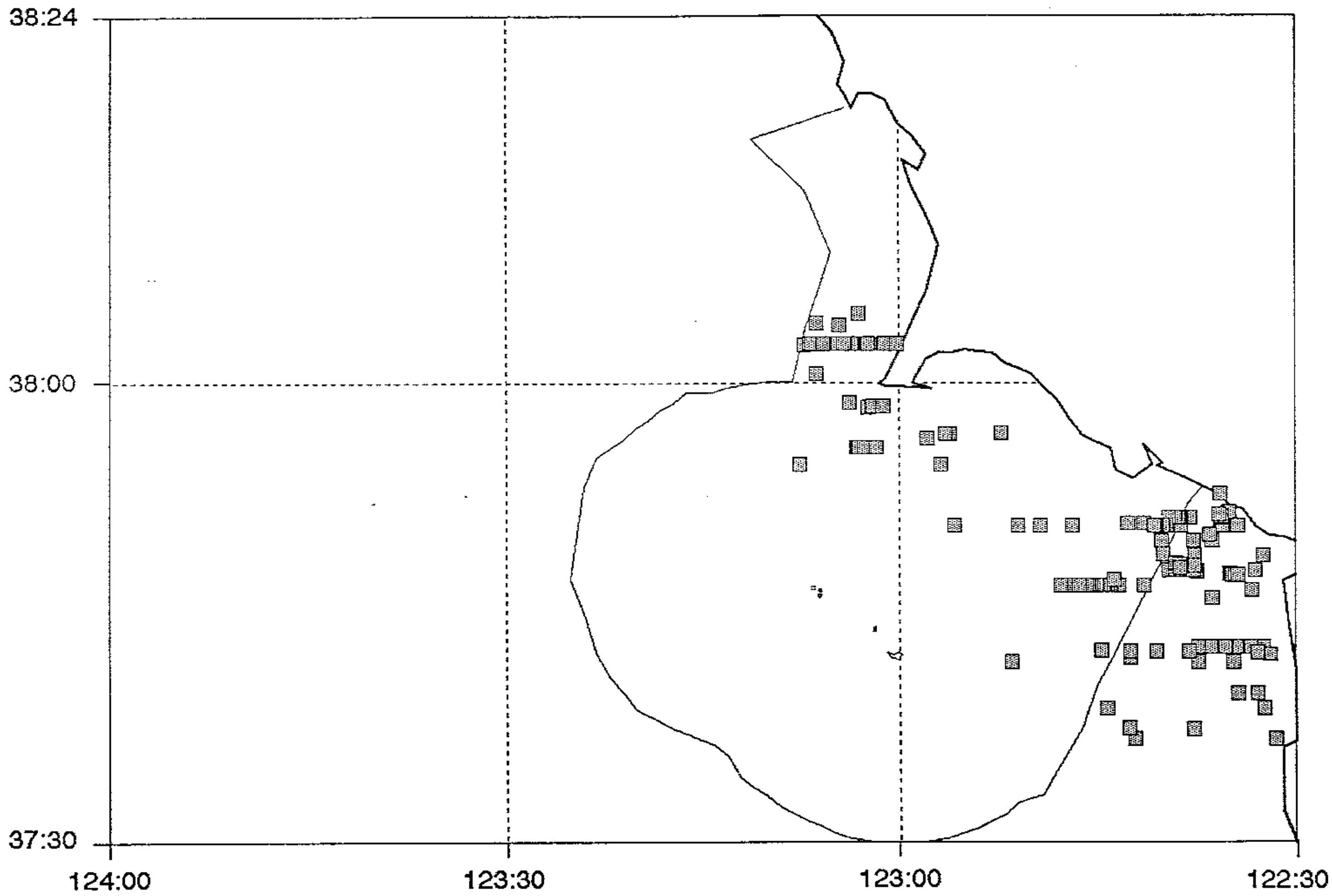

Figure 4. Locations of harbor porpoise sightings made while on transect. Does not include off effort or calibration surveys.

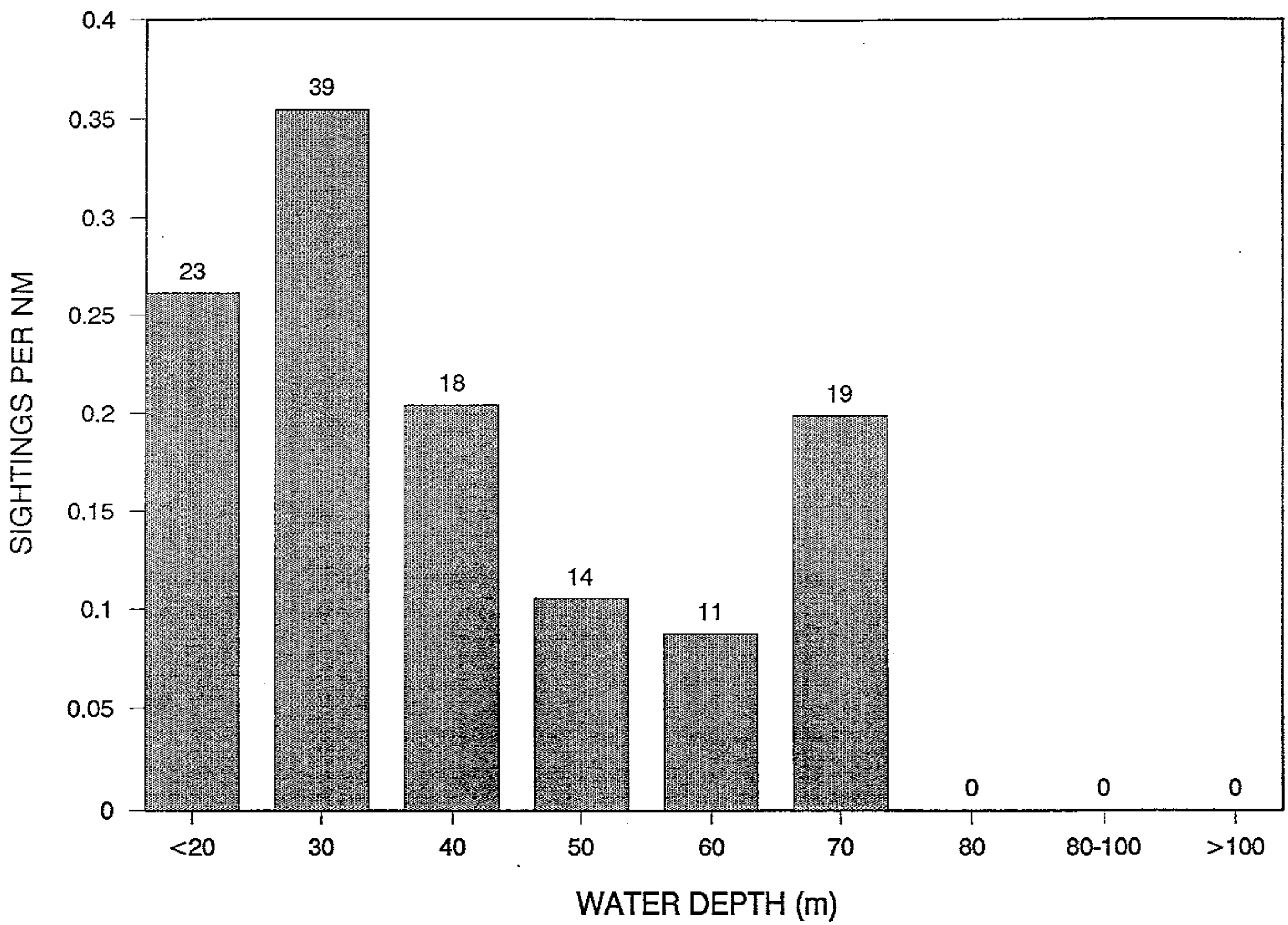

Figure 5. Sighting rate of harbor porpoise by nm of effort at different water depths. Numbers above bars indicate number of sightings.

