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Auks in Peril

DECLINE OF THE COMMON MURRE IN CENTRAL CALIFORNIA, 1980–1986

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Abstract. Aerial surveys of 13 Common Murre (*Uria aalge*) colonies were conducted in California in 1985 and 1986. Breeding population estimates for eight colonies in central California and five colonies in northern California were compared with estimates determined in 1980–1982. The central California population declined 52.6% within 4–6 years, from 229,080 in 1980–1982 to 108,530 in 1986. The northern California population remained relatively unchanged during the same period; combined totals at four colonies declined 5.4% from 118,080 in 1979–1982 to 111,730 in 1986. Population decline in central California was caused by high mortality from an intensive nearshore gill-net fishery, compounded by that from oil spills and a severe El Niño-Southern Oscillation event in 1982–1983. Individual colonies declined 45.8–100% and the most severe declines occurred at colonies located nearest to areas of highest gill-net fishing mortality.

Key Words: Aerial surveys; Alcidae; Common Murre; El Niño; oil spill; gill-net fishery; *Uria aalge*.

In 1979 and 1980, over 360,000 Common Murres (*Uria aalge*) nested in colonies distributed between Castle Rock, Del Norte County, in northern California and Hurricane Point Rocks, Monterey County, in central California (Sowls et al. 1980). Eight colonies in central California (about 30% of the state population) occurred south of Point Reyes (37°59′N, 123°59′W), whereas 12 northern California colonies (about 70% of the state population) occurred north of Cape Vizcaino (39°43′N, 123°49′W) (Fig. 1). We think there is little immigration or emigration between populations in central and northern California because they are separated by a distance of about 200–250 km, and in both areas birds remain near breeding colonies throughout the year (Storer 1952; DeGange and Sowls 1981; Ainley and Boekelheide 1990).

While murre numbers have increased at some colonies throughout this century (Osborne and Reynolds 1971, Osborne 1972, Sowls et al. 1980), increases in Farallon Island colonies in central California followed a severe historical population decline due to human occupation, egging, and chronic oil pollution in the Gulf of the Farallones. An estimated population of 400,000 birds in the mid-1800s fell to a few thousand birds in the mid-1900s (reviewed in Ainley and Lewis 1974). Partial protection was afforded colonies in 1909 when North Farallon (Fig. 1) and West End islands (Fig. 2) were established as the Farallon National Wildlife Refuge (NWR), under the jurisdiction of the U.S. Fish and Wildlife Service (USFWS). Egging stopped around the turn of the century and Dawson (1923) reported as many as 20,000 murres in 1911. However, mortalities caused by oil pollution from ship bilge discharges and oil spills continued to occur in the area (Palmer 1921, Moffitt and Orr 1938, Houldson 1952) and only a few hundreds to thousands of murres were reported from the 1920s to 1950s (e.g., Chaney 1924).

Additional protection was established in 1969 when Southeast Farallon Island (SEFI) and neighboring islets (Fig. 2) were included within the Farallon NWR. Since 1967 Point Reyes Bird Observatory (PRBO) has conducted research on the Farallon Islands, and since 1971 PRBO personnel have resided on the refuge through a cooperative agreement with USFWS, providing wardens for the first time on the islands and monitoring marine bird populations. Between 1959 and 1972 the murre population grew from about 6000 to 22,000 birds, despite the major 1971 San Francisco oil spill when thousands were killed (Smail et al. 1972, Ainley and Lewis 1974). In 1974 North Farallon and West End islands were designated as Wilderness Areas. This protection and lessened oil pollution allowed the breeding population to increase through the 1970s and early 1980s (DeSante and Ainley 1980; Ainley and Boekelheide 1990). By 1980, the South Farallon Islands (including West End Island, SEFI, and neighboring islets) supported the second largest murre colony in California (about 17% of the state population). The largest was at Castle Rock in northern California (Sowls et al. 1980), which was designated a NWR in 1980. There is little historical information on murre colonies in northern California, but numbers also increased there through the 1970s (Osborne 1972, Sowls et al. 1980). In southern California, murres for-

