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FINAL REPORT

POPULATION ESTIMATES OF HUMPBACK AND BLUE WHALES MADE THROUGH PHOTO-IDENTIFICATION FROM 1993 SURVEYS OFF CALIFORNIA

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EXECUTIVE SUMMARY

This report summarizes the photographic identification research conducted in 1993 both from the SWFSC (PODS) cruises and those conducted during coastal surveys. It provides new abundance estimates and information on whale movements. A total of 128 blue whales and 247 humpback whales were individually identified during these surveys. Abundances were estimated primarily using the Peterson capture-recapture model with samples consisting of identifications in different years or samples based on survey procedure (SWFSC systematic surveys vs. Cascadia's coastal effort). The coefficients of variation for these estimates were calculated both using conventional methods as well as new more conservative jackknife procedure that treated subsamples as all the identifications in a region in a given time period.

The best estimates of blue whale abundance were 2,038 (jackknife CV=0.33, left side) and 1,997 (CV=0.42, right side) based on comparison of all photographs taken on the 1991 and 1993 SWFSC cruises and the identifications from the coastal surveys for the same period. These estimates of about 2,000 blue whales are twice that obtained in previous capture-recapture analyses and are similar to the estimates obtained from line-transect estimates for the California coast.

The best estimate of humpback whale abundance was 597 (CV=0.07) based on all samples obtained from surveys in 1992 and 1993. Using similar pairs of years since 1988, abundance estimates increased steadily from 498 to 597, or about 5% per year. These abundance estimates were in good agreement with those obtained using other capture-recapture methods (Jolly-Seber) as well as those obtained using line-transect methods.

Additional data were obtained in 1993 on blue whale movements and distribution along the California coast. Three individual blue whales were photographed in both the 1991 and 1993 SWFSC surveys, a surprisingly high number. Although evidence of preferences by some blue whales for coastal and others for offshore waters was again found, several individual whales were seen in both offshore and inshore waters during a season or between seasons.

Most humpback whales identified during the SWFSC cruises were seen in coastal waters with only six identifications made in offshore waters outside the typical range of the coastal surveys (more than 50 nmi offshore). All but one of the six identifications made farther offshore were of whales that had been seen at other times in coastal waters. These findings confirm that most humpback whales use coastal waters and the few seen farther offshore are part of the same aggregation using coastal waters. Although a higher proportion of humpback whale calves were seen in 1993 (4.4 to 5.0%) compared to past years, this proportion remains low compared to studies of humpback whale populations in other areas.

INTRODUCTION

Humpback whale (*Megaptera novaeangliae*) and blue whale (*Balaenoptera musculus*) populations were depleted by whaling that continued off California until 1965 (Rice 1963, 1974). Abundance estimates of these two endangered species have been made recently using two techniques: capture-recapture methods through photo-identification research (Calambokidis *et al.* 1993) and line-transect methods from ship surveys (Barlow 1994, 1995). Long-term photo-identification research on these whales began off central California in 1986 (Calambokidis *et al.* 1989a, 1989b, 1990a, 1990b) and was expanded to include all coastal waters off California in 1991 (Calambokidis *et al.* 1993). Ship surveys, using line-transect methodology off California since 1979 (Hill and Barlow 1992, Lee 1993), were used to estimate the abundance of many cetacean species (Barlow 1994, 1995). Estimates of abundance using the two techniques were similar for humpback whales (581 (C.V.=0.03) from capture-recapture for 1991-1992 and 626 (C.V.=0.41) from line-transect surveys for 1991) but for blue whales, capture-recapture estimates were about half of that made from vessel surveys (904 to 1112 from capture-recapture and 2250 (C.V.=0.38) from transect) (Calambokidis *et al.* 1993, Barlow 1995).

Long-term photo-identification research on humpback whales off California has been valuable by providing information on migratory pathways (Calambokidis *et al.* 1993, Steiger *et al.* 1991), stock separation (Calambokidis *et al.* 1993, In press), and reproductive histories of females (Steiger and Calambokidis, In prep.). We can define the group of humpback whales that feeds off California each summer and fall as a separate sub-population that ranges from southern California and Washington (Calambokidis *et al.* 1993, In press). Our research was limited, however, because it covered only the nearshore waters out to 35 nautical miles (nmi). While humpback whales appear to have a nearshore distribution, blue whales were seen over 100 nmi offshore during vessel transect surveys (Barlow 1995). The relationship between these animals and those studied nearshore is poorly understood. Data from a sample of photographs taken by SWFSC in 1991 (CAMMS surveys) suggested that the offshore and inshore groups do not intermix randomly (Calambokidis *et al.* 1993).

Cascadia Research was contracted by Southwest Fisheries Science Center (SWFSC) to obtain identification photographs of both blue and humpback whales during their vessel surveys (PODS-93) in 1993 on board the *McArthur*. This report summarizes the photographic identification research conducted in 1993 both from the SWFSC (PODS) cruises and those conducted during coastal surveys and provides new abundance estimates and information on whale movements.

METHODS

Photographs were taken in conjunction with the SWFSC (PODS-93) cruises that conducted line-transect vessel surveys for marine mammals using the NOAA ship *McArthur*. During these cruises, a 5.7 m inflatable boat, the *AR-1*, was launched on 17 days between 28 July and 27 October 1993 to approach and photograph humpback and blue whales for photo-identification research (Table 1, Figure 1). The *AR-1* was launched in areas of expected encounters with blue whales or upon encountering humpback or blue whales. Some identification photographs were taken directly from the *McArthur* on at least 12 days. Locations of identifications of blue and humpback whales from the 1991 and 1993 SWFSC cruises are shown in Figures 2 and 3.

We also conducted photo-identification surveys along the California coast out to 30 nmi (Figure 1) in a 5.3 m inflatable boat. Twenty-seven coastal surveys were conducted from 20 August and 22 October 1993 (Table 2). Between 28 August and 24 September 1993, effort was focussed off central California (between Monterey Bay and Half Moon Bay) and was in conjunction with satellite tagging efforts by Oregon State University led by Bruce Mate. All other surveys attempted to sample as many humpback and blue whales as possible along California; effort was focussed between Pt. St. George and the Gulf of the Farallones. Additional data and identification photographs were contributed to our study by collaborators including Oceanic Society (Nancy Black and coworkers), Oregon State University (Dr. Bruce Mate and coworkers), and others (see Acknowledgments for full list of contributors). These photographs were generally taken opportunistically in the course of other activities, or in one case, a survey was conducted to collect photographs for us (Tom Kieckhefer).

We used data from previous research for comparison to the 1993 data in this report. These included whales identified during the SWFSC (CAMMS) line-transect ship surveys in 1991 and data from coastal surveys that were reported by Calambokidis *et al.* (1993). The numbers of humpback and blue whales that were identified by region and year are summarized in Tables 3 and 4.

The movement of each vessel and the survey conditions were recorded including: time, latitude and longitude, and weather conditions. Additional data were collected during each closing (when whales were approached and followed to photograph). Closing data included: start and end times of closing effort, locations, number of whales, number and species of birds within 300 m of the whales, roll and frame numbers shot by each photographer, and whale behavior. Whales were approached slowly from behind or for blue whales, from the side.

Photographic identification

Humpback and blue whales were identified photographically by natural marks as described in previous reports (Calambokidis *et al.* 1989a, 1989b). For humpback whales, the ventral side of the flukes was photographed; for blue whales, the right and left sides of the region surrounding the dorsal fin of blue whales were photographed. *Ilford* HP-5 Plus black-and-white negative film was shot with *Nikon* motor-advance 35mm cameras with 300mm f4.5 lenses. Shutter speeds were 1/1000 or faster when lighting conditions permitted. The film was exposed for ISO rating 1200 and development times were adjusted accordingly.