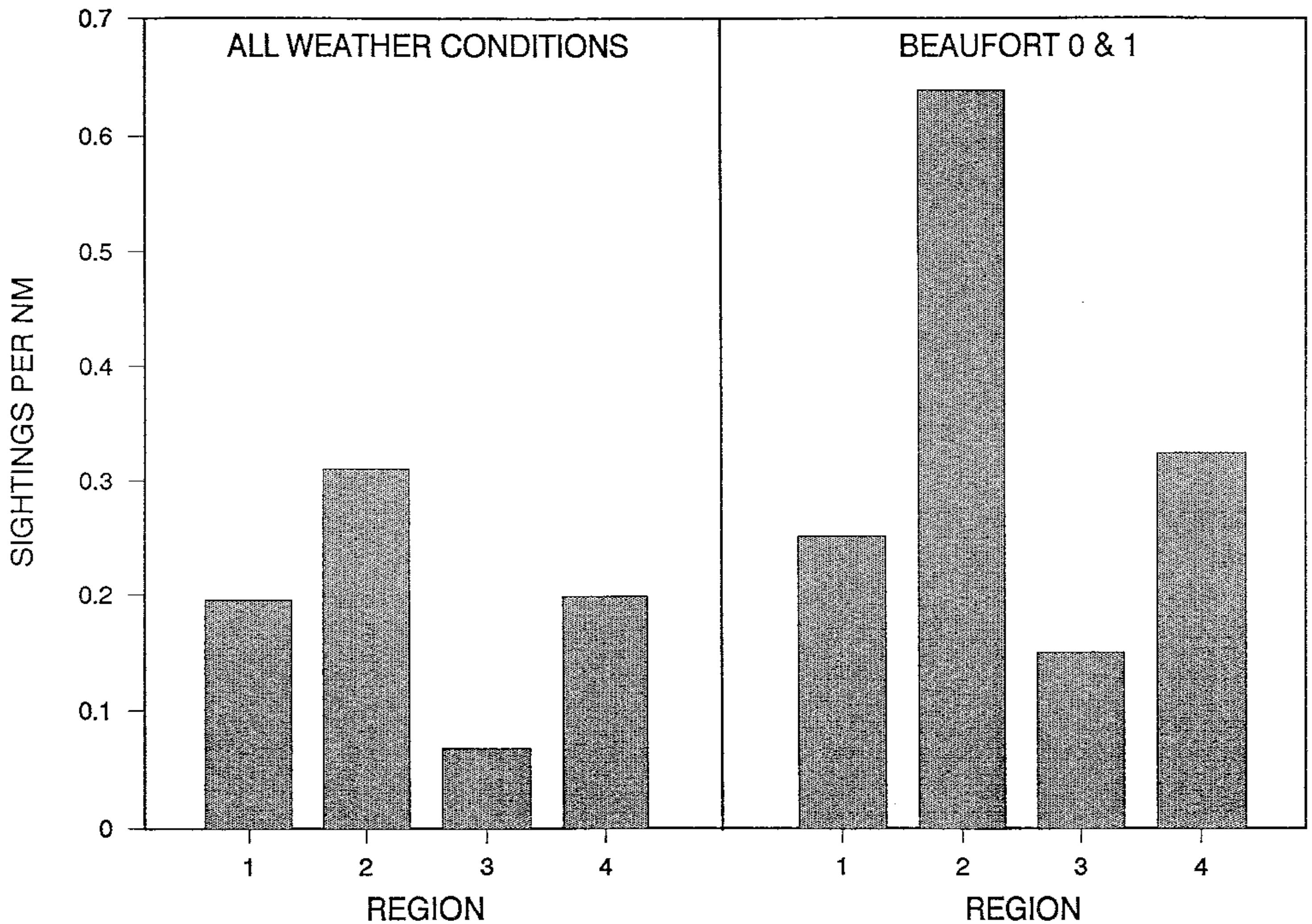

Figure 6. Effort-corrected sighting rate of harbor porpoise by region. Only sightings during regular transect surveys are included.

Seasonal variation in sighting rates

Sighting rates of harbor porpoise varied by season (Tables 4, Figure 7). Sighting rates were higher in summer and fall than those in winter and spring. This difference was most dramatic when number of animals (rather than sightings) per nautical mile (nm) of effort is used (Table 5). Animals seen per nm were about three times higher during summer and fall. Weather condition differences did not appear to be responsible for the seasonal changes. The proportion of survey effort conducted in ideal conditions (Beaufort 0 or 1) was similar in all seasons (33 to 42% of the total effort).

Seasonal differences in the sighting rate of porpoise within each region were harder to evaluate because number of sightings was too small to isolate the potential effects of region, season, sea state. Some dramatic seasonal shifts were apparent, however, in several regions (Figure 7). Few harbor porpoise (<0.05 animals per nm) were seen in Region 4, west and north of Point Reyes, during all seasons of the first year of surveys. In the fall of 1989, however, this region had a higher number of animals seen per nm of effort than any other region or season. The sighting rate of harbor porpoise in Region 2, off San Francisco Bay, consistently was high during the study.

Weather effects on sighting rate

The sighting rate of harbor porpoise appeared to be affected most by Beaufort sea state (Figure 8). Sighting rates of harbor porpoise decreased steadily from Beaufort 0 to Beaufort 4. In most cases surveys were aborted when sea state reached Beaufort 4. The largest jump in sighting rates occurred between Beaufort 1 and 2.

Sighting rates also declined with decreasing visibility quality as judged by the observers (Figure 8). This subjective determination was closely related with sea state, which observers considered the strongest influence on the quality of observation conditions. Because sea state provided a less subjective determination of conditions, it was used instead of quality to stratify weather conditions.

No patterns were apparent in sighting rates based by swell height or sky cover (Figure 8). Sightings rates during fog and rain were lower than in other conditions.

Group sizes

Group sizes of harbor porpoise sighted during vessel surveys ranged from 1 to 13. Average group size appeared to be consistently higher during the two fall sample periods (Table 6), but group size among seasons fell just short of statistical significance (ANOVA, $n=177$, $F=2.3$, $p>0.05$). The size of porpoise groups was significantly higher in fall than in winter and spring (t-test, $p<0.05$ for both cases).

Table 4. Effort and harbor porpoise sightings by season for different regions.

Region	Winter			Spring			Summer			Fall 88			Fall 89			All		
	nm	S	S/nm	nm	S	S/nm	nm	S	S/nm	nm	S	S/nm	nm	S	S/nm	nm	S	S/nm
All sea state conditions																		
1	33	4	0.12	21	3	0.15	15	7	0.48	47	12	0.25	27	2	0.07	142	28	0.20
2	47	6	0.13	34	12	0.35	19	10	0.53	63	24	0.38	33	9	0.27	196	61	0.31
3	37	7	0.19	45	1	0.02	17	1	0.06	64	0	0.00	38	5	0.13	201	14	0.07
4	17	0	0.00	27	1	0.04	9	0	0.00	29	1	0.03	17	18	1.07	100	20	0.20
ALL	134	17	0.13	127	17	0.13	60	18	0.30	203	37	0.18	115	34	0.29	639	123	0.19
Beaufort 0 & 1 only																		
1	3	2	0.71	4	0	0.00	4	3	0.86	26	9	0.35	27	2	0.07	63	16	0.25
2	0			9	12	1.33	11	4	0.35	22	16	0.72	11	2	0.19	53	34	0.64
3	28	7	0.25	15	0	0.00	0			12	0	0.00	16	4	0.25	72	11	0.15
4	17	0	0.00	13	0	0.00	0			8	0	0.00	17	18	1.07	55	18	0.33
ALL	48	9	0.19	42	12	0.29	15	7	0.47	68	25	0.37	71	26	0.37	244	79	0.32

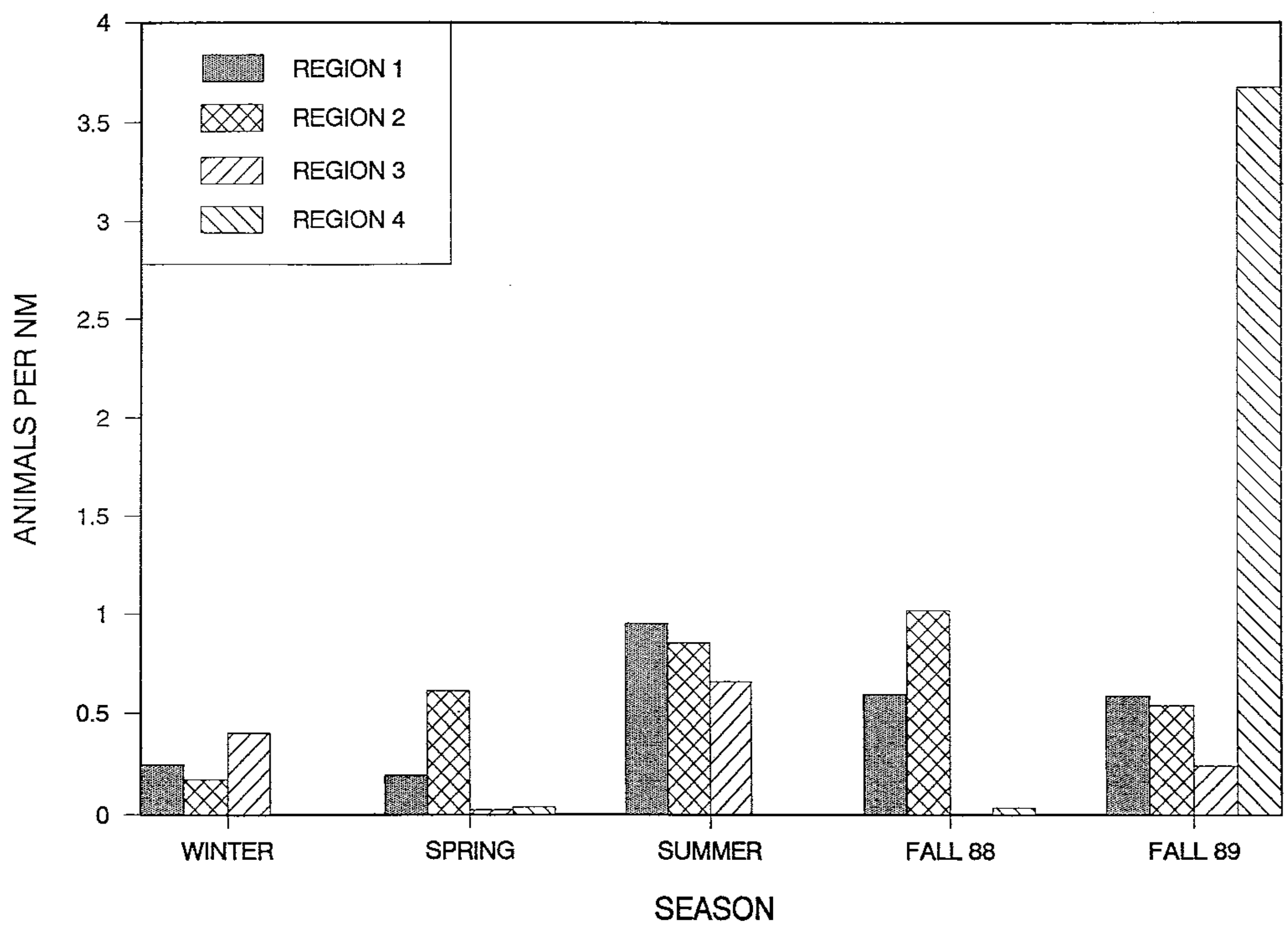

Figure 7. Effort-corrected number of harbor porpoise seen per nm of survey effort by season and region.

Table 5. Effort and number (#) of harbor porpoise seen by season for different regions.