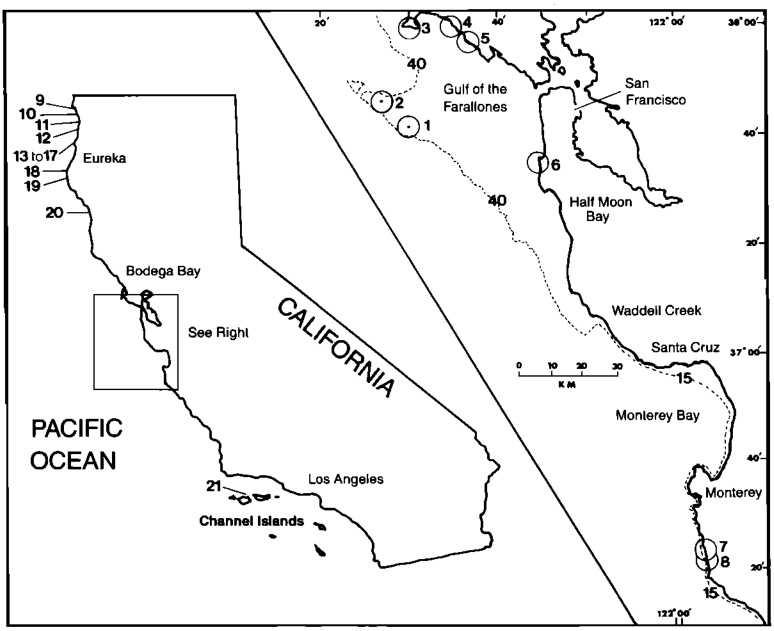

FIGURE 1. Locations of 21 Common Murre colonies in California (from Sowls et al. 1980). Central California colonies (inset): 1, South Farallon Islands; 2, North Farallon Islands; 3, Point Reyes; 4, Point Resistance; 5, Double Point Rocks; 6, Devil's Slide Rock; 7, Castle Rocks; 8, Hurricane Point Rocks. Northern California colonies (left): 9, Castle Rock; 10, Sister Rocks; 11, False Klamath Rock; 12, Redding Rock; 13, White Rock; 14, Green Rock; 15, Flatiron Rock; 16, Blank Rock; 17, Pilot Rock; 18, False Cape Rocks; 19, Steamboat Rock; 20, Cape Vizcaino. Southern California colonies (left): 21, Prince Island. The 40 and 15 fathom contours (inset) are indicated by the dashed line north and south of Waddell Creek, respectively.

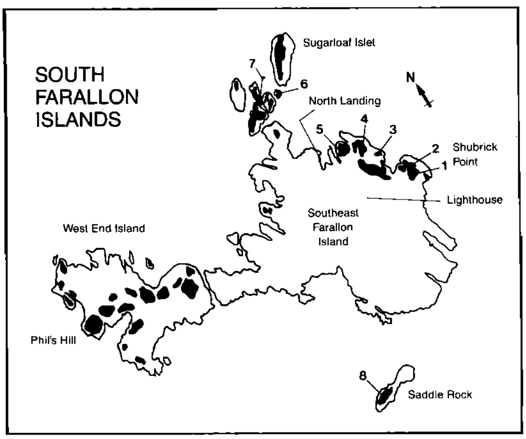

FIGURE 2. Map of the South Farallon Islands, San Francisco County. Common Murre nesting areas in 1986 are darkened. Numbered plots were used to monitor murres and to provide correction factors: 1, Upper Shubrick Point; 2, Lower Shubrick Point; 3, Cove Point; 4, Tower Point; 5, North Landing; 6, Chocolate Chip Islet; 7, Finger Rock; 8, Saddle Rock.

merly bred at Prince Island, but have been absent since the early 1900s (Hunt et al. 1979, Sowls et al. 1980).

After 1979 a decline in the numbers of murres breeding at the Farallon Islands occurred following heavy mortality of murres from gill-net fishing, two major oil spills, and the effects of the intense 1982–1983 El Niño-Southern Oscillation event (ENSO) (Carter 1986; Atkins and Heneman 1987; Ford et al. 1987; Page et al. 1990; Ainley and Boekelheide 1990). ENSO causes reduced ocean productivity, thereby affecting seabird reproduction. However, gill-net mortality was of special concern, because it was restricted to the smaller central California population and thousands of murres were being killed (California Department of Fish and Game [CDFG] 1981, 1987; Atkins and Heneman 1987; Stenzel et al. 1988; CDFG, unpubl. data).

Declines were first detected at the Farallon Islands in 1984. Other colonies had not been censused since 1982 and their status was unknown. In 1985 and 1986, USFWS and PRBO conducted aerial surveys to refine breeding popu-

FIGURE 3. Rock #4 subcolony at Point Reyes, 1986, showing the high resolution and clarity of slides used to count murres.

lation estimates at the Farallon Islands and determine the status of other colonies. In this paper, we compare our results to earlier population estimates to determine the extent of decline of the central California murre population between 1980 and 1986, and evaluate causes for this decline. We discuss several procedural inconsistencies that made it difficult to determine trends at some colonies, recognition of which should assist in interpreting past and future trends.

METHODS

AERIAL SURVEYS

In 1985, aerial surveys were conducted at five colonies in central California (South and North Farallon islands, Point Reyes, Point Resistance, and Double Point Rocks) and at Castle Rock in northern California. Surveys in 1986 covered all eight central California colonies (adding Devil's Slide, Castle, and Hurricane Point rocks) and five major colonies in northern California (Castle, False Klamath, Redding, Green, and Flatiron rocks), north of Eureka (Fig. 1). In both years, colonies in central California were surveyed on two days (30 May and 12 June 1985, 4 and 5 June 1986), whereas northern California colonies were surveyed on one day (5 June 1985, 19 June 1986). Surveys were flown at 50–90 knots (depending on wind speed) from a single engine, wing-over Cessna 150 or 182 aircraft at altitudes of 120–150 m in northern California. A quieter twin engine, wing-over Partanavia aircraft was used at altitudes of 150–200 m in central California, where murres were more sensitive to disturbance by aircraft, particularly at the South Farallon Islands. All surveys were flown without flushing birds.

Colonies were photographed by two photographers, each using a 35 mm camera set at rapid shutter speeds (1/500 or 1/1000 secs), a 300 mm telephoto lens, and color slide film (ASA 400). Overview photos were also taken using a 50 mm lens and color slide film (ASA 64). We attempted to pass directly overhead to minimize oblique photographs; however, when surveying the South Farallon Islands, passes were flown farther off the island due to steep topography and to prevent disturbance. At Point Reyes, high winds and steep topography made full coverage difficult.