Humpback whales were matched from the black-and-white negatives; each frame was matched to a catalog of humpback whales identified previously off California, Oregon, and Washington. Photographs of all unidentified whales were printed and then rematched. For blue whales, the best shot of the right and left sides of each whale was selected from the negatives to print and then match. Prints were custom enlarged on RC paper. Some collaborating researchers provided color slides. These were copied with a duplicator onto black-and-white negative film and custom enlarged.

Capture-recapture analyses

Capture-recapture population estimates were based on individually identified whales and conducted as described in Hammond (1986) and Seber (1982) and previously conducted for this population by Calambokidis *et al.* (1993). Annual samples for capture-recapture calculations included only single recaptures of an identified whale. The Chapman modification of the Peterson estimate (Seber 1982) was used because it was appropriate for sampling without replacement (Hammond 1986). For humpback whales, samples primarily consisted of identifications in concurrent years. Samples from concurrent years maximizes the opportunity for mixing between seasons while minimizing the violation to closure due mortality/natality. For blue whales, the primary samples were based on platform with identifications from SWFSC ship surveys consisting of one sample and the other sample consisting of all other effort (primarily CRC coastal surveys). This approach was chosen because the SWFSC effort sampled the entire region (including offshore waters) systematically and was independent from the Cascadia coastal effort, therefore avoiding heterogeneity of capture probabilities due to resampling the same geographic region.

Unless otherwise noted, capture-recapture analyses included all photographs of identifiable whales. Humpback whales were cataloged only if the photograph was judged to be of sufficient quality to insure a match would be found if it existed. Some matches are likely missed, however, as demonstrated by an occasional reconciliation of two different photographs of the same whale that have been found to match only after a better quality photograph was obtained later on. For blue whales, all photographs were graded into three categories based on photographic quality. Different capture-recapture computations were conducted using only photographs of a certain quality and the outcomes were compared. Some matches could be missed between lower quality photographs. Separate abundance estimates were calculated for left and right sides of blue whales. Some blue whales were only identified by left sides and some only by right sides. Because we could not match right to left sides, it was necessary to compute separate estimates based on each side.

A new, more conservative method for calculating the variance of Peterson capture-recapture estimates based on the jackknife procedure was employed here. Traditional estimates of variance from capture-recapture estimates may be biased downward because identifications are not independent events. Geographical clumping of animals into areas of concentration often resulted in heavy research effort sampling these regions. Other concentrations of animals may have not been noted and not sampled. Although humpback whales often range widely along the coast of California, Oregon, and Washington during the season, animals show a preference to return to similar areas each year (Calambokidis *et al.* 1993). To incorporate the variance introduced by this geographic clumping of whales and sample effort, a jackknife estimate of

variance was calculated using entire regions as samples. Each sample was divided into five to eight subsamples based on regions and time period. To obtain similar sample sizes, some regions were pooled together and some areas of high coverage divided into subsamples by season (see Tables 5 and 6 for detials on subsamples used). For humpback whales, annual samples from the Gulf of the Farallones were divided into three samples based on month. Because blue whale capture-recapture calculations were based on multi-year samples taken from different platforms (SWFSC vs. other), each platform was divided into five roughly equal subsamples based on year of sample and broad regions. Pseudovalues for generating the jackknife variance were calculated by excluding each sample from the estimate. Because the Peterson estimate is based on two samples, between 10 and 14 pseudovalues were calculated for each estimate.

Variance was calculated using the following formula from Efron (1982):

$$VAR = \frac{(n-1)}{n} \sum (P - P_i)^2$$

where n is the number of estimates, P_i is each of the abundance estimates calculated by excluding one set of samples, and P is the abundance estimate using all data.

Humpback whale reproductive rates

Gross reproductive rates were estimated using 1) the proportion of all humpback whales approached (including calves) that were calves, and 2) the number of cows with calves identified as a percentage of the total number of whales identified (including cows). Cow identifications were used instead of calves because calves fluked less often and therefore were sometimes not identified. For these analyses, only data from Cascadia personnel were used to insure the criteria used for calf determination were consistent.

RESULTS

Blue whales were identified on 218 occasions in 1993, 70 from the SWFSC surveys and 148 from the Cascadia coastal surveys (including collaborators). This yielded a total of 132 individual whales, after subtracting matches of the same whales. All but four of these, 128 (Table 3) were from waters off California. The other four were from the *David Star Jordan* off southern Baja. Humpback whales were identified on 499 occasions off California in 1993, 65 from SWFSC surveys and 434 from Cascadia coastal surveys. These yielded 247 individual humpback whales (Table 4).

Abundance estimates

Blue whales

Blue whale abundance estimates were based primarily on comparison of the identifications obtained during the 1991 and 1993 SWFSC cruises and those for the same period (1991-93) from coastal effort by Cascadia Research (Table 5). Eight estimates (four quality criteria and two sides), yielded abundances from 1,924 to 2,639. Surprisingly, estimates based on only the highest quality photographs yielded higher estimates than those based on less strict criteria, indicating there was not a detectable upward bias in the other estimates using a wider range of photographic quality due to missed matches. The estimates based on the strictest quality criteria, however, had high coefficients of variation (CVs) due to the small sample size that made them of little value.

The best estimates of blue whale abundance were 2,038 (jackknife CV=0.33, left side) and 1,997 (CV=0.42, right side) based on all photographs (no quality criteria). These estimates were considered best because they yielded similar estimates as with quality criteria but the larger sample resulted in lower variance estimates. CVs calculated using the new jackknife procedure and regional/seasonal subsamples gave higher variances than those computed using conventional methods cited by Hammond (1986) and Seber (1982). This was expected because any bias contributed by geographic heterogeneity of capture probabilities would be reflected in the jackknife variance. The jackknife variance gave very high variance estimates for estimates based on the smallest samples.

We were surprised to find three matches between the 1991 and 1993 SWFSC samples. It was not expected that these samples would be large enough to provide matches that would allow them to be used for an independent abundance estimate. All three of the matches were based on right side photographs only; an abundance estimate using these two samples would have yielded only 371 whales. The presence of three matches between these two small independent samples is troubling but could be an artifact of the small samples involved. The locations of these matches are discussed further (see Movements section).

The estimates of about 2,000 blue whales are twice those based only on the 1991 SWFSC survey and reported in Calambokidis *et al.* (1993). The inclusion of the 1993 surveys almost tripled the sample size with a higher proportion of good quality photographs. The higher estimates from the combined 1991/1993 sample stems from 1) the lower overall proportion of

matches obtained from the 1993 sample and 2) because some of the matches between both of the SWFSC samples and the coastal sample were of the same whale which was then be counted as a single match. One other difference between the estimates reported here and those in Calambokidis *et al.* (1993) is that the coastal sample used here does not include identifications off Baja obtained by Mingan Island Cetacean Study (Sears 1987). A comparison of blue whales obtained by MICS through 1993 to those from the 1993 SWFSC surveys was not conducted for this report.

The estimates of 2,000 blue whales reported here are in closer agreement with the estimate of 2,250 (CV=0.38) found using line-transect methods from the 1991 SWFSC surveys (Barlow 1995). Given the large variances associated with both line transect and the capture-recapture estimates, this is surprisingly close agreement. These abundance estimates, however, measure different things. The line-transect estimate covers only the blue whales actually present in waters off California out to 300 nmi at the time of the surveys. The capture-recapture method estimates the entire population that could inhabit these waters even though all might not be present at any one moment in time. The capture-recapture estimate would be expected to yield a higher value if it was unbiased and if there is a portion of the population outside the line-transect study area at the time of the surveys. The identification of some blue whales off Baja during the 1993 surveys and the reported presence of blue whales off Oregon and Washington in 1994 suggests this would be the case.