Region	Winter			Spring			Summer			Fall 88			Fall 89			All		
	nm	#	#/nm	nm	#	#/nm	nm	#	#/nm	nm	#	#/nm	nm	#	#/nm	nm	#	#/nm
All sea state conditions																		
1	33	8	0.24	21	4	0.19	15	14	0.95	47	28	0.59	27	16	0.59	142	70	0.49
2	47	8	0.17	34	21	0.61	19	16	0.86	63	64	1.02	33	18	0.54	196	127	0.65
3	37	15	0.40	45	1	0.02	17	11	0.65	64	0	0.00	38	9	0.24	201	36	0.18
4	17	0	0.00	27	1	0.04	9	0	0.00	29	1	0.03	17	62	3.67	100	64	0.64
ALL	134	31	0.23	127	27	0.21	60	41	0.69	203	93	0.46	115	105	0.91	639	297	0.47
Beaufort 1 & 2																		
1	3	2	0.71	4	0	0.00	4	10	2.86	26	24	0.94	27	16	0.59	63	52	0.82
2	0			9	21	2.33	11	8	0.71	22	46	2.07	11	5	0.47	53	80	1.50
3	28	13	0.47	15	0	0.00	0			12	0	0.00	16	8	0.49	72	21	0.29
4	17	0	0.00	13	0	0.00	0			8	0	0.00	17	62	3.67	55	62	1.12
ALL	48	15	0.31	42	21	0.50	15	14	0.94	68	70	1.03	71	91	1.28	244	215	0.88

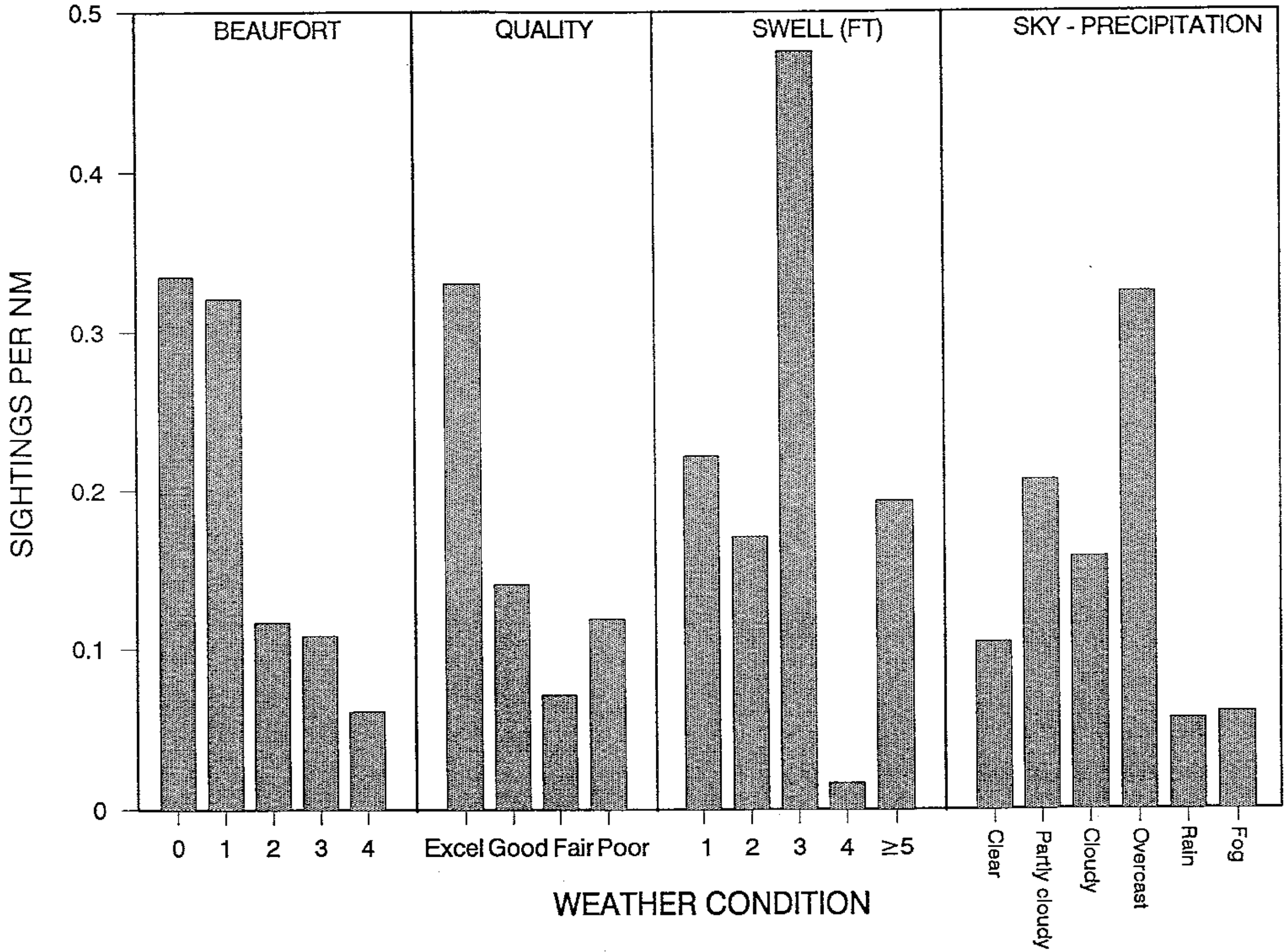

Figure 8. Number of harbor porpoise sightings per nm of effort by weather condition.

Table 6. Group sizes of harbor porpoise sighted from vessel surveys in the Gulf of the Farallones. Results are shown for all sightings and restricted to only sightings on effort.

	All vessel sightings				On-effort sightings			
Season	n	Anim.	Avg	SD	n	Anim.	Avg	SD
Winter	34	62	1.8	1.4	18	32	1.8	1.4
Spring	18	28	1.6	0.9	17	27	1.6	0.9
Summer	19	42	2.2	2.6	18	41	2.3	2.7
Fall 88	46	114	2.5	1.7	37	93	2.5	1.7
Fall 89	60	157	2.6	2.0	51	143	2.8	2.1
All	177	403	2.3	1.9	141	336	2.4	1.9

Abundance of harbor porpoise

Line transect estimates of harbor porpoise abundance were computed for the entire study period as well as for each season (Table 7). The amount of effort, number of sightings, and replication of lines all increased after the summer of 1988 because of the shift in effort to the coastal areas. Because sightings in fall were conducted in two years and more often (because of the shift in survey design), our best population estimate was made during this season.

Abundance estimates are sensitive to the portion of animals assumed to be missed on the transect line. We provide the results of two estimates in Table 7; one is a minimum value and the other is our best estimate. For the minimum abundance estimate, we used a correction factor of 22% of porpoise missed that was estimated by Barlow (1988). This correction factor was determined during NOAA surveys that used a higher observation platform and more observers than we used. Our best estimate assumed 50% of animals on the transect line are missed. The problem of estimating the proportion of animals on line-transect surveys remains one of the primary unresolved problems with line-transect surveys for marine mammals.

Land and aerial calibration experiments conducted during this study did not provide an adequate sample size to estimate independently the proportion of animals missed. Both land and vessel calibrations yielded comparisons between vessel sightings and land/air sightings of harbor porpoise (Table 8). The high density of harbor porpoise encountered during the aerial calibration, however, made accurate matching of groups seen from the air and vessel difficult. Land calibrations were hampered by the lack of near-shore sightings of harbor porpoise, making tracking of groups several mile offshore difficult. The vessel was generally successful in sighting most of the groups tracked from land. Harbor porpoise group sizes during the land calibrations, however, were extremely large (Table 8), making the results not representative of sighting rates with more typical group sizes.

The abundance estimates were surprisingly similar between fall 1988 and 1989 with estimates of 2,108 and 2,109, respectively. The similarity between these two figures should be viewed as somewhat coincidental because of the high variances involved in these estimates. Additionally, as discussed previously, there were differences in the distribution of harbor porpoise sightings between fall 1988 and fall 1989. The highest abundance was for summer, however, this was based on the lowest level of effort in Beaufort 0 and 1. The pooled estimate was weighted by the effort in each season therefore the high fall estimates contributed disproportionally to the overall estimate.

The high standard error for the individual season estimates indicates that they should be viewed with some caution, especially those for summer and spring. The high variance in

Table 7. Estimates of abundance of harbor porpoise in the study area (see text). Only effort and sightings in Beaufort 0 or 1 included in analysis.

	Period						
	Winter	Spring	Summer	Fall 1988	Fall 1989	Fall 88-89	All
Effort (km)	88	77	27	126	131	258	452
Replicate lines	5	4	2	6	7	13	24
Sightings	9	12	7	24	24	48	76
f(0)	2.71	2.71	2.71	2.71	2.71	2.71	2.71
cv (f(0))	0.11	0.11	0.11	0.11	0.11	0.11	0.11
cv (N)	0.47	1.1	0.45	0.48	0.63	0.39	0.29
Density (per km^2)	0.14	0.21	0.35	0.26	0.25	0.25	0.23
SE (D)	0.07	0.23	0.16	0.13	0.16	0.10	0.07
Area (km^2)	1,640	1,640	1,640	1,640	1,640	1,640	1,640
Estimated groups	227	344	568	422	406	413	374
Average group size	1.8	1.6	2.2	2.5	2.6	2.6	2.3
Uncorrected abundance	408	551	1,249	1,054	1,055	1,075	860
Corrected abundance (low) for 22% missed on line	524	707	1,601	1,351	1,352	1,378	1,102
Corrected abundance for 50% missed on line	817	1,102	2,497	2,108	2,109	2,150	1,719

Table 8. Harbor porpoise sightings during calibration surveys by air and land. Number of sightings and the number of porpoise seen by group (calves noted with parentheses) are listed for both vessel and calibration observers.