Slides of the highest quality (Fig. 3) were projected onto white paper and areas to be counted were demarcated using landmarks or colony outlines. Slides were scrutinized by several observers who dotted each bird with a felt tip pen and later tallied dots with a hand-held counter. All slides and counting sheets were archived at the San Francisco Bay NWR office.

Aerial survey results were compared to similar surveys conducted in 1979 and 1980 by Sowls et al. (1980) and in 1980 and 1982 by Briggs et al. (1983). Data from 1981 surveys by Briggs et al. (1983) were excluded due to lower photo quality (K. T. Briggs, pers. comm.). In both previous studies, birds had been counted individually. However, in large colonies or when individual birds could not be distinguished in slides, they were counted in blocks of 10, 50, or 100 by Sowls et al. (1980) and in blocks of 100 by Briggs et al. (1983). Our slides were generally of larger scale, higher resolution, and greater clarity, so that we were able to count birds individually and achieve a higher degree of accuracy.

GROUND AND BOAT SURVEYS

Colonies on the South Farallon Islands were surveyed by PRBO using ground and boat counts in 1972, 1979–1982, and 1984–1986 (Ainley and Lewis 1974; Ainley and Boekelheide, 1990; PRBO, unpubl. data). Birds on SEFI were counted mainly from several ac-

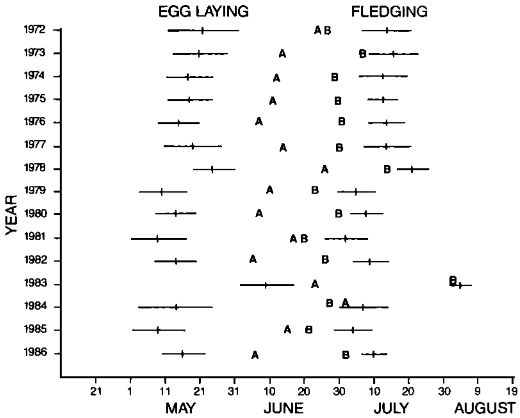

FIGURE 4. Annual variation in mean (±SD) egg-laying and fledging dates of Common Murres in the Upper Shubrick Point plot, SEFI. Symbols A and B refer to last egg laid and first chick fledged, respectively. Data are from Ainley and Boekelheide (1990) and PRBO (unpubl. data).

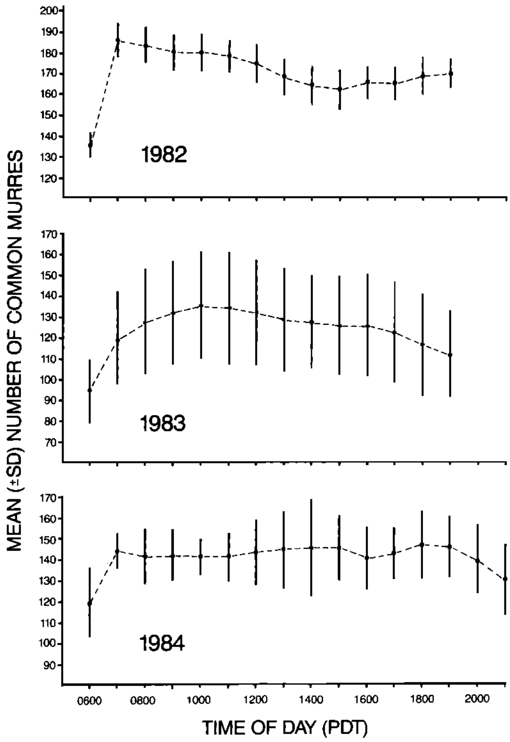

FIGURE 5. Mean (±SD) numbers of Common Murres in the Upper Shubrick Point plot at hourly intervals throughout the day during the census period in 1982, 1983, and 1984. Data are from L. B. Spear (unpubl. data) and PRBO (unpubl. data).

cessible vantage points on the island, whereas those on neighboring islets and West End Island were counted mainly from a small boat. Murres were counted individually in small colonies and in blocks of 10, 50, or 100 in larger or very dense colonies.

PRBO recognized several potential sources of counting error (primarily for boat surveys) including environmental conditions, visibility, and observer experience. Hence, we initiated aerial surveys in 1985 to estimate populations more accurately on West End Island and elsewhere. Murres on SEFI continued to be surveyed mainly by ground counts due to their accessibility and the greater accuracy of these counts.

Census Period

Aerial surveys were conducted between the end of egg laying and the start of fledging as determined at the South Farallon Islands. Murre numbers are high and least variable during this period (Birkhead 1978, Slater 1980, Gaston and Nettleship 1981), although Hatch and Hatch (1989) found a wider window. We based census dates on information from South Farallon Islands, where timing and success of breeding have been monitored in the Upper Shubrick Point plot (Fig. 2) since 1972 (data from Ainley and Boekelheide, 1990; PRBO, unpubl. data). Breeding phenology in northern California appears to be similar to that in central California (Sowls et al. 1980).