Humpback whales

Abundance estimates of humpback whales calculated from all survey data using pairwise annual samples yielded estimates that increased from 498 to 597 (Table 6). The four estimates from 1988 to 1993 (excluding 1989 when effort was limited) increased at about 5% per year. The most recent estimate was 597 for the years 1992 to 1993. CVs for the estimates based on jackknife estimates of precision ranged from 0.07 to 0.29. Similar results were obtained using the open Jolly-Seber model for the three years with the best geographic coverage (1991-93) which yielded an estimate of 531 (for 1992) with a CV of 0.05.

An abundance estimate of 655 (CV=0.15) was also calculated using the identifications from the 1991 and 1993 SWFSC surveys (Table 6). Because sample sizes from each cruise were small, the 1991 and 1993 were combined into one sample and compared to Cascadia's total sample for 1992. Additional years were not included in the Cascadia sample because some of the identifications obtained in 1991 and 1993 were not independent from those obtained during the SWFSC cruises. This occurred most dramatically on 24 September 1993 when the largest sample of humpback whale identifications were obtained from the NOAA ship and inflatable while operating in the same area at the same time as a separate Cascadia team was obtaining identifications. The estimate of 655 may be biased upward in part by the violation of closure due to natality and mortality occurring over a longer period than the estimates based on adjacent years.

Movements

Blue whales

Identifications made from the 1991 and 1993 SWFSC surveys provide important new insights on blue whales movements off California. The interchange of blue whales between inshore and offshore areas of California is particularly important because of its relevance to the capture-recapture estimates. Overall, 21 of the 86 blue whales identified in the SWFSC surveys, including both whales seen near shore and far offshore, had been seen at some other point in time in the coastal effort. Resightings of blue whales among regions for all years (1975-93) is shown in Table 7. Blue whales seen in offshore waters (more than 30 nmi from the coast) of southern California (code 39) and offshore of central and northern California (code 59) have been seen in numerous other areas, though with a lower resighting rate than for coastal regions. Of 56 whales identified offshore of southern California and 12 identified offshore of central and northern California, resightings were made in a number of areas including the Santa Barbara Channel, Monterey Bay, the Gulf of the Farallones, and off Fort Bragg (Figure 4, Table 7).

Locations of blue whales that were seen during the 1991/1993 SWFSC surveys and in our coastal surveys (1991-1993) included whales that moved between inshore and offshore areas (Figure 2). Four of the blue whale matches were expected because they were photographed on nearshore legs of the SWFSC surveys in areas near the Gulf of the Farallones, Half Moon Bay, and near the entrance to the Santa Barbara Channel, all areas sampled as part of the coastal surveys. However, most of the matches were of animals seen farther offshore from Cascadia's effort. Two of these offshore animals were from areas off central and northern California and five were from areas offshore of southern California (south of 35°N).

Four blue whales identified from the SWFSC surveys were seen on multiple days in the same year (Figure 5). Two of these involved offshore/inshore movement of whales: 1) whale ID# 629 was seen close to shore on 17 July 1991 and then was seen over 100 nmi west on 24 September 1991, and 2) whale ID# 303 was seen more than 100 nmi offshore on 30 July 1991 and then moved inshore and more than 300 nmi north off Bodega Bay by 30 October 1991. Two other intra-year matches showed little change in position: 1) whale ID# 853 was seen in the Southern California Bight during both the SWFSC surveys on 30 July 1993 and then again on 14 August 1993 by an independent researcher, and 2) whale ID# 636 was seen far offshore of central California on 26 September 1993 and 4 October 1993. Even though blue whales using offshore and inshore waters do not intermix as frequently as whales using different coastal waters, interchange of whales between offshore and inshore areas does occur.

Additional inter-year matches of blue whales were made from 1991 to 1993 involving whales seen during the SWFSC cruises and coastal surveys. In nine cases, blue whales seen from SWFSC surveys were seen during coastal surveys in the same period (1991-93) but not during the same year. Additionally, three whales were seen on both the 1991 and 1993 SWFSC surveys, sometimes in very different areas (Figure 5). Whale ID# 620 was seen during both 1991 and 1993 SWFSC cruises in offshore waters of southern and central California and was seen in coastal waters of northern California during the coastal surveys in 1992. Whale ID# 636 (mentioned above for an intra-year match) was seen on three occasions in 1991 and 1993, all of which were some of the farthest offshore sightings of blue whales made off southern and central

California. Whale ID# 650 was seen in both 1991 and 1993 off the Southern California Bight outside the Channel Islands.

Blue whales seen in offshore waters of California had a lower matching rate with whales seen in coastal waters of Mexico. Though matching of the 1993 blue whales with the Mingan Island Cetacean Study collection from the Sea of Cortez has not been conducted, only one blue whale from offshore waters has been matched to locations in Mexico. This compares with the 10-20% of whales from most coastal regions that have been matched to Mexican waters. More matches may be found with the additional comparisons to Mexico, but it is unlikely to greatly alter the disparity.

Humpback whales

All but 5 of the 60 individual humpback whales identified during the 1991 and 1993 SWFSC cruises have been seen at some other time or location. This is consistent with the high proportion of the entire humpback whale population that has been photographically identified indicated by the similarity between the total number of whales identified and the overall capture-recapture estimate. Resighting histories of the animals identified in the SWFSC surveys is detailed and complex. Table 8 shows the resighting locations of animals seen in different regions of California, Oregon, and Washington.

As with blue whales, the resighting histories of humpback whales seen farther offshore than the typical coastal effort is one of the primary insights provided by the SWFSC surveys. Three humpback whales were identified in offshore waters of southern California and three in offshore waters of central California (Figure 3, Table 8). One of these whales was seen in offshore waters of both southern and northern California, yielding a total of five offshore whales. All but one of these whales had been seen at some other location and resighting locations for these animals included numerous locations around southern and central California. Within the 1991-1993 period, three of the five whales had been seen in other areas (Figure 6).

Reproductive rates of humpback whales

Ten humpback whales that we identified were noted as cows that were with calves in 1993 (including one whale with a possible calf). Identification photographs of four other cow-calf pairs were provided by collaborators. Four of the cows seen with calves in 1993 were seen with calves in previous years (Figure 7).

During our effort in 1993, 4.4% (23 of 527 whales) of humpback whales seen were calves. From photo-identification, 5.0% of all whales identified were cows with calves (10 of 199 whales identified by our personnel). Since 1986, the number of calves has ranged between 0.6% and 6.0% of all whales seen, and cows identified with calves have comprised 1.1% to 4.8% of all humpbacks identified (Steiger and Calambokidis, In prep.).

Although the proportion of calf sightings and identification of cows with calves were higher in 1993 than in most years, they remain low compared to reproductive rates determined for humpback whales in other areas. The proportion of calves determined at other feeding grounds through photo-identification studies averaged 7.9% in the Gulf of Maine (Clapham and

Mayo 1987, 1990), 9.5% in Prince William Sound (von Ziegesar *et al.* 1994), and were 12.5% in 1986 in southeastern Alaska (Baker *et al.* 1992). Studies based upon whaling data and sighting surveys have estimated reproductive rates between 4% and 13% (Chittleborough 1965, Herman and Antinoja 1977, Whitehead 1982).

It not possible for a population with 4% calves to be increasing at 5% a year (from this report) given natural mortality and no signs of immigration. It is unclear whether the low reproductive rate reflects a bias in our sampling, a low reproductive rate, or high neonatal mortality before arrival on the feeding grounds. Steiger and Calambokidis (In prep.) examine many factors that could have caused bias, such as possible geographic segregation of cows with calves, differences in arrival and departure times by gender or age-class, or early weaning and separation of cows and calves that could cause animals to not be classified as calves. We could find no strong evidence for any bias. At this point, we cannot reconcile a low reproductive rate of humpback whales off California with the evidence supported in this report and by Barlow (1994) that this population is increasing.