Date	Pass	Time	Vessel #s	Vessel #porp by grp	Air or land #s	Air or land #porp by grp	Comments
14 Oct 88	A	1058-1101	2	4,2	1	4	
	B	1106-1113	5	1,2,1,2,2	2	1,4	ves passes 20&75m from grps
	C	1131-1139	1	1	2	1,4	ves passes 150m from 4, 200m from 1
	D	1142-1154	3	1,2,2	1	1	ves too far-abandon
	E	1156-1206	2	1,2	1	5	ves 50m from grp
	F	1210-1223	3	2,2,1	1	2	ves 130m from grp
	G	1228-1234	-				abandon too many grps
	H	1238-1241	-				abandon too many grps
15 Sept 89	A	0907-0912	0	-	0	-	
	B	0914-0929	2	6(3),1	1	4(2)	
	C	0938-1000	2	4(1),6	2	8(1?),8-10	
	D	1010-1032	2	9,5(1)	2	3,8-12	
	E	1038-1055	3	1,2,5(1)	1	12	
	F	1115-1129	0	-	1	15	
	G	1149-1202	0	-	0	-	
	H	1257-1306	1	4	1	4	
	I	1311-1321	1	3	1	4-7	
	J	1325-1337	1	9(2)	1	7	
	K	1407-1427	1	10(1)	1	6-8	
	L	1444-1501	0	-	0	-	
	M	1506-1516	0	-	0	-	
	O	1521-1530	0	-	0	-	
20 Sept 89	A	0838-0854	0	-	0	-	
	B	0906-0929	3	2,1,5	2	2-5,6	ves passes both grps
	C	0942-1011	1	6	1	8-12	ves passes 1nm E of grp
	D	1042-1053	0	-	1	7-15	ves passes 500m E of grp
	E	1105-1124	0	-	2	4,8-20	ves passes 200&800m E of lrg grp
	F	1132-1149	0	-	1	10	ves passes 300-400m E of grp
	G	1206-1225	2	7(2),4	2	5,5-10	ves passes 500m but we lose porp
	H	1253-1313	0	-	0	-	

these estimates is primarily the result of the relatively few replicate lines sampled during Beaufort 0 or 1 sea states and the variable sighting rates between these replicates. Harbor porpoise distribution was usually clumped resulting in some lines with large numbers of sightings and others with none.

The abundance estimates we report here are higher than those previously reported for this area. From two ship surveys conducted along the entire California, Oregon, and Washington coast, Barlow (1988) estimated 112 harbor porpoise in the Gulf of the Farallones region; he noted that this appeared to be an underestimate. Barlow *et al.* (1988) reported the results of aerial surveys along the California, Oregon, and Washington coasts. Although they did not report an abundance estimate, they did report a density (corrected for animals missed) of 0.35 animals per km^2 for this region. This is lower than the density we found (corrected for animals missed and group size) of 1 porpoise per km^2. Dohl *et al.* (1983) estimated 1,600 to 3,000 harbor porpoise for the entire central and California coast. These are probably major underestimates because no attempt was made to correct for animals missed, a major problem especially with aerial surveys for harbor porpoise.

Our estimates of harbor porpoise agree generally with those reported by Szczepaniak (1988) from vessel surveys conducted in the Gulf of the Farallones in September and October 1986. These surveys yielded an estimate of 1,300 harbor porpoise for the region outside San Francisco Bay. Our estimates are similar when we employed a 22% correction factor for missed animals as used by Szczepaniak (1988). Our surveys included areas west and north of Pt. Reyes, where we found high harbor porpoise densities (especially in fall of 1989). These areas were not included in the estimate by Szczepaniak (1988). Although Szczepaniak (1988) used similar vessels and observation methods as those we report, there were also differences in sample design and analysis between the two studies. The surveys by Szczepaniak (1988) disproportionally sampled the area of higher harbor porpoise density just outside San Francisco Bay. Disproportionate sampling of a high density area would result in an upward bias in the density estimate. Additionally, we assumed 50% of animals are missed on the transect line for our best estimate. Given these differences in sample area, survey design, and correction factors, our estimates are surprisingly similar to those reported by Szczepaniak (1988).

Analysis of historical data for annual changes

Weather factors also significantly affected the sighting rates of harbor porpoise during the Oceanic Society nature trips conducted between 1983 and 1987. The number of harbor porpoise sightings varied significantly by both sea state/Beaufort scale (ANOVA, $p<0.000$) and swell height (ANOVA, $p=0.004$). A similar difference existed with the total number of animals seen on the trip. Regression analysis of these variables indicated the number of sightings and animals increased with decreasing sea state and swell height. Because of the apparent strong influence of sea state on sighting rate, the analyses on the effects of other factors were conducted using only trips with sea-state conditions of less than Beaufort 4; sea state was also used as a covariate in Analyses of Variance to determine other factors.

Sighting rates were significantly higher on the outbound (morning) leg of the trip than on the return (afternoon) legs, even when the effect of sea state was considered (ANOVA using sea state as covariate, $p<0.000$ for both number of sightings and number of animals). This may have been the result of differences in observer vigilance, route taken, or diel differences in harbor porpoise distribution.

These data from nature trips showed annual differences in the sighting rate of harbor porpoise. The number of sightings and the number of animals varied significantly among years (ANOVA, $p<0.001$ and $p=0.02$, respectively). Annual differences remained significant even when adjusted for the effects of sea state and trip leg ($p=0.004$ for sightings and $p=0.02$ for animals in a multi way analysis of covariance with year and trip leg as factors and sea state as a covariate). The annual change in sighting rates was mostly caused by the higher sighting rate starting in 1985 (Figure 9). The number of sightings and animals seen did not vary significantly by month (ANOVA with sea state as a covariate, $p>0.05$).

Despite the somewhat complicated set of factors that influenced the sighting frequency of harbor porpoise on the nature trips, they do indicate that harbor porpoise numbers have remained stable or increased from 1983 to 1987. The five year time period is still relatively small and therefore annual trends in abundance should be interpreted with some caution. Forney *et al.* (1989) reviewed some of the difficulties in determining trends in abundance of harbor porpoise from survey data conducted over relatively few years. It is possible that differences in sighting rates also may have been influenced by other effort or weather-related factors that were not identified.

Reproduction

Eighteen sightings of 24 calves were made during vessel surveys; 9 sightings of 11 calves were made during line-transect surveys and 9 sightings of 13 calves were made during calibration surveys. Calves were seen in all survey blocks although the small number of sightings did not allow their distribution to be analyzed statistically. Most of the calf sightings were off Point Reyes in 1989. Over half (5 of 9) of all calf sightings during line-transect surveys were made on 8 September 1989 just north of Point Reyes. The two vessel calibration surveys were conducted in this area 1-2 weeks later when 13 calves recorded. However, this was not the only region where calves were seen during this time. The mean depth of calf sightings during line-transect surveys was 42 m (n=9, SD=23) and ranged from 10 to 70 m. Depths of calf sightings were not significantly different

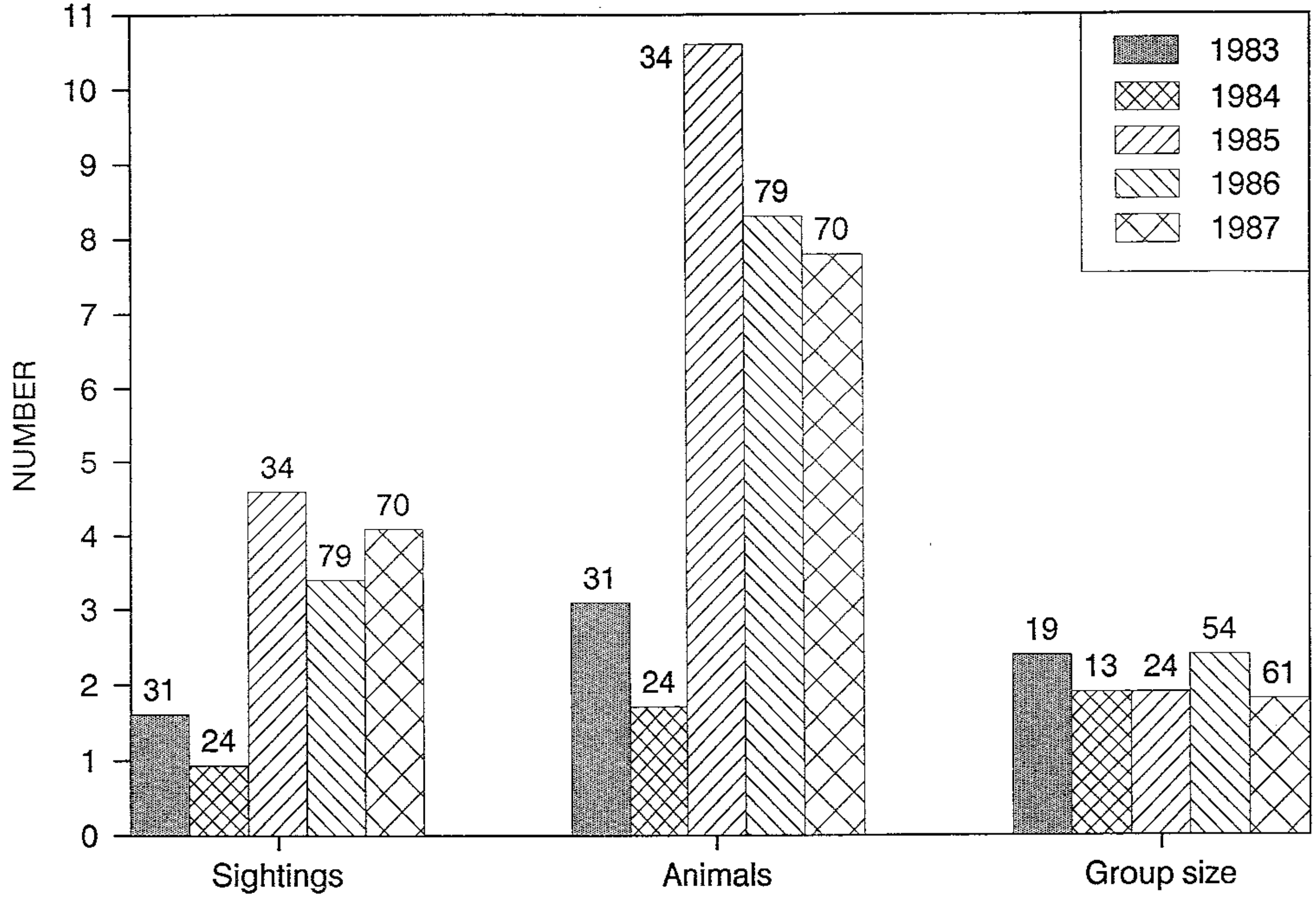

Figure 9. Average harbor porpoise sightings and animals seen per trip aboard Oceanic Society trips from 1983 to 1987. Each trip consisted of either an outbound or inbound leg between San Francisco and the Farallon Islands. Only trips in Beaufort 3 or better and good visibility were included.

from depths of all other harbor porpoise sightings (t-test, $p>0.05$).