There is much annual variation in breeding phenology on South Farallon Islands (Fig. 4). Egg laying was protracted; on average, only 16.2 ± 10.4 days (N = 15 years, R = 0–41 days) occurred between dates when the last egg was laid (excluding replacement eggs) and the first chick fledged. We attempted to conduct aerial surveys of the Farallon Islands near the date when the last egg was expected to be laid. Other colonies were surveyed as soon as possible thereafter. Boat and ground surveys at South Farallon Islands were conducted slightly later, usually in early to mid-June when egg laying was completed, except in 1984 when rough weather and prolonged egg laying (Fig. 4) delayed the census until 1 July.

Time of Census

Surveys were conducted during mid-day when numbers of murres attending colonies are usually high and least variable (Birkhead 1978, Birkhead and Nettleship 1980). Although diurnal patterns of attendance have been found to vary between colonies (Gaston and Nettleship 1981, Piatt and McLagan 1987), it generally has been assumed that year-to-year patterns are similar at specific colonies (see Birkhead and Nettleship 1980).

To determine the time of day when murre numbers were most constant at SEFI, we examined counts made in the Upper Shubrick Point plot from 1982 to 1984 (Fig. 5) between when the last egg was laid (excluding replacements) and the first chick fledged (6–29 June 1982, N = 10 days; 24 June–22 July 1983, N = 25 days). In 1984 we widened this window of time (27 May–10 July, N = 10 days) when the first chick fledged before the last egg was laid. Diurnal attendance patterns varied widely between years (Fig. 5). In 1983 and 1984, greater coefficients of variation (CV) occurred around hourly means, averaging 0.19 ± 0.01 (SD; R = 0.16–0.21; N = 14 means from 06:00–19:00 [PDT]) and

TABLE 1. NUMBERS OF COMMON MURRES IN THE UPPER SHUBRICK POINT PLOT ON SEFI USED TO CALCULATE THE K CORRECTION FACTOR AND BREEDER : NON-BREEDER RATIO (BNR), 1980–1986

Year	Date	No. birds per site in plot[1] TB	TNB	K	BNR
1986	3 Jun	1.03 (119)[2]	1.71 (7)	1.76	19.83
	4 Jun	1.02 (117)	1.50 (6)	1.83	26.00
	5 Jun	1.03 (118)	1.83 (6)	1.77	21.45
	mean	1.03	1.68	1.79	22.43
1985	19 Jun	1.08 (121)	2.50 (8)	1.60	12.10
	21 Jun	1.07 (121)	2.63 (8)	1.61	11.52
	mean	1.08	2.57	1.61	11.81
1984	1 Jul	1.17 (86)	1.52 (33)	1.14	3.44
1981	8–9 Jun	1.14 (155)	—	1.66	31.00
1980	7 Jun	1.17 (150)	—	1.64	42.86

[1] Total breeders (TB) includes failed breeders; total non-breeders per non-breeding site (TNB).
[2] The number of sites are indicated within parentheses.

0.10 ± 0.03 (R = 0.06–0.16), respectively. The CV was lower in 1982, averaging 0.05 ± 0.01 (R = 0.04–0.06). These values were within the range of those found by Lloyd (1975) and Gaston and Nettleship (1981). Only in 1984 did CV vary slightly with time of day.

Diurnal attendance patterns in 1982 and 1983 may have been influenced by the intense 1982–1983 ENSO (Ainley and Boekelheide 1990). We conducted hourly counts of murres in the Upper Shubrick Point plot on 13 and 29 June 1985 and 1 and 17 June 1986. Murre numbers most closely approximated the diurnal pattern of attendance exhibited in 1984 (Fig. 5) and we suspect that in most years, murre numbers are consistent throughout mid-day. Therefore, we conducted aerial surveys of the South Farallon Islands between 10:00–12:00 when murre numbers there should be high and least variable. Other colonies were surveyed between 10:00–14:00 to provide sufficient time to survey several colonies in a day and to minimize effects of any diurnal variation. Previous surveys were also conducted in mid-day (Sowls et al. 1980), although Briggs et al. (1983) used a wider window of time (09:00–17:00).

K CORRECTION FACTOR

Birkhead and Nettleship (1980) and Gaston and Nettleship (1981) used the K correction factor to convert total counts of birds into estimates of breeding pairs as follows:

$$K(t_1) = n_e/n_t(t_1) \quad (1)$$

where: n_e = number of first eggs laid in a plot and $n_t(t_1)$ = total number of birds present in a plot at time t_1. We used a slight variation of K to convert total counts of birds into estimates of total numbers of breeding birds as follows:

$$K(t_1) = n_s(2)/n_t(t_1) \quad (2)$$

where: n_s = number of egg-laying sites for first eggs in the Upper Shubrick Point plot on the census day (multiplied by two breeding birds per site). Since some sites were partially obscured in some years (R. J. Boekelheide, pers. comm.), only those sites fully visible on the census day were used. In 1981 and 1986, the last egg (excluding replacements) was laid a few days after the census date (see Fig. 4). Although these factors slightly biased our calculation of K, overall error probably remained within about 5% (see Gaston et al. 1983).