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Table 1. Dates and locations of photo-identification surveys conducted using an inflatable (AR-1) launched from the NOAA ship McArthur in 1993.

Date	Start position	End position	Spp seen		Personnel
			Hump	Blue	
28-Jul-93	32 36N 117 24W	32 39N 117 32W			JAC
29-Jul-93	31 38N 118 43W	32 23N 118 19W			JAC,RS
30-Jul-93	33 05N 118 01W	33 15N 118 08W		x	JAC,RS
31-Jul-93	33 05N 118 48W	32 50N 119 54W		x	JAC,RS
02-Aug-93	33 09N 120 55W	33 33N 120 30W		x	JAC,RS
03-Aug-93	33 38N 120 33W	34 22N 120 21W		x	JAC,RS
04-Aug-93	35 02N 120 45W	34 44N 121 37W	x	x	JAC,RS
05-Aug-93	36 30N 122 22W	36 56N 121 59W	x		JAC,RS
07-Aug-93	36 10N 125 39W	36 04N 125 56W		x	JAC,RS
15-Aug-93	39 06N 124 47W	39 13N 125 00W		x	JAC,RS
17-Aug-93	41 45N 124 30W	41 56N 124 30W	x		JAC,RS
21-Aug-93	40 35N 124 28W	40 40N 124 31W	x		TEC,RS
31-Aug-93	37 18N 122 33W	36 06N 122 29W	x	x	TEC,RS
01-Sep-93	35 46N 122 38W	35 35N 122 24W		x	TEC,RS
07-Sep-93	34 14N 123 19W	34 38N 122 13W		x	TEC,RS
24-Sep-93	37 39N 123 03W	37 39N 123 00W	x		RS,DG
26-Sep-93	38 30N 126 49W	38 30N 126 49W		x	RS
11-Oct-93	37 15N 124 53W	37 08N 124 48W		x	RS,WA
12-Oct-93	35 53N 125 38W	35 49N 125 39W		x	RS,WA

Table 2. Dates of coastal survey effort by Cascadia Research in 1993. Collaborator effort is not included.

Date	Ves	Region	Start	End	Spp seen		Org
					Hump	Blue	
20–Aug–93	Nov	Pt St George	Crescent City	Crescent City	x		CRC
22–Aug–93	Nov	Pt St George	Crescent City	Crescent City			CRC
25–Aug–93	Nov	Pt Pinos	Santa Cruz	Santa Cruz	x	x	CRC
26–Aug–93	Nov	Pt Pinos	Santa Cruz	Santa Cruz	x	x	CRC
27–Aug–93	Nov	central California	Bodega Bay	Santa Cruz	x	x	CRC
28–Aug–93	Nov	Pt Pinos	Santa Cruz	Santa Cruz	x	x	CRC/OSU
29–Aug–93	Nov	Pt Pinos	Santa Cruz	Santa Cruz	x	x	CRC/OSU
30–Aug–93	Nov	Pt Pinos	Santa Cruz	Haul Moon Bay	x		CRC/OSU
31–Aug–93	Nov	Half Moon	Santa Cruz	Half Moon Bay	x	x	CRC/OSU
01–Sep–93	Nov	Half Moon	Half Moon Bay	Half Moon Bay	x	x	CRC/OSU
05–Sep–93	Nov	Gulf of Farallones	Bodega Bay	Bodega Bay			CRC
06–Sep–93	Nov	Gulf of Farallones	Bodega Bay	SE Farallon Is	x	x	CRC
07–Sep–93	Nov	Gulf of Farallones	SE Farallon Is	Bodega Bay	x	x	CRC/OSU
08–Sep–93	Nov	Half Moon	Half Moon Bay	Half Moon Bay	x		CRC
09–Sep–93	Nov	Half Moon	Half Moon Bay	SE Farallon Is	x		CRC/OSU
23–Sep–93	Nov	Half Moon	Half Moon Bay	Half Moon Bay	x	x	CRC/OSU
24–Sep–93	Nov	Half Moon	Half Moon Bay	Half Moon Bay	x	x	CRC
25–Sep–93	Ach	Gulf of Farallones	Bodega Bay	Bodega Bay	x	x	CRC
26–Sep–93	Ach	Gulf of Farallones	Bodega Bay	Bodega Bay	x	x	CRC
12–Oct–93	Ach	Gulf of Farallones	Sausalito	Sausalito	x		CRC/PEL
13–Oct–93	Ach	Gulf of Farallones	Sausalito	Sausalito	x		CRC/PEL
15–Oct–93	Ach	Gulf of Farallones	Bodega Bay	Bodega Bay	x		CRC
17–Oct–93	Dar	Gulf of Farallones	Sausalito	Sausalito			CRC/PEL
19–Oct–93	Ach	Gulf of Farallones	Bodega Bay	Bodega Bay	x	x	CRC
20–Oct–93	Ach	Ft Bragg	Ft Bragg	Ft Bragg	x		CRC
21–Oct–93	Ach	Cape Mendocino	Eureka	Eureka			CRC
22–Oct–93	Ach	Pt St George	Crescent City	Crescent City	x		CRC

CRC–Cascadia Research Collective
OSU–Oregon State Univ
PEL–Pelagikos

Table 3. Number of blue whales identified by region and year off California.

	Year									
Region	Pre-86	86	87	88	89	90	91	92	93	All yrs.
S. Califoirnia Bight	1	0	0	0	0	4	17	0	9	30
N. Califoirnia Bight	1	2	0	0	0	0	1	19	5	28
Santa Barbara Channel	0	0	0	0	0	0	0	108	0	108
S. California-offshore	3	1	0	0	0	0	20	0	32	56
Pt. Conception - Pt. Sur	0	0	0	0	0	0	4	0	4	8
Monterey Bay	9	43	62	25	15	0	0	6	18	155
Half Moon Bay	0	0	0	0	0	2	0	1	45	48
Cordell/Farallones	8	36	74	95	64	102	27	109	25	328
Bodega-Pt Arena	0	0	0	17	1	0	0	20	0	36
C. California-offshore	0	0	0	0	0	0	3	0	9	12
Pt Arena-Cape Mendocino	0	0	0	0	0	0	2	94	0	95
Pt. St. George	0	0	0	0	0	0	4	4	0	8
All areas	**22**	**80**	**129**	**122**	**77**	**108**	**76**	**285**	**128**	**642**

Table 4. Number of humpback whales identified by region and year. Includes data from Cascadia Research, Center for Whale Research, and collaborators.

	Year									
Region	pre-86	86	87	88	89	90	91	92	93	Total
S. Califoirnia Bight	0	0	0	0	0	0	1	0	5	6
N. Califoirnia Bight	0	0	0	1	0	1	0	3	1	6
Santa Barbara Channel	0	0	0	4	0	6	15	97	9	107
Offshore S. California	0	0	0	0	0	0	3	0	0	3
San Luis	0	0	8	58	0	0	79	4	1	119
Morro Bay	0	0	0	2	0	1	11	0	0	14
Monterey Bay	3	0	4	15	2	13	13	63	45	137
Half Moon Bay	0	0	0	2	0	19	0	0	27	46
Cordell/Farallones	16	90	141	133	111	158	86	171	171	442
Pt. Arena	0	1	0	5	0	0	0	63	6	74
Offshore central Calif.	0	0	0	0	0	0	0	0	3	3
S. Cape Mendocino	0	0	0	0	0	0	4	73	2	77
Humbolt	1	0	0	8	0	0	4	0	4	16
Pt. St. George	0	0	0	3	0	0	84	50	16	124
S Oregon	0	0	0	0	0	0	0	2	0	2
Cent. Oregon	0	0	0	0	0	22	0	0	0	22
N Oregon	0	0	0	0	0	0	0	6	0	6
Washington coast	0	0	0	0	0	5	0	0	0	5
Puget Sound	0	0	0	2	0	0	0	0	0	2
All areas	20	91	151	213	111	204	264	397	247	645

Table 5. Abundance of blue whales using Peterson mark-recapture methods. Sample 1 is from 1991 and 1993 SWFSC surveys of entire Californinia coast out to 300 nmi and sample 2 from Cascadia coastal effort for 1991-93. All IDs from California except four from Baja west coast.