Timing of calf sightings

Most harbor porpoise cow and calf pairs were seen in the Gulf of the Farallones in September and October (Figure 10). Twenty-three of the 24 calves seen on surveys were during these two months. The other sighting on 9 June 1988 was noted as tentative. Stranding information also supports that calves probably are born in early to mid-summer. Five neonatal harbor porpoise stranded between late May and early August and one lactating female also was found stranded in June.

Most of the calf sightings from opportunistic platforms in the Gulf of the Farallones were generally in late summer or early fall. Five harbor porpoise calves were seen between 6 Aug and 1 Oct during the whale research in this region between 1986 and 1989 (Calambokidis *et al.* 1989, and unpubl. data). Of 19 calves seen during Oceanic Society nature trips between 1983 and 1987, 15 were seen in September and October; 3 sightings were in June and July.

In other studies in the Gulf of the Farallones, five cow and calf pairs were seen on 5 and 19 September during fall vessel surveys (Szczepaniak 1988). Dohl *et al.* (1983) found no seasonal bias in sightings of young harbor porpoise off California, a finding that conflicts with other studies of harbor porpoise.

Generally, harbor porpoise parturition is thought to occur in late spring and early summer (Scheffer and Slipp 1948, Fisher and Harrison 1970, Goetz 1982, Gaskin *et al.* 1984). Stuart Simons (1984) reported the calving off California to occur in May and June; Schonewald and Szczepaniak (1981) suggested that calving extends into July. This timing supports that the calves seen in this study probably are animals less than six months old.

Calving rate

On surveys during September and October, 23 of the 492 (4.7%) porpoise seen were calves. During whale research conducted by Cascadia Research in the Gulf of the Farallones in August to October of 1986 and 1989, 4.1% of the harbor porpoise seen were calves (5 calves of 122 porpoise).

The proportion of calves seen is lower than rates reported in other areas, which vary widely. Taylor and Dawson (1984) reported that calves comprised 6% of population in Glacier Bay in September. Gaskin *et al.* (1984) reported the observed proportion of calves seen in the Bay of Fundy was 10% in 1970-78; this same percentage was estimated in the western North Atlantic in age-determination studies in 1968-73 (Gaskin and Blair 1977). Thirty-three percent of all porpoise seen between August and October off Washington state were calves (Flaherty and Stark 1982). Gaskin and Watson (1985) reported 63% of the porpoise

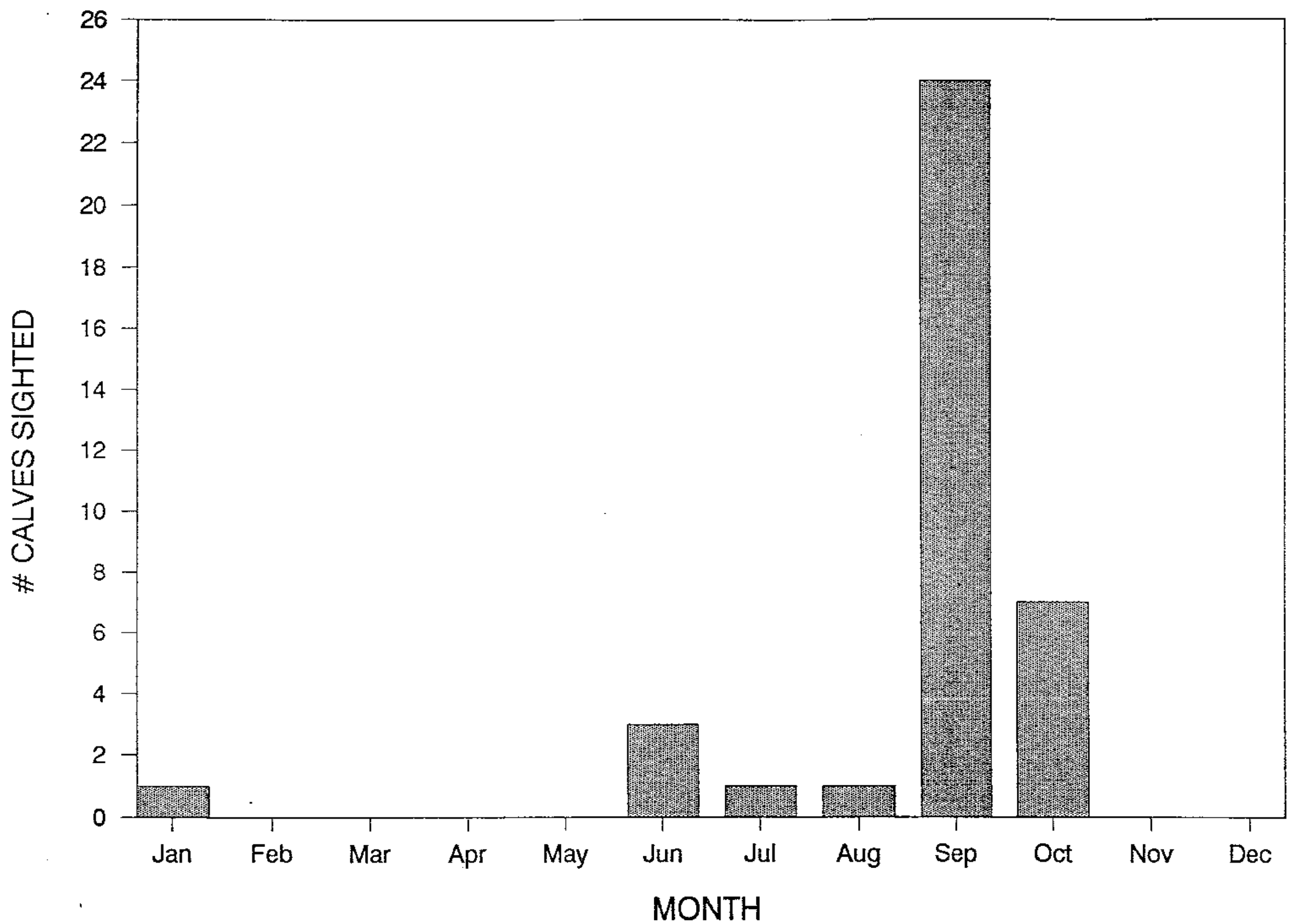

Figure 10. Number of harbor porpoise calves seen in different months during vessel surveys, Cascadia Research humpback and whale research, and during Oceanic Society nature trips.

seen were cows with calves in an area off New Brunswick between July and September in 1973-75, however, sample sizes and sampling methods to determine this rate were not given.

Photo-identification

Approximately 46 harbor porpoise were photographed on four days to identify individuals off San Francisco Bay, Point Reyes, and Bodega Bay between 1987 and 1989 (Table 9). Twenty-three of 63 frames taken were good quality photographs that were close enough to examine 28 individuals for scars and dorsal fin aberrations (usually cuts or notches). No porpoise photographed had markings that could be used for identification. The low prevalence of marked porpoise in this region was surprising.

Dorsal fin markings and body scars have been used to identify and track individual harbor porpoise in the Bay of Fundy (Watson 1976, Gaskin and Watson 1985), off Washington state (Flaherty and Stark 1982), and in Glacier Bay, Alaska (Taylor and Dawson 1981, Calambokidis and Steiger 1982). Marks on harbor porpoise could be caused by net entanglement, collision with objects, or natural defects; some body scars are caused by wounds from lampreys (van Utrecht 1959, Pike 1951). It is possible that the incidence of markings is higher in some regions than others.

Mortality

Thirteen harbor porpoise stranded in the Gulf of the Farallones during the course of our research (Table 10). These were examined by project personnel or by Dr. Ray Dieter as part of the local stranding network and the California Academy of Science. Stranded animals yielded information on reproductive timing, food habits, and contaminants (reported in other sections).

The number of strandings recovered was lower than has been found in past years (Figure 11). The number of stranded harbor porpoise reported to the California Academy of Science was highest in 1982 and 1983 and has steadily declined since then. A similar decline in the number of harbor porpoise strandings from peak numbers in 1983-84 to 1987 was noted for all of California (Seagars and Jozwiak, In press). Incidental catches of harbor porpoise in coastal gillnets was the principal cause of the large numbers of strandings in previous years. An estimated 150-200 harbor porpoise were killed annually by incidental take in set nets in the San Francisco area from April 1983 through March 1985 (Diamond and Hanan 1986, Hanan *et al*. 1986). Strandings were primarily found from June to September (Figure 12).

The reduction in harbor porpoise strandings could be attributable to three causes: 1) a reduced effort or success recovering and reporting strandings, 2) a reduced harbor porpoise population, and 3) lower mortality caused by changes in fishing practices. The first two possible explanations seem unlikely. Effort recovering harbor porpoise by personnel with the

Table 9. Harbor porpoise photographic identification survey effort. Estimated number of different harbor porpoise photographed and number of porpoise images that were good quality for photo-identification are listed.