K varied between 1.14–1.79 during the 5 years examined (Table 1). In 1984, K was very low (1.14) due to larger-than-normal numbers of non-breeding birds and sites and a sharp decrease in the number of breeding sites in the plot. In the remaining years (1980, 1981, 1985, and 1986), K varied little between days and years (R = 1.60–1.83). We averaged these annual K values to derive a mean (±SD) K-value of 1.68 ± 0.08 (N = 4 years) and applied it to all aerial counts by Sowls et al. (1980), Briggs et al. (1983), and this study, except for Farallon Islands counts. Thus, atypical breeding years such as 1983 and 1984 were not used to develop the mean K value and, coincidentally, aerial surveys were not conducted in those years. This mean K value was very close to the value of 1.67 that Sowls et al. (1980) and Briggs et al. (1983) used to adjust their counts (Ainley and Boekelheide 1990). K values specific to each year were used to adjust counts at the South and North Farallon islands, except for 1982 when K was not determined; here the 1981 K value was substituted because these years seemed similar. All breeding population estimates were then rounded to the nearest 10.

South and North Farallon islands aerial survey counts were further refined with a ground truthing correction factor determined each year on SEFI. Breeder : non-breeder ratios and minimal non-breeding population estimates were also determined at the South Farallon Islands (see Appendix).

RESULTS

CENTRAL CALIFORNIA POPULATION TRENDS

The total breeding population in central California declined 52.6%, from 229,080 in 1980–1982 to 108,530 in 1986 (Table 2). Progressive declines were striking when colonies were compared in slides taken from 1979–1980 through 1986 (Figs. 6 and 7). Individual colonies decreased 45.8–100%.

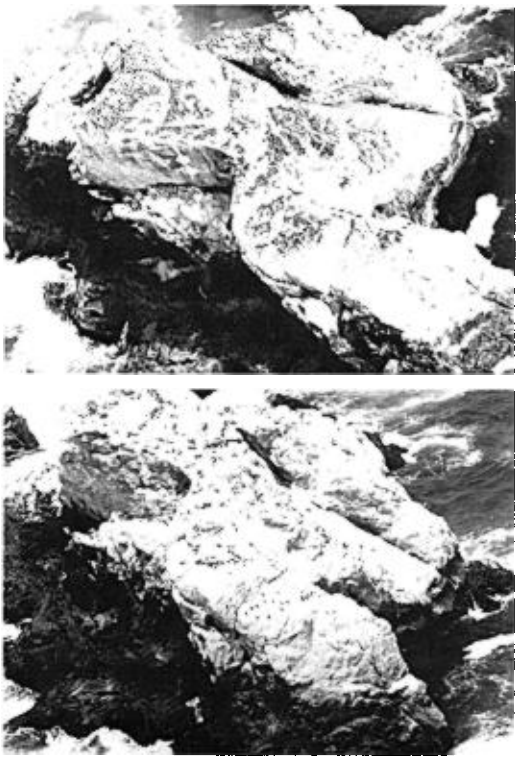

FIGURE 6. Common Murres on the south island at the North Farallon Islands in 1982 (top) and following a 55.4% decline in 1986 (bottom).

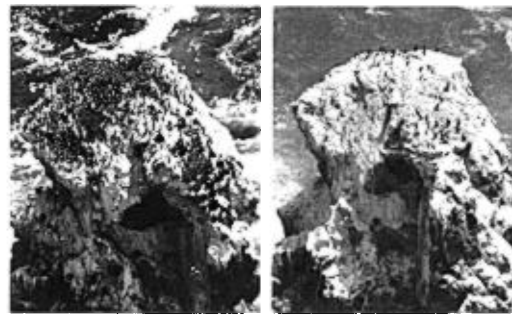

FIGURE 7. Common Murres on Devil's Slide Rock in 1982 (left) and after the colony disappeared in 1986 (right). Fewer than 100 murres were present on 5 June 1986, and none on 4 June.

Farallon Islands

The breeding population peaked at 102,110 birds in 1982 on the South Farallon Islands (Briggs et al. 1983), followed by a 46.8% decline with only 54,370 birds remaining in 1985 (Table 2). Numbers were similar in 1986, with a decline of 45.6% since 1982.

Boat and ground survey results also peaked in 1982 (Fig. 8) and declines of similar magnitudes occurred between 1982 and 1985 (55.4%) and 1982 and 1986 (53.6%) (see Ainley and Boekelheide 1990). However, when results were compared to 1980–1982 aerial survey results for the South Farallon Islands (Briggs et al. 1983), it became clear that combined ground and boat surveys greatly underestimated murre numbers; even so, trends from both methods were similar, indicating that they provided an effective population index.

Plots can sometimes reflect direction of change in colony numbers (e.g., Harris et al. 1983, Mudge 1988). The Upper Shubrick Point plot confirmed trends for the whole colony, but the degree of change may not have been representative because the plot was one of the few areas on the South Farallon Islands where murres bred in 1983 (H. R. Carter, pers. obs.). In 1980 and 1981, similar numbers of egg-laying sites (145 and 146) were recorded, but by 1983 eggs were laid at only about 52% of 84 known-individual sites that had been monitored the previous year (Kaza and Boekelheide 1984; PRBO, unpubl. data). By 1984, there was only 52.7% of the 1981 total. While changes in numbers of egg-laying sites in 1983 reflected depressed breeding activity, many breeding birds were still present. For example, about 90% of known-individuals that bred in the plot in 1982 were observed sometime in 1983 (PRBO, unpubl. data). Thus, population decline began in 1983 but major mortality may not have occurred until after the breeding season.