Qual.	Either side			Left side			Right side			Mean
n1-n2	n1	n2	mat.	Est.	CV1	CV2	Est.	CV1	CV2	
C - C	86	347	12	2038	0.29	0.33	1997	0.26	0.42	2018
B - B	86	343	12	1924	0.30	0.38	2054	0.29	0.53	1989
B - A	86	246	6	1990	0.38	0.98	2357	0.39	0.60	2174
A - A	42	246	3	1990	0.55	1.06	2639	0.55	0.99	2315

Qual.-Minimum photographic quality for each sample from A-best to C-worst.
n-Number of individuals in sample from either left or right sides.
mat.-Number of matches between the two samples
Est.-Abundance estimate using photographs from one side only.
CV1-Coefficient of Variation using capture-recapture methods from Seber (1982).
CV2-Coefficient of Variation using jackknife w/ subsamples as shown below:

Vessel	n	Regions and seasons used for samples
SWFSC	5	1991: 31-39, 41-63; 1993: 31-39 (2 samples by month), 41-63
CRC	5	1991: all; 1992: 31-33, 41-54, 61-63; 1993: all

Table 6. Humpback whale abundance using Peterson mark-recapture estimates with samples based on years or vessels. Best estimate is shown in bold print. Variance is a jackknife estimate based on treating regions as samples.

Sample 1				Sample 2							
Sample	Year	Ident.	n	Sample	Year	Ident.	n	Match	Est.	CV1	CV2
All CA-WA	1988	565	213	All CA-WA	1990	395	204	87	498	0.06	0.19
All CA-WA	1990	395	204	All CA-WA	1991	661	264	101	532	0.05	0.29
All CA-WA	1991	661	264	All CA-WA	1992	1019	397	184	569	0.03	0.07
All CA-WA	**1992**	**1019**	**397**	**All CA-WA**	**1993**	**499**	**247**	**164**	**597**	**0.03**	**0.07**
SWFSC only	1991-3	81	61	Non SWFSC	1992	1019	397	36	666	0.10	0.15

Ident.-Number of identifications during period

n-Number of unique individuals in sample used in mark-recapture estimate

Est.-Estimated abundance

CV1-Coefficient of Variation using capture-recapture methods from Seber (1982).

CV2-Coefficient of Variation using jackknife method with samples by region and season (see below).

	Year	n	Samples	Regions
Combined	1988	213	6	31-42, 42-52, 53(3 months), 54-79
and CRC	1990	204	5	31-52, 53(3 months), 54-75
samples	1991	264	6	31-42, 43-52, 53-54 (3 months), 60-63
	1992	397	8	31-33, 41-52, 53 (3 months), 54, 61, 63-73
	1993	247	6	31-49, 50-52, 53 (3 months), 54-63
SWFSC	1991 &	61	8	1991: 39, 53, 62-63
sample	1993			1993: 33-41, 51-52, 53, 59, 62-63

Table 7. Blue whale matches between regions for all years. Matches shown between the same region indicate the number of matches between years (dependent on effort). Some regions were pooled. Region names indicate either boudaries or location in region where most whales were seen.

			Region code											
			31	32	33	39	41–2	51	52	53	54	59	61	63
Region	Code	n	30	28	108	56	8	158	48	328	36	12	95	8
S. California Bight	31	30	1											
N. California Bight	32	28	0	0										
Santa Barbara Channel	33	108	2	1	0									
S. California–offshore	39	56	2	1	1	0								
Pt. Concept.–Pt. Sur	41–2	8	0	0	1	0	0							
Monterey Bay	51	158	3	1	17	5	2	19						
Half–Moon Bay	52	48	0	1	10	0	0	15	0					
Gulf of Farallones/Cordell	53	328	3	1	33	3	2	64	30	119				
Bodega–Pt. Arena	54	36	0	0	7	0	0	8	7	22	2			
C. California–offshore	59	12	0	0	0	2	0	1	0	2	0	0		
Ft Bragg–Cape Mendocino	61	95	2	1	9	3	0	17	15	68	11	1	1	
Pt. St. George	63	8	0	0	0	0	0	1	0	6	0	1	0	0

Table 8. Number of identifications of humpback whales for each region and matches between regions for all years (through 1993). Matches shown between the same region indicate the number of matches between years (dependent on effort). Region names indicate either boudaries or location in region where most whales were seen.

			Region code																	
			31	32	33	39	41	42	51	52	53	54	59	61	62	63	71	72	73	75	79
	Reg.	n	6	6	107	3	119	14	137	46	442	74	3	77	16	124	2	22	6	5	2
S. Califoirnia Bight	31	6	0																		
N. Califoirnia Bight	32	6	0	0																	
Santa Barbara Channel	33	107	5	4	19																
Offshore S. California	39	3	0	0	2	0															
San Luis	41	119	1	2	45	0	34														
Morro Bay	42	14	1	0	8	0	12	0													
Monterey Bay	51	137	1	0	30	1	34	5	20												
Half Moon Bay	52	46	0	0	4	0	10	1	18	2											
Cordell/Farallones	53	442	2	4	42	1	60	7	79	29	283										
Pt. Arena	54	74	0	0	6	0	6	1	14	5	65	1									
Offshore central Calif.	59	3	0	0	1	1	1	0	0	0	2	0	0								
S. Cape Mendocino	61	77	0	1	5	0	6	0	10	5	59	22	0	2							
Humbolt	62	16	0	0	0	0	0	0	0	2	8	2	0	2	2						
Pt. St. George	63	124	1	0	4	0	4	0	9	4	80	28	0	25	9	27					
S Oregon	71	2	0	0	0	0	0	0	0	0	2	0	0	0	0	1	0				
Cent. Oregon	72	22	0	0	0	0	0	0	2	2	13	2	0	3	3	10	0	0			
N Oregon	73	6	0	0	0	0	0	0	0	1	4	0	0	1	0	1	0	1	0		
Washington coast	75	5	0	0	0	0	0	0	0	1	2	0	0	0	1	4	0	3	0	0	
Puget Sound	79	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