Date	Time	Location		porpoise photographed	
				est. # of individuals	# animals with good quality photos
17 Oct 87	0915	37°49.7	122°35.2	1	1
17 Oct 87	0924	37°49.7	122°35.0	1	1
18 Oct 87	1024	37°49.9	122°36.4	3	2
18 Oct 87	1240	37°49.9	122°36.5	1	0
01 Oct 88	1807	38°14.6	123°08.0	12	12
14 Sep 89	0900	38°03.4	123°04.7	9	3
14 Sep 89	1747	38°02.8	123°10.5	19	10

Table 10. Harbor porpoise that stranded in the Gulf of the Farallones area and reported to California Academy of Science (CAS) or to the National Marine Fisheries Service. Examinations were conducted by project personnel, Ray Dieter of Bolinas Animal Hospital, or personnel at CAS.

Animal	Date examined	Location	Length (cm)	Sex	Age	Examined for contam	Examined for prey	Other ID	Comments
CAS 4001	11 Jun 1987	Ocean Beach 37°45N 122°31W	168	F	adult	x	x	IS70 RLD191	lactating
CAS 4003	14 Jun 1987	Ocean Beach 37°45N 122°30W	78	F	neonate	x	0	IS71	possible calf of CAS 4001
CAS 4079	13 Jun 1987	Bolinas Beach 37°54N 122°43W	84	M	neonate	x	0	RLD192	died at or near birth
CAS 4079	16 Jun 1987	RCA Beach 37°54N 122°44W	91	M	neonate	x	0	RLD201	stillborn
CAS 4011	19 Jun 1987	Pacifica 37°39N 122°30W	152	F		-	-	IS72	
RLD 201	16 Aug 1987	Bolinas Point 37°54N 122°43W	85	M	neonate	-	-		
CAS 4070	01 Jan 1988	Drakes Beach 38°02N 122°55W	184	F	adult	x	0	RLD265	not lactating
CAS 4103	29 May 1988	Ocean Beach 37°47N 122°30W	79	M	neonate	x	0	MAW52	stranded live
CAS 4102	02 Jun 1988	China Beach 37°481 122°29W	143	M	adult	x	0	MAW51	
CAS	13 Nov 1988	Limantour Bch 38°02W 122°55W	153	-		-	-		
CAS	04 Feb 1989	Moss Beach 37°32W 122°31W	156	-		-	-		
CAS 4235	12 Jul 1989	Ft. Funston 37°44N 122°30W	149	M		x	x	IS84	
CAS 4240	24 Jul 1989	Ocean Beach 37°44N 122°30W	144	F		x	x		

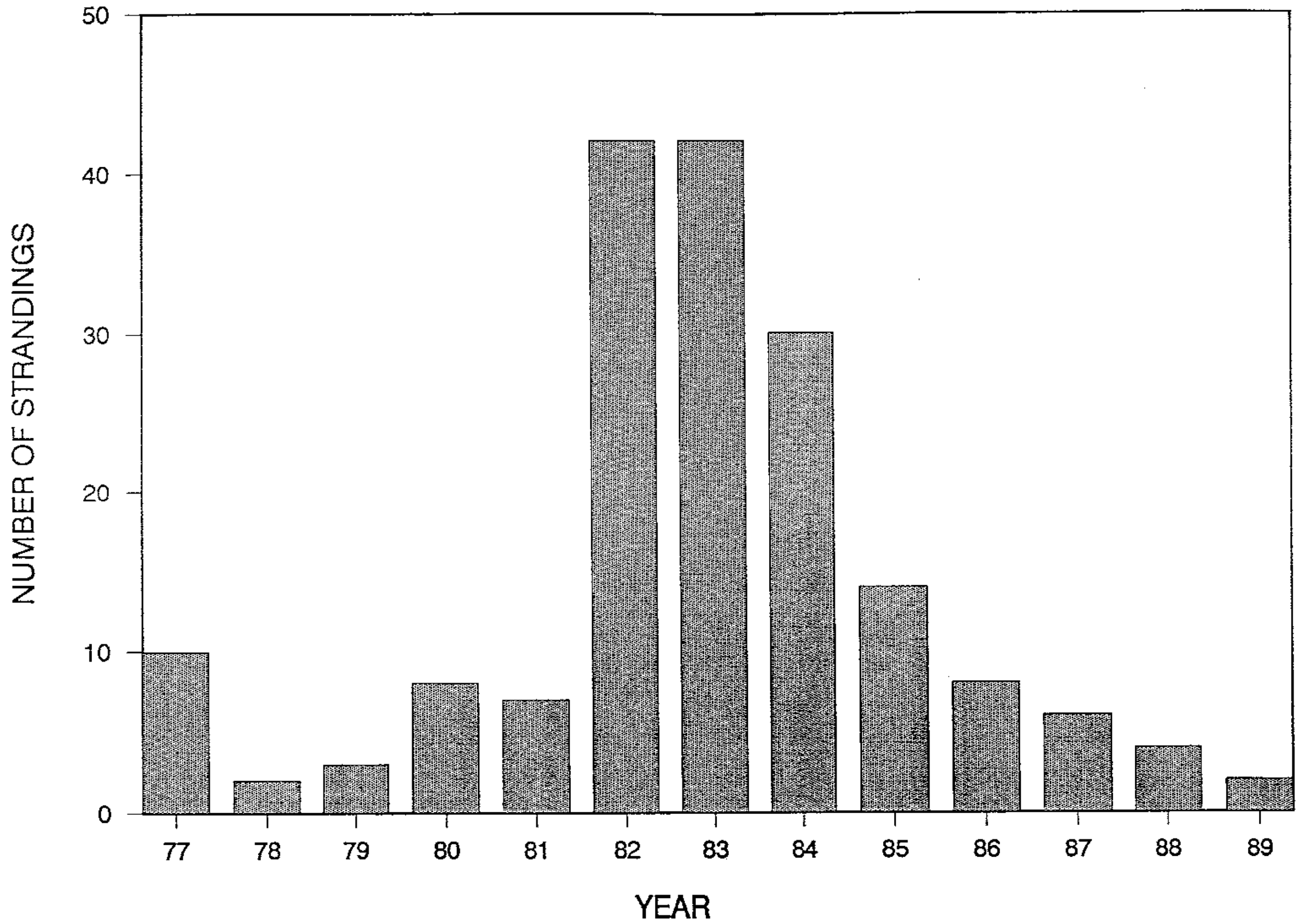

Figure 11. Harbor porpoise strandings by year as reported to the California Academy of Sciences and Museum of Vertebrate Zoology. Data were compiled from Szczepaniak (In prep.) and this study.

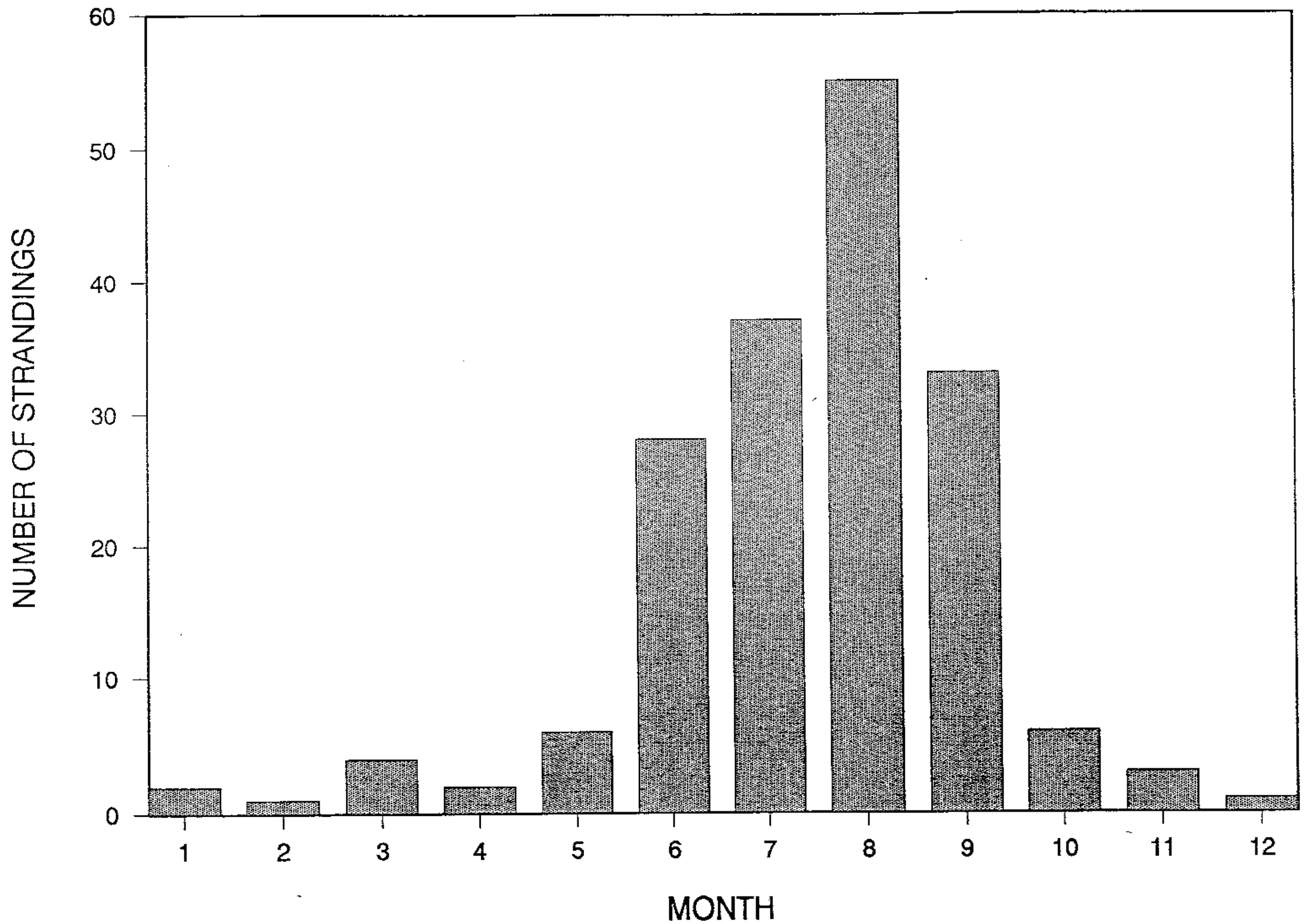

Figure 12. Harbor porpoise stranding by month as reported to the California Academy of Sciences and Museum of Vertebrate Zoology. Data were compiled from Szczepaniak (In prep.) and this study.