Numbers at the North Farallon Islands peaked at 51,540 in 1980 but declined 55.6% to 22,900 by 1986 (Fig. 6, Table 2). The total Farallon Island murre population declined 48.9%, from 153,560 in 1980–1982 to 78,470 in 1986.

Nearshore central California

Both Sowls et al. (1980) and Briggs et al. (1983) surveyed colonies at Point Resistance, Double Point, Castle, and Hurricane Point rocks in 1980. We used the higher totals, mainly of Sowls et al. (1980), as the more accurate representation of peak breeding populations because their 12 June survey occurred within the optimum survey period at South Farallon Islands in 1980, whereas Briggs et al. (1983) surveyed later on 1–2 July. In 1986, slides of Castle and Hurricane Point rocks could not be easily separated, so these colony totals were combined. At Double Point Rocks, a small natural arch fell into the ocean sometime between 1982 and 1985 and breeding habitat for less than 5% of the population was lost.

Populations at nearshore colonies in central California declined more severely, and in most cases, began to decline earlier than populations at the South and North Farallon islands. All colonies peaked in 1980 and declined through 1986, except for Point Reyes, which peaked in 1982 (Table 2). Sharpest declines occurred at colonies located between Point Reyes and Devil's Slide Rock. In fact, the Devil's Slide Rock colony had disappeared by 1986, after peaking at almost 3000 birds in 1980 (Fig. 7). Small subcolonies of murres breeding on the mainland at Point Reyes and Castle Rocks also declined and even disappeared at Castle Rocks. The total for all six colonies decreased by 60.1%, from a peak of 75,430 in 1980–1982 to 30,060 in 1986.

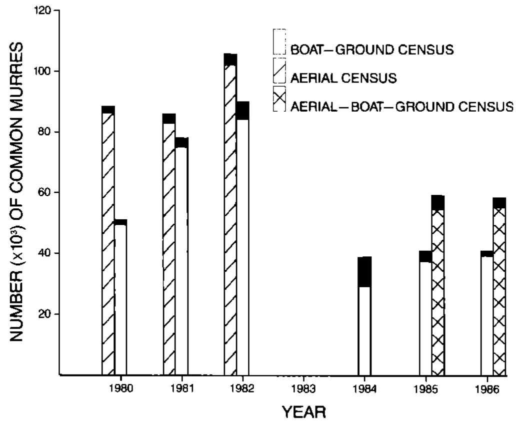

FIGURE 8. Estimates of the total numbers of Common Murres on the South Farallon Islands from 1980–1986 using various methods. Minimal estimates of the numbers of non-breeding birds (NB) are indicated by the darkened portion of each bar.

Northern California Population Trends

Populations in northern California remained relatively unchanged between 1979 and 1986 (Fig. 9, Table 3). Large colonies at False Klamath and Flatiron rocks decreased 9.7% between 1982 to 1986 but increased 13.0% between 1979 and 1986, respectively. We discount trends at large colonies that changed ≤10% because of counting error, single censuses, and differences in survey methods. Thus, these colonies were considered relatively unchanged from 1979 to 1986 and appeared similar in slides (Fig. 9; Sowls et al. 1980). Declines of 40% or more were obvious when we compared slides for different periods (see Figs. 6 and 7).

At Castle Rock, Briggs et al. (1983) estimated 143,220 birds in 1982, compared to our estimate of 100,570 birds in 1986 (Table 3). However, a change was not discernible in slides and may be at least partly due to inaccurate block counting by Briggs et al. (1983). The estimate of 126,750 by Sowls et al. (1980) could not be used for comparison due to their late survey date (mid-July).

Both Sowls et al. (1980) and Briggs et al. (1983) surveyed Green and Redding rocks in 1980, on 9 July and 2 July, respectively, producing widely disparate estimates (Table 3). Sowls et al. (1980) surveyed at the time of peak fledging in 1980 at the South Farallon Islands (Fig. 4) and after the highest ground counts were obtained during periodic counts at Green Rock (DeGange and Sowls 1980). By this late date, large chicks may have

TABLE 2. Estimates of Common Murre Breeding Populations Determined from Aerial Surveys at All Colonies in Central California, 1979–1986

Colony							% change:
No.	Name	1979	1980	1982	1985	1986	peak (1980 or 1982) to 1986 (see text)
1	S. Farallon Is.	—	86,140[b]	102,110[b]	54,370	55,570	−45.6
2	N. Farallon Is.	—	51,540[b]	51,320[b]	29,940	22,900	−55.6
3	Pt. Reyes	16,600[a]	22,550[b]	44,250[b]	15,380[c]	20,590	−53.5
4	Pt. Resistance	—	7360[b]	6890[b]	3790	3030	−59.8
			7540[a]				
5	Double Pt. Rks.	—	14,870[b]	11,930[b]	5680	3280	−77.9
			13,080[a]				
6	Devil's Slide Rk.	2310[a]	2940[b]	2570[b]	—	0	−100.0
7	Castle Rks.	—	1340[b]	1860[b]	—		
			3520[a]				
8	Hurricane Pt. Rks.	—	1920[b]	1710[b]	—	3160[d]	−45.8
			2310[a]				

[a] Source: Sowls et al. (1980).
[b] Source: Briggs et al. (1983).
[c] Minimal number due to incomplete coverage.
[d] Castle Rocks and Hurricane Point Rocks combined (see text).