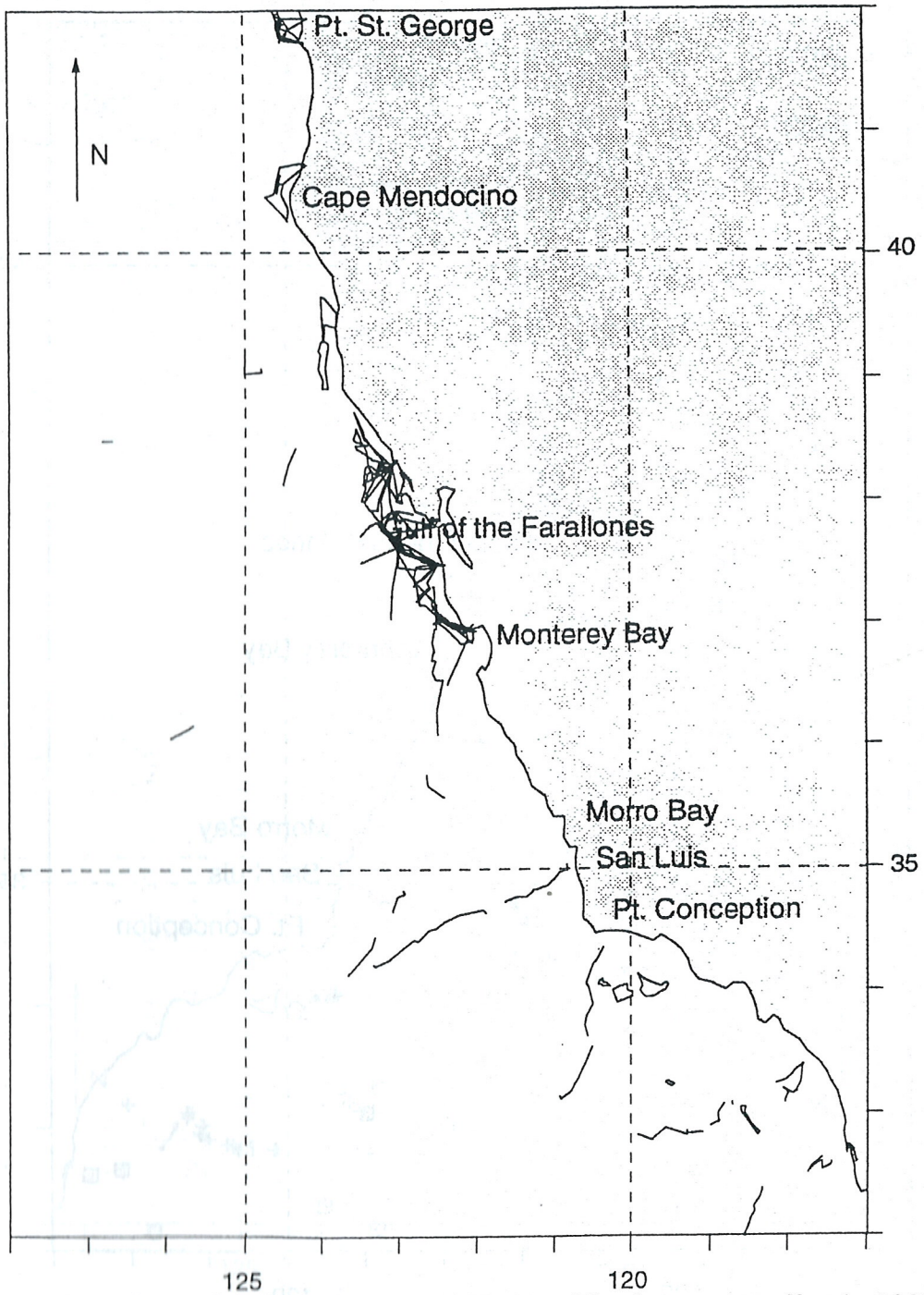

Figure 1. Locations of dedicated photographic identification survey effort in 1993 including both that conducted from an inflatable launched during the SWFSC surveys and Cascadia's coastal effort. Does not show opportunistic identification effort from the NOAA ship MacArthur.

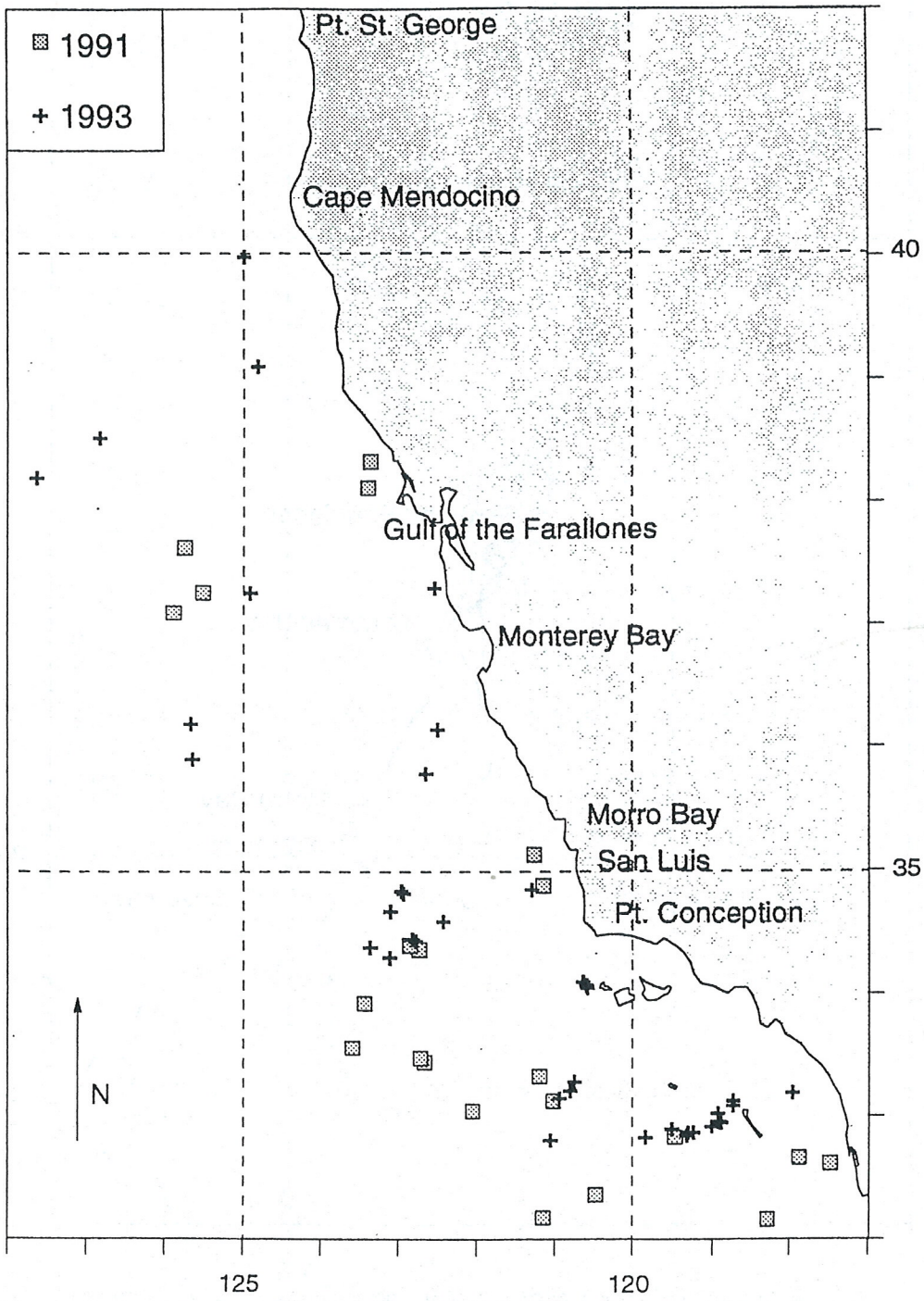

Figure 2. Locations of blue whales that were identified photographically during SWFSC ship surveys in 1991 and 1993.