California Academy of Science, Bolinas Animal Hospital, and Museum of Vertebrate Zoology has continued through recent years. Beach searches were made by project personnel in recent years. Dieter (In press) suggested that mortality of harbor porpoise farther offshore and the evisceration of incidentally caught porpoise have contributed to reduced numbers of porpoise washing ashore. The impact the incidental mortality had on the harbor porpoise populations is not known, however, a substantial population remains in the study area, as indicated by the survey results. A low number of harbor porpoise remaining in this region does not appear to be responsible for the low number of strandings. The most likely explanation for the low number of strandings is the success of the restrictions on coastal set net fishing put into effect beginning in 1984 to reduce marine mammal and seabird mortality (reviewed by Salzman 1989).

Food habits

Most of the stranded porpoise examined had empty stomachs; this is not surprising because 4 of 9 porpoise examined for stomach contents were neonatal animals that probably would not be feeding on fish. Three porpoise had stomach contents that could be examined (Table 11). At least three market squid (*Loligo opalescens*) were identified in one sample and plainfin midshipman (*Porichthys notatus*) in another.

Squid and plainfin midshipman are commonly found in California waters (Miller and Lea 1976, Okutani and McGowan 1969). Market squid comprised 84 percent of the invertebrate remains of harbor porpoise stomachs examined off northern California (Jones 1981). Although plainfin midshipman have not been reported as harbor porpoise prey, midshipman are often prey of other marine mammals (Eschmeyer *et al.* 1983).

Harbor porpoise feed primarily on fishes in the families Clupeidae and Gadidae (Rae 1965, Smith and Gaskin 1974, Gaskin *et al.* 1974, Recchia and Read 1989) and squid (Sergeant and Fisher 1957). The predominant prey reported previously for harbor porpoise in northern California included juvenile rockfish (Sebastes sp.), northern anchovy (*Engraulis mordax*), Pacific whiting (*Merluccius productus*), Pacific tomcod (*Microgadus proximus*) and market squid (Jones 1981). Northern anchovies were the second most common prey item found in the stomachs of humpback whales taken during whaling in the Gulf of the Farallones; rockfish, squid, and cod species were also found in humpback stomachs (Calambokidis *et al.* 1989b).

Contaminants

Five blubber samples from stranded harbor porpoise were examined for chlorinated hydrocarbon contaminants as a part of this study (Table 12). Along with samples reported in Calambokidis and Barlow (In press) and additional samples recently analyzed as part of an ongoing study with the Southwest Fisheries Center, a total of 19 harbor porpoise from the Gulf of

Table 11. Prey remains found in stomachs of stranded harbor porpoise. Results of CAS 4235 and CAS 4240 were determined by R.E. Jones.

Animal	Prey found	Identified from
CAS 4001	plainfin midshipman (Porichthys notatus) worms-Anisakis spp.	whole and partly digested fish
CAS 4235 (IS 84)	squid (Loligo opalescens) unidentified fish	beaks and eye lenses vertebrae and bones
CAS 4240 (REB 14)	unidentified	unidentified eggs or lenses

Table 12. Contaminant concentrations found in harbor porpoise from the Gulf of the Farallones region. Results include those reported in Calambokidis and Barlow (In Press) and Calambokidis (1986) as well as new samples examined for this contract as part of ongoing research with Southwest Fisheries Center. See Table 10 for additional information on samples collected and examined as part of this study.

Sample no.	Lat. degrees	Date Year Mo Day	Sex	Std. len (cm)	Blub. (cm)	% lipid	Concentration ppm (ug/g wet wt.) PCB	DDE	HCB	Ratios PCB/ DDE	HCB/ DDE	HCB/ PCB
CAS-15892	37.9	1971 04 23	F	69	1.0	51%	3.2	14.2	0.07	0.23	0.0048	0.021
CAS-22173	37.9	1980 05 27	F	80	1.5	48%	9.5	13.0	0.11	0.73	0.0086	0.012
CAS-A3209	37.8	1980 07 01	M	75	1.0	59%	8.8	20.3	0.25	0.43	0.0125	0.029
CAS-A3870	37.3	1984 06 30	F	85	1.7	85%	8.2	11.5	0.33	0.72	0.0286	0.040
REJ-1414	38.4	1985 05 08	M	145	1.0	51%	6.1	26.9	0.16	0.23	0.0059	0.026
REJ-1415	38.4	1985 -- --	F	132	1.7	90%	5.6	21.9	0.28	0.25	0.0128	0.050
MVZ-172408	38.4	1986 07 15	M	162	0.5	49%	63.6	101.0	0.38	0.63	0.0038	0.006
MVZ-172409	38.3	1986 07 15	F	108	2.0	92%	2.1	8.3	0.15	0.26	0.0181	0.070
MVZ-173468	38.5	1986 08 20	F	154	2.0	81%	5.1	14.1	0.12	0.36	0.0085	0.024
M0001	39.5	1987 04 28	M	174	1.9	85%	13.7	59.4	0.25	0.23	0.0043	0.019
CAS-4001	37.8	1987 06 11	F	168	2.2	77%	1.4	3.5	0.04	0.40	0.0103	0.026
CAS-4003	37.8	1987 06 14	F	79	1.1	85%	1.0	2.7	0.05	0.35	0.0188	0.054
RLD-192	37.9	1987 06 14	M	84	1.6	66%	5.0	11.0	0.16	0.45	0.0147	0.033
RLD-201	38.0	1987 08 16	M	91	1.6	84%	23.8	40.6	0.79	0.59	0.0196	0.033
RLD-265	38.0	1988 01 01	F	184	1.4	80%	4.4	11.2	0.11	0.39	0.0096	0.025
CAS-4103	37.8	1988 05 29	M	49	1.4	76%	5.4	12.2	0.25	0.45	0.0204	0.046
CAS-4102	38.5	1988 06 02	M	143	1.3	77%	23.9	51.7	0.33	0.46	0.0064	0.014
CAS-4235	37.8	1989 07 12	M	149	1.0	81%	42.8	61.3	0.27	0.70	0.0044	0.006
CAS-4240	37.8	1989 07 24	F	144	1.1	81%	86.5	38.8	0.44	2.23	0.0113	0.005
Mean				120	1.4	74%	16.8	27.6	0.24	0.53	0.0118	0.028
S.D.				41	0.4	14%	22.6	24.8	0.17	0.43	0.0066	0.017
Minimum				49	0.5	48%	1.0	2.7	0.04	0.23	0.0038	0.005
Maximum				184	2.2	92%	86.5	101.0	0.79	2.23	0.0286	0.070

the Farallones region have been tested. The results of samples analyzed as a part of this study are reported in conjunction with these other values.

Concentrations of PCBs ranged from 1 to 87 ppm (ug/g, wet weight). PCBs were quantified by summing only the more chlorinated individual PCB congeners that were not interfered with by DDT and its derivatives. Although this provided the most reliable value for the ratio comparisons (Calambokidis and Barlow, In press), it resulted in total PCBs being underestimated by about 30%.

PCB and HCB concentrations from the Gulf of the Farallones area were similar to those found in harbor porpoise from other areas of the North Pacific (Table 13). Harbor porpoise from the European waters, the Bay of Fundy, and off New England had PCB concentrations that were generally higher than found in the Gulf of the Farallones. DDT concentrations were lower than seen in harbor porpoise off southern California.

The highest concentration of PCBs was found in a female (144 cm long) found just outside San Francisco Bay. This animal also had an unusually high PCB to DDT ratio, suggesting it may have been feeding on a food source with higher PCB concentrations than other harbor porpoise. Elevated PCB concentrations in relation to DDT are typical found in more industrial area such as inside San Francisco Bay.

As reported in Calambokidis and Barlow (In press), significant statistical relationships were found between contaminant concentrations and 1) length, 2) sex, and 3) region. These same associations were found with the expanded data set that included the new samples analyzed for this study.

Concentrations of PCBs and DDT were below those associated with reproductive problems in marine mammals from other areas. PCBs have been shown to inhibit reproduction in captive harbor seals (Reijnders 1986) and were suspected to cause reproductive failure in seals from the European waters including the Baltic Sea (Reijnders 1982, Reijnders *et al.* 1982, Helle *et al.* 1976a, 1976b, Helle 1980). DDT has been associated with premature births in California sea lions in southern California (DeLong *et al.* 1973, Gilmartin *et al.* 1976) though at higher levels than we found in harbor porpoise. A reduction of testosterone levels in response to relatively low concentrations of DDE was reported recently for Dall's porpoise from western North Pacific (Subramanian *et al.* 1987). The validity of this association, however, has been questioned (Calambokidis, In press).