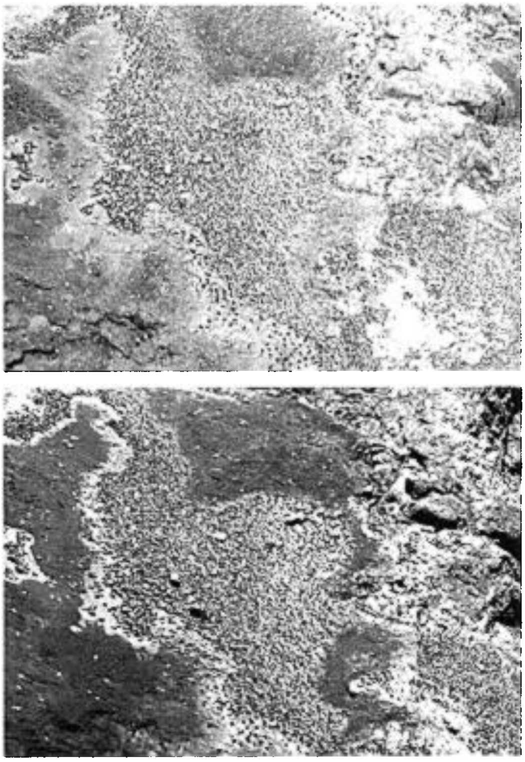

FIGURE 9. Subcolony of Common Murres on Castle Rock in northern California in 1982 (top) and in 1986 (bottom). This colony appeared similar in extent and density, indicating little change.

been indistinguishable from adults in slides, partly accounting for the higher estimate. Differences between 1980 survey results at Redding Rock were not as great, but Sowls et al. (1980) again produced a higher population estimate (19%). For these reasons, we compared our results to 1980 or 1982 data from Briggs et al. (1983) (Table 3).

The combined population for False Klamath, Redding, Flatiron, and Green rocks decreased 5.4% from 118,080 in 1979–1982 to 111,730 in 1986, a difference that could not be assessed by our methods.

DISCUSSION

Implications for Farallon Islands Populations

As reflected for the whole colony (Table 2) in aerial surveys, breeding populations were similar in the Shubrick Point plot in 1985 and 1986. Numbers of egg-laying sites equaled 78.1% and 77.7% of the 1981 total, respectively. This increase over 1984 reflected a change in population structure, which can be best understood by combining non-breeding and breeding sites. Non-breeding sites were not observed in 1980–1982, but in 1984 33 non-breeding sites made up 30% of the total. In 1985 and 1986 non-breeding sites comprised 9.5% (12 sites) and 5.1% (6 sites) of the totals, respectively. Thus, when all sites in 1984, 1985, and 1986 were compared to the 1981 total, proportions were similar (75.3%, 86.3%, and 80.8%, respectively). Thus, the increase in the breeding population from 1984 through 1986 in the plot reflected a decrease in an inflated non-breeding population. However, in 1986 the minimal non-breeding population size (NB) was 2480 birds, or 4.3% of the total breeding and non-breeding population of 58,050 birds (see Appendix). This proportion was still slightly higher than in 1982 (3.1%; N = 3290 birds) suggesting that by 1986 population structure may not have returned to pre-1983 conditions.

Declines probably were buffered by recruitment in 1983–1986 of strong year classes of young birds produced during 1979–1981 (Ainley and Boekelheide 1990). Common Murres in the North Atlantic Ocean breed for the first time when 4 to 6 years old (reviewed by Hudson 1985). However, the stormy fall and winter of 1982–1983 may have led to higher mortality of hatching year

TABLE 3. Estimates of Common Murre Breeding Populations Determined from Aerial Surveys at Five Colonies in Northern California, 1979–1986

Colony						
No.	Name	1979	1980	1982	1986	% change: peak (1979–1982) to 1986 (see text)
9	Castle Rk.	126,750[a]	132,590[b]	143,220[b]	100,570	see text
11	False Klamath Rk.	26,660[a]	37,820[b]	53,430[b]	48,320	−9.6
12	Redding Rk.	—	1730[b] 2110[a]	1180[b]	1310	−24.3
14	Green Rk.	—	28,490[b] 53,330[a]	38,780[b]	34,820	−10.2
15	Flatiron Rk.	24,140[a]	17,810[b]	18,070[b]	27,280	+13.0

[1] Symbols as in Table 4.

(HY) birds from 1982, almost no chicks were raised to nest leaving in 1983, and lowered population size and poor breeding success led to a weak 1984 year class (Ainley and Boekelheide 1990; PRBO, unpubl. data). Thus, recovery will be further delayed due to much lower recruitment.

Causes for Decline of the Central California Murre Population

Between 1979 and 1986, three sources of mortality (excluding usual levels of natural mortality) affected Common Murres in central California: ENSO in 1982–1983, oil spills, and gill-net fishing (Carter 1986). Comparing patterns of colony decline with other studies of these specific mortalities provided a rare opportunity to assess how, when, and why the murre population in central California declined so rapidly and drastically; to what degree different sources of mortality were responsible for the decline; and why decline is expected to continue for at least several years.