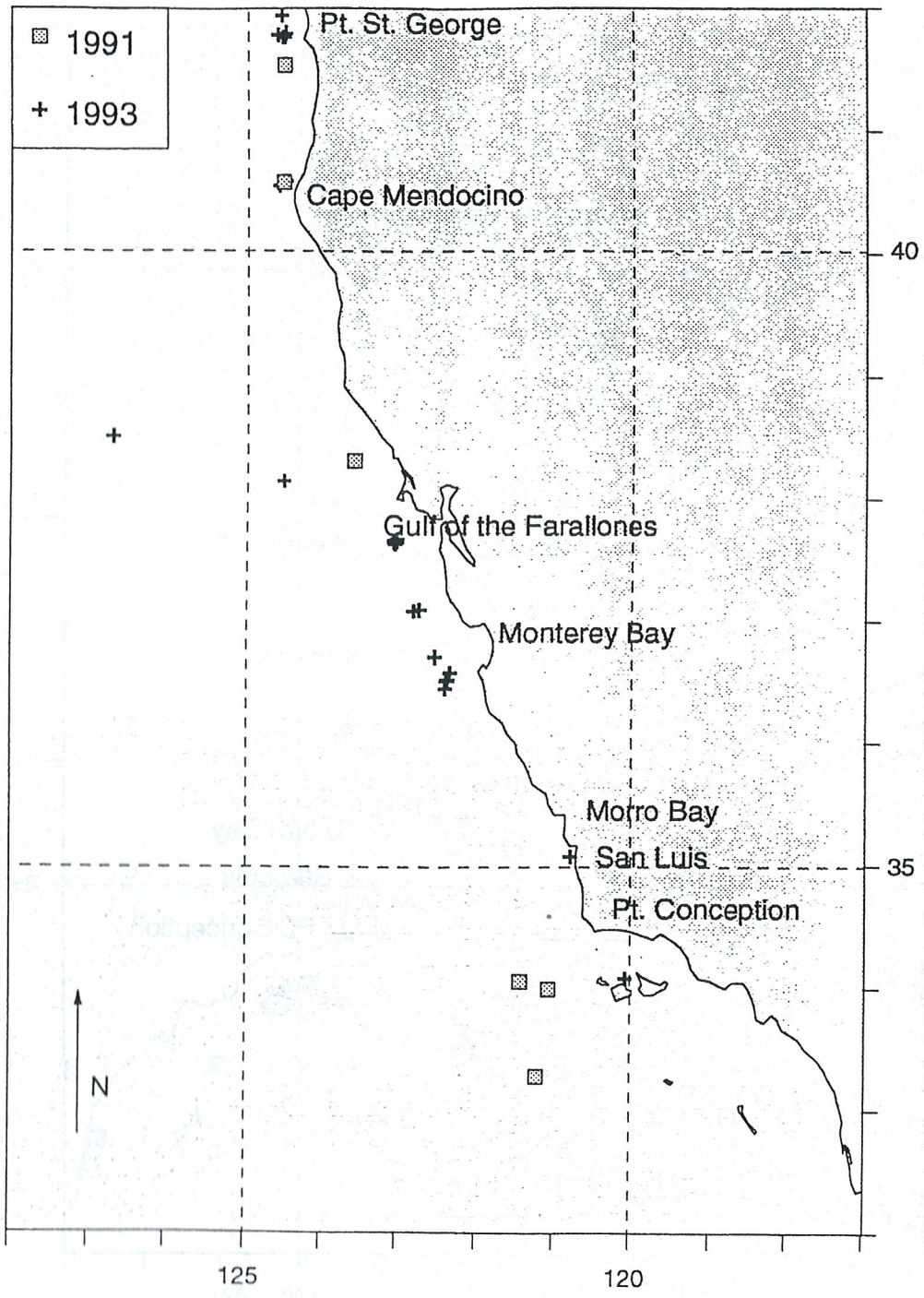

Figure 3. Locations of humpback whales that were identified photographically during SWFSC ship surveys in 1991 and 1993.

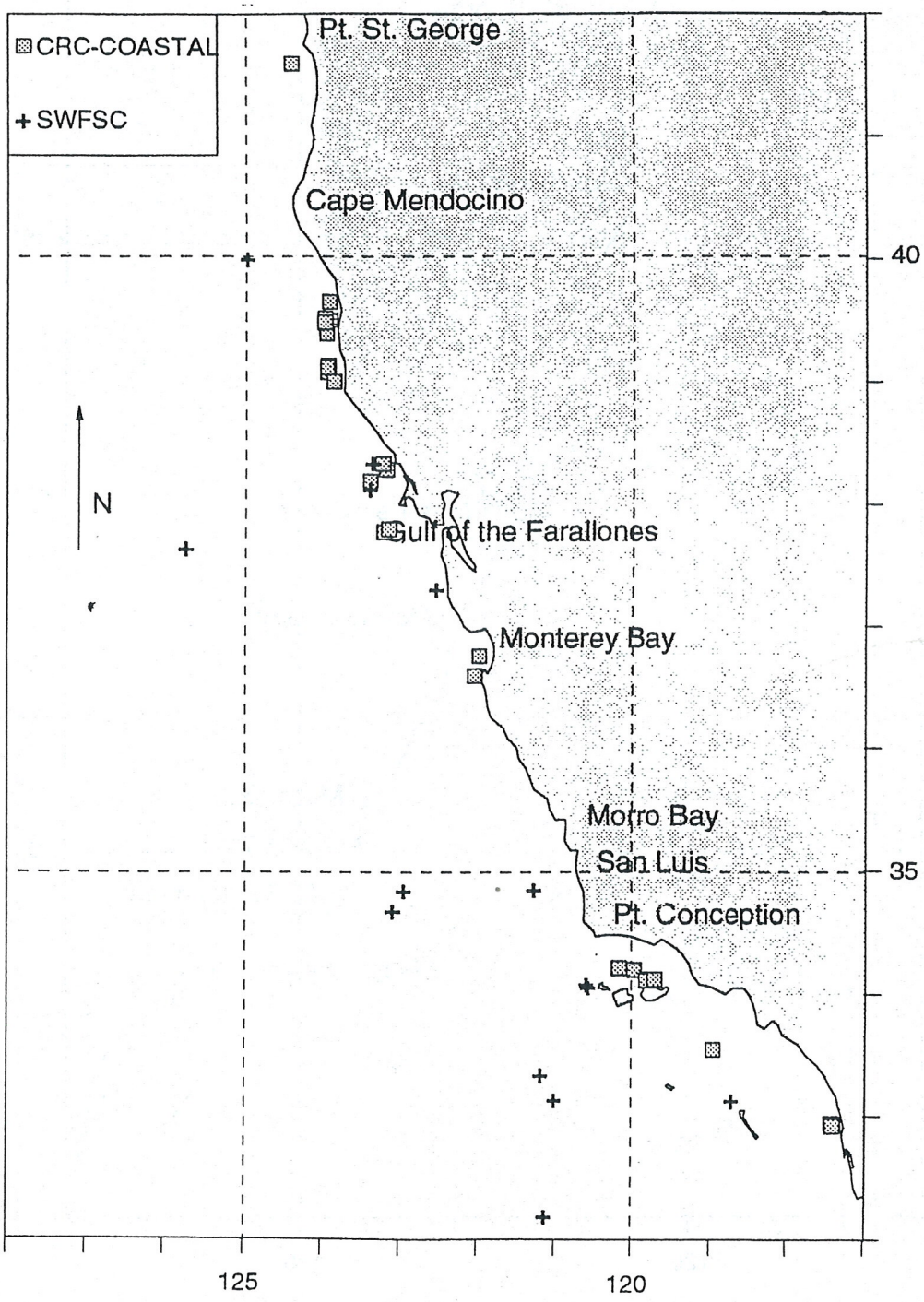

Figure 4. Locations of blue whales that matched between the sample of photographs taken during the SWFSC ship surveys in 1991 and 1993 and sample collected during coastal surveys between 1991 and 1993.