Geographic interchange based on contaminant ratios

Ratios of the more stable contaminants (PCBs, DDE, and HCB) have been shown to be good biological indicators of the regions where marine mammals feed (Calambokidis *et al.* 1979a, Calambokidis and Barlow In press). Because these contaminants

Table 13. Levels of total total PCBs, DDT, and HCB reported in harbor porpoise blubber tissues. Concentrations are listed as parts per million (ppm) including weight basis of contaminant concentration (W). Literature published before 1984 was taken from summaries by Calambokidis et al. (1984) and Wagemann and Muir (1984). See following page for abbreviation explanations.

Location	Year	Age	Sex	W	n	total PCBs			total DDT			HCB			Reference
						mean	low	high	mean	low	high	mean	low	high	
N. Pacific															
Monterey Bay	83-85	-	M+F	W	10	16	2.6	42	47	6.3	102	.43	.07	.89	Calambokidis 1986
Morro Bay	83-85	-	M+F	W	2	19	16	22	110	85	132	.68	.58	.77	Calambokidis 1986
S. California	75	S	F	W	1	84			335						O'Shea et al. 1980
S. California	78-84	-	M+F	W	11	9.1	0.1	26	277	1.2	610				Schafer et al. 1984
Oregon	81-86	-	M+F	W	13	11	1.4	50	19	2.1	52	.64	.08	1.8	Calambokidis 1986
Washington	81-85	-	M+F	W	7	17	0.2	30	13	0.2	26	.56	.01	.91	Calambokidis 1986
Puget Sound	77	-	-	W	1	55			14						Calambokidis et al. 1984
Puget Sound	79	f	M	W	1	1.7			1.4						Calambokidis et al. 1984
NW Atlantic															
Canadian Atlantic	70	A	M	W	12				307	151	520				Gaskin et al. 1971
Canadian Atlantic	70	C	M	W	2				131	75	186				Gaskin et al. 1971
Canadian Atlantic	70	C	F	W	1				155						Gaskin et al. 1971
Canadian Atlantic	70	A	F	W	15				214	112	448				Gaskin et al. 1971
Canadian Atlantic	70	A	F	W	6				69	40	122				Gaskin et al. 1971
Bay of Fundy	69-73	all	M	L	60					30	556				Gaskin et al. 1982
Bay of Fundy	69-73	all	F	L	55					16	352				Gaskin et al. 1982
Bay of Fundy	71-77	-	F	W	40	45	-	-							Gaskin et al. 1983
Bay of Fundy	71-77	-	M	W	65	79	-	-							Gaskin et al. 1983
Rhode Island	71-72	S	F	W	2	20	0.9	40							Gaskin et al. 1983
Rhode Island	73	A	F	W	1	74			58						Taruski et al. 1975
Maine	71	S	F	W	1	91									Gaskin et al. 1983
Prince Edward Is	72	A	M	W	1	74									Gaskin et al. 1983
Newfoundland	73	C	F	W	1	17									Gaskin et al. 1983
European waters															
West Wales	88	all	M+F	W	4	56	23	61	6.5	1.4	12	.45	.35	.59	Morris et al. 1989
France coast	77	f	U	D	1	1.5			0.4						Alzieu and Duguy 1979
France coast	77	A	F	D	1	6.2			1.7						Alzieu and Duguy 1979
North Sea, Germany	76	U	F	W	1	15			2.4						Harms et al. 1978
Netherlands	78	f	U	L	1	59			6.7						Duinker and Hillebrand 1979
Baltic, Germany	76	U	B	W	2	114	89	140	38	29	46				Harms et al. 1978
Baltic Sea	72	U	B	L	8	93	28	190	171	30	289				Otterlind 1976
W. coast Sweeden	74	U	U	L	6	159	56	260	160	25	560				Otterlind 1976
E coast, Denmark	75	U	U	L	4	142	68	210	8.1	2.2	12				Otterlind 1976
E. Scotland	65-67	A	U	-	3				43	28	45				Holden and Marsden 1967
E. Scotland	68-71	A	U	-	9	47	31	68	23	-	-				Holden 1975
Dutch Coast	78	A	F	W	1	122									Duinker et al. 1988
Dutch Coast	78	A	M	W	3	104	51	140							Duinker et al. 1988
Denmark	72-73	S	M+F	-	4	78	28	125	18	3.9	27				Anderson and Rebsdorff 1976
North Sea	70	U	U	W	7	88	35	148							Koeman et al. 1972
Other areas															
Greenland	72	u	U	W	2	6.7	1.9	11							Clausen et al. 1974

Abbreviations used in Table 13.

Year: Year or range of years that the samples were collected. The midpoint of the year range is given in some cases.

Age: Age class of the sample
- f-fetus
- C-calf (<1 yr)
- S-sub-adult
- A-adult
- all-all ages
- U-unknown

Sex: Sex of sample
- F-female
- M-male
- M+F-both sexes
- U-unknown

W: Weight basis of the pollutant concentration
- W-wet weight
- L-lipid weight
- D-dry weight

N: number in sample

are highly stable and accumulate in the blubber over much of the life of the animal, they would not change rapidly if an animal moved to a different region. Previous to this study relatively few harbor porpoise samples from the Gulf of the Farallones had been available for comparison to other regions.

Contaminant ratios in harbor porpoise from the Gulf of the Farallones region were highly variable and overlapped with ratios from harbor porpoise examined from Monterey Bay (Figure 13). Harbor porpoise from Monterey Bay, however, showed less variability in contaminant ratios compared to the Gulf of the Farallones. Harbor porpoise samples have not been examined from northern California, but samples from Oregon generally differed from those in the Gulf of the Farallones with a small amount of overlap (Figure 13). The highly variable contaminant ratios found in harbor porpoise from the Gulf of the Farallones could be the result of: 1) movement of animals from other regions, 2) differential exposure to contaminants within the region (e.g. some animals feeding in or near San Francisco Bay), and 3) differences between porpoise subgroups in consumption of prey types with variable contaminant loads. Unlike other regions, such as Monterey Bay, the contaminant ratios in the Gulf of the Farallones area do not suggest the presence of a discrete population with limited interchange with other areas.

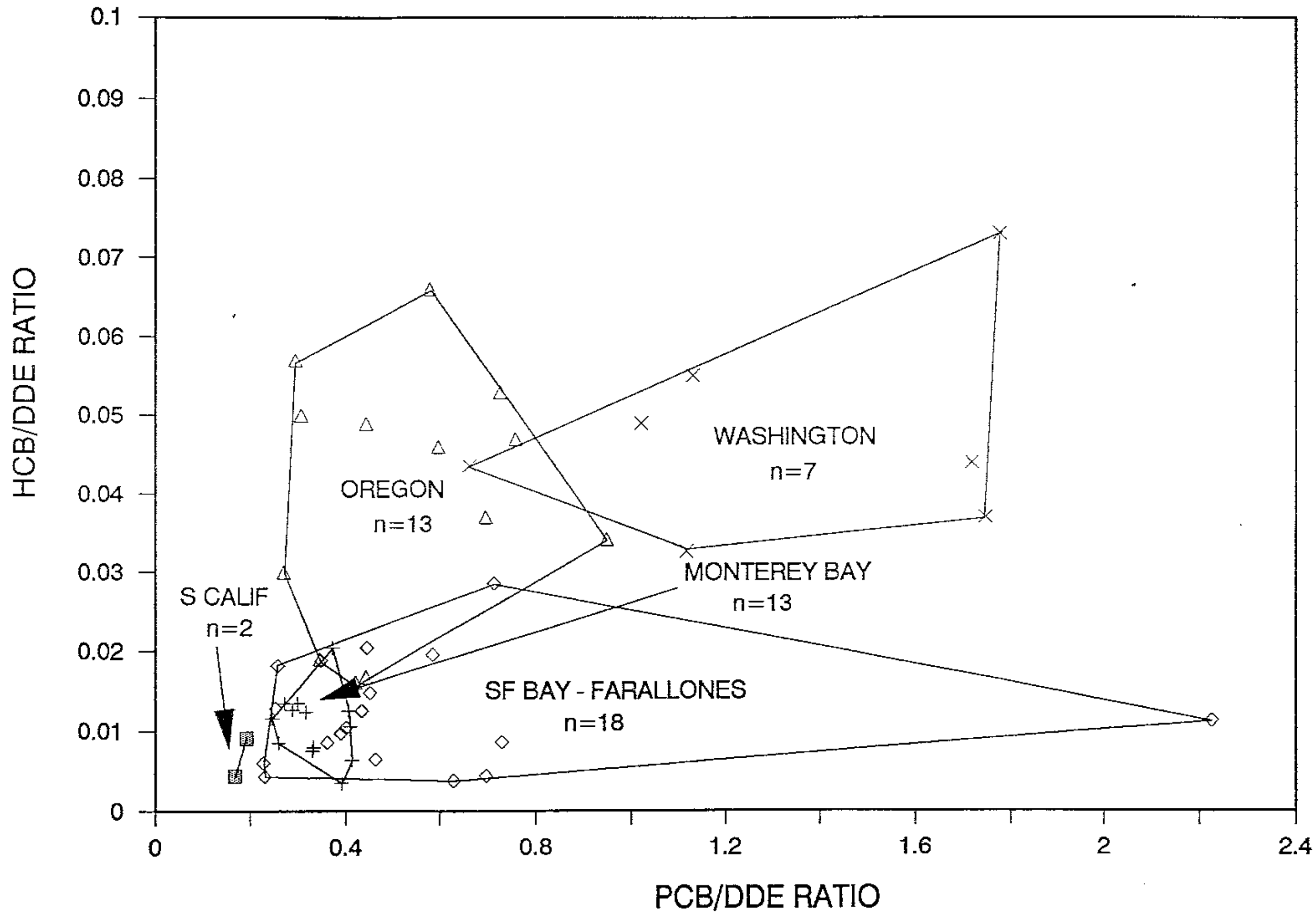

Figure 13. Ratios of contaminants found in stranded harbor porpoise from California, Oregon, and Washington. Lines bracket the ranges for different regions. Data are from Calambokidis and Barlow (In press) and this study.

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