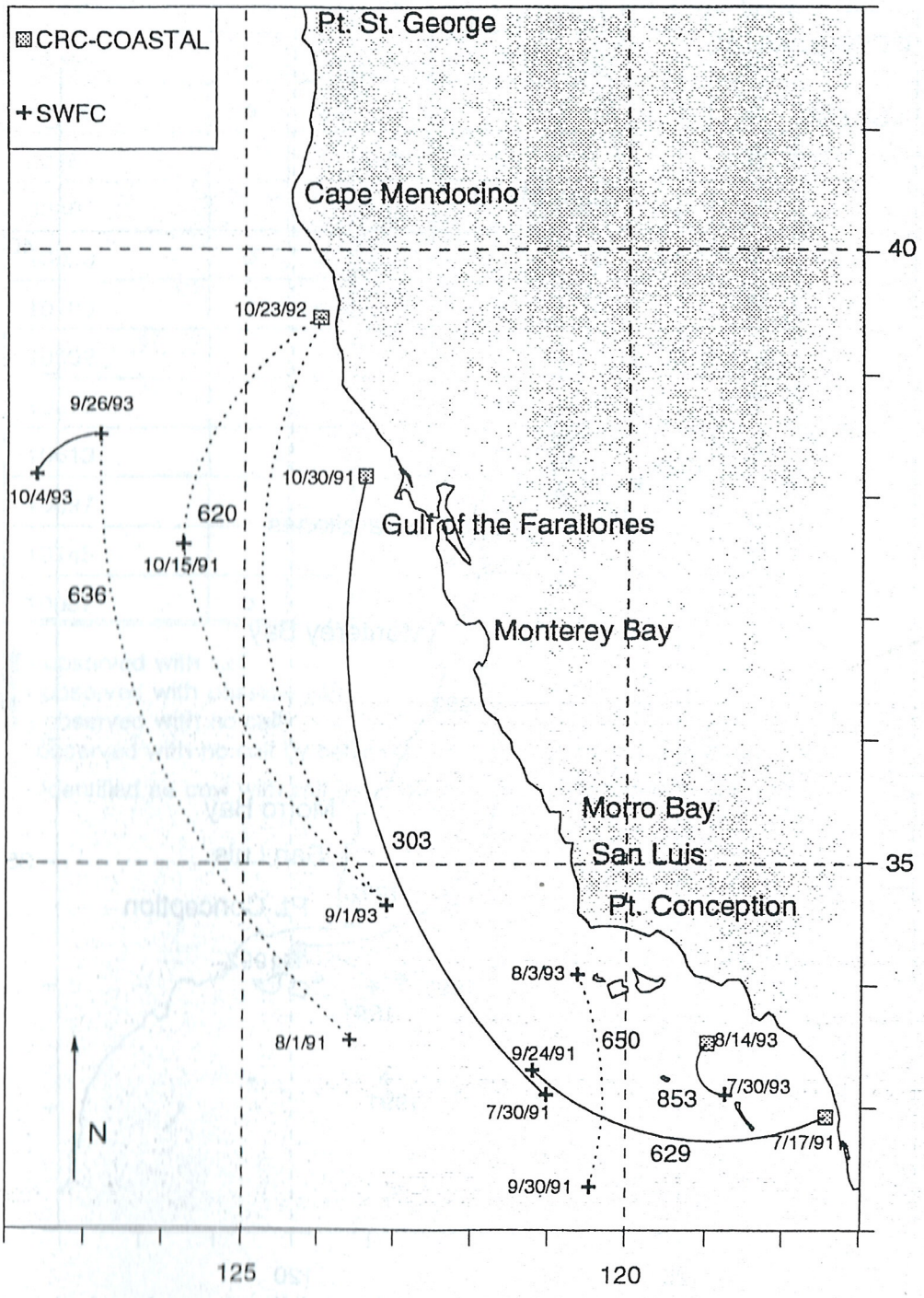

Figure 5. Intra-year matches (solid lines) of blue whales seen during 1991 or 1993 SWFC surveys and inter-year matches (dotted lines) of blue whales seen in the 1991 and 1993 SWFSC surveys.

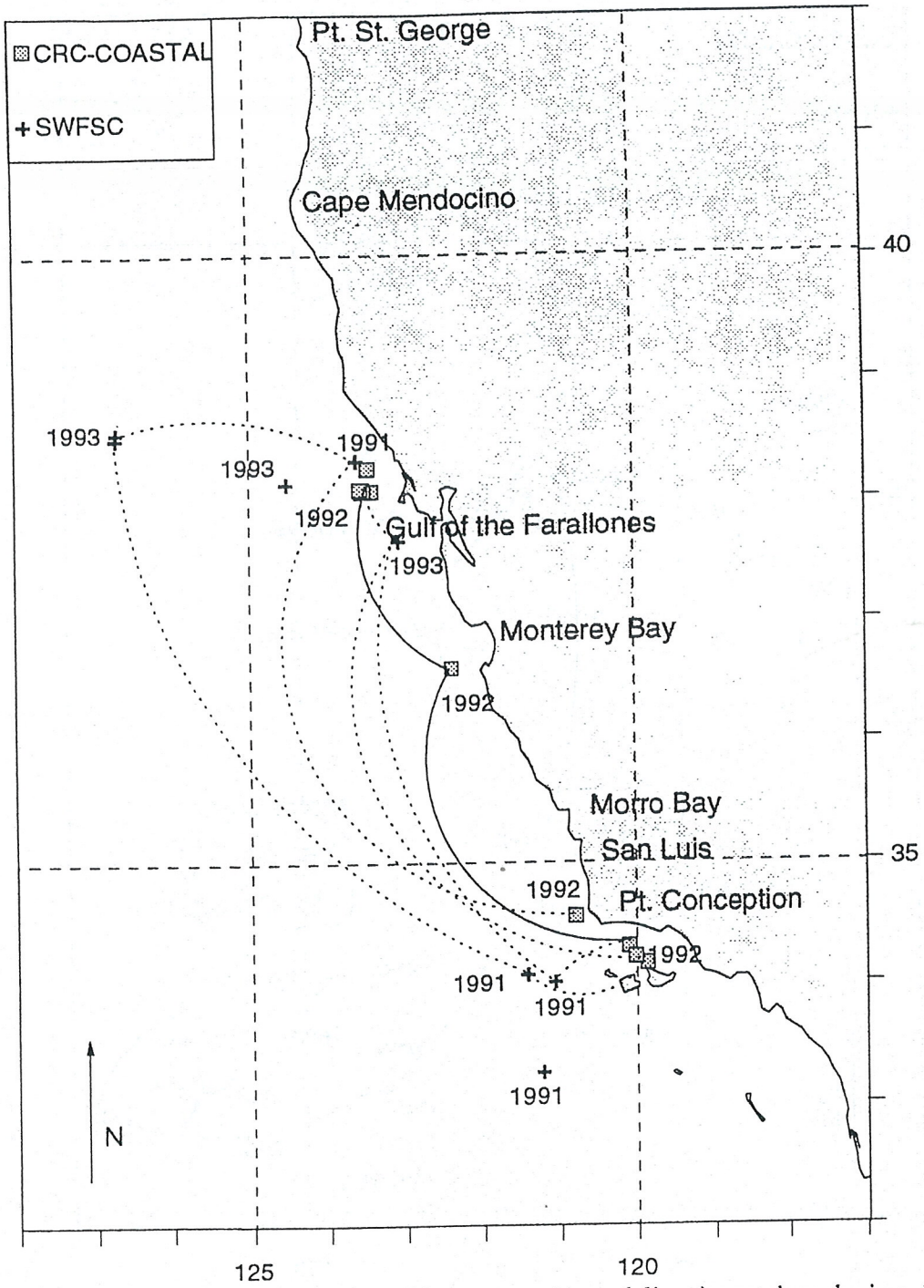

Figure 6. Intra-year (solid lines) and inter-year (dotted lines) matches during 1991-93 for five humpback whales seen in offshore waters during SWFSC surveys. The two sightings with no connecting lines show the two whales that were not seen at any other time between 1991 and 1993.

ID	86	87	88	89	90	91	92	93
10165		■	■				o	■
10230			■	o			o	■
10081	o				▒	▒		■
10009	o	o				■	o	■
9046			o					■
9048			o		o		o	■*
10050	o	o			o	o	o	■
10180		o				o		■
10502						o	o	■*
10579						o		■
10613							o	■
10697							•	■*
10745								■
10057	o		o			o	o	▒

■ - observed with calf
▒ - observed with possible calf
o - observed with no calf
• - observed with no calf by collaborators only (not included in calculations)
* - identified as cow with calf by collaborators (not included in calculations)

Figure 7. Reproductive histories of fourteen humpback whales cows that were seen with calves off California in 1993. Whales were not seen in years where the box is blank.