El Niño-Southern Oscillation 1982–1983

ENSO first began to affect seabirds at the South Farallon Islands prior to the murre fledging period in June 1982, but did not affect fledging success that year (Ainley and Boekelheide 1990). During the fall and winter of 1982–1983 murres exhibited much lower winter attendance of this colony than usual (Kaza and Boekelheide 1984) and egg laying in 1983 was delayed (Fig. 4) and reduced. It appeared that many birds moved into inshore waters to feed and the few birds that bred in 1983 foraged at great distances from the colony (Kaza and Boekelheide 1984).

Although ENSO occurred in the period when the major population decline occurred at the South Farallon Islands, additional evidence suggests that ENSO mortality was not focused on breeding adults. While the 1982–1983 ENSO event affected seabird reproduction in central and northern California, and Oregon (Hodder and Graybill 1985), large declines were not found at northern California colonies surveyed between 1982 and 1986 (Table 3). However, ENSO may have affected future recovery of the central California population by causing minimal reproduction in 1983 and lower survival to breeding of pre-breeders.

Oil pollution

Two major and several smaller oil spills caused mortality of Common Murres in central California between 1979 and 1986. In November 1984, the *Puerto Rican* oil spill spread across the outer shelf of the Gulf of the Farallones (Herz and Kopec 1985, PRBO 1985) killing an estimated 1500–2000 murres (Dobbin et al. 1986; R. G. Ford and G. W. Page, unpubl. data). In February 1986, the *Apex Houston* oil spill occurred between San Francisco and the Monterey Peninsula, killing 7500 murres or more (Page et al. 1990). Despite significant chronic oiling problems during the 1979–1986 period (see Stenzel et al. 1988), we have no estimate of numbers affected.

The *Puerto Rican* spill occurred before the main arrival of migrant murres that winter in central California but breed farther north; thus, mortality was focused on the resident central California population. Although the *Apex Houston* spill and chronic oiling (Stenzel et al. 1988) affected both central California and other breeding populations, effects on northern California colonies may be limited because murres appear to be year-round residents there (DeGange and Sowls 1981). Little information is available on the age and sex classes of murres affected by these oil spills. In the *Apex Houston* spill, both first-year (FY) and after-first-year (AFY) murres were killed and no evidence of sex-biased mortality was found. Of 164 birds examined, 54.9% were male (H. R. Carter, unpubl. data).

By assuming that 50% of 7500 murres killed by the *Apex Houston* spill and a projected minimum of 500 birds from chronic oiling were from the central California population, and that 50% of these and of murres killed by the *Puerto Rican* spill were breeding adults, we estimate that 3000 breeding adults were killed by oil spills in central California from 1979–1986. This corresponded to 2.5% of the 120,550 murres lost from the central California breeding population from 1980–1982 to 1986.

Gill-net fishing

Gill-net fishing for California halibut (*Paralichthys californicus*) and starry flounder (*Platichthys stellatus*) has occurred in central California since at least the 1930s. In the late 1970s, the number of gill-net fishermen increased by as much as 400–500% in some areas (Atkins and Heneman 1987) and a new white croaker (*Genyonemous lineatus*) fishery began in Monterey Bay, using long monofilament nets. Fishing effort intensified and the halibut fishery gradually shifted from using twine to monofilament nets, all of which resulted in a much higher catch of nontarget species, especially seabirds (CDFG 1981, 1987; Atkins and Heneman 1987).

From 1979 to 1982 fishing effort was concentrated in Monterey Bay. By 1980 it was evident that large numbers of murres and other seabirds were being killed in gill nets (CDFG 1981, Stenzel et al. 1988). In late 1982, CDFG established the Central California Gill and Trammel Net

TABLE 4. NUMBERS OF COMMON MURRES CAUGHT PER GILL NET MONITORED IN CENTRAL CALIFORNIA FROM 1980–1986 DURING THE CALIFORNIA DEPARTMENT OF FISH AND GAME MONITORING PROGRAM (P. W. WILD AND C. W. HAUGEN, UNPUBL. DATA). EACH NET WAS MONITORED FOR ONE SET

Period	N Murres	No. Murres caught per net				
		Monterey Bay[1]	Half Moon Bay	San Francisco	Bodega Bay	Total
Jun–Nov 1980	123	3.4 (36)[2]	—[3]	—	—	3.4 (36)
Dec–Mar 1980–1981	1	1.0 (1)	—	—	—	1.0 (1)
Apr–Nov 1981	365	6.0 (61)	—	—	—	6.0 (61)
Dec–Mar 1981–1982	1	0.1 (11)	—	—	—	0.1 (11)
Apr–Nov 1982	94	2.2 (42)	—	—	—	2.2 (42)
Dec–Mar 1982–1983	—	—	—	—	—	—
Apr–Nov 1983	1156	6.8 (16)	23.1 (31)	2.7 (87)	2.3 (43)	6.5 (177)
Dec–Mar 1983–1984	1	0.0 (9)	0.0 (5)	0.0 (2)	0.1 (10)	<0.1 (26)
Apr–Nov 1984	498	0.1 (148)	1.6 (72)	1.2 (109)	1.6 (149)	1.0 (478)
Dec–Mar 1984–1985	5	0.5 (10)	0.0 (8)	0.0 (6)	—	0.2 (24)
Apr–Nov 1985	962	0.1 (67)	1.3 (83)	3.2 (168)	2.9 (108)	2.3 (426)
Dec–Mar 1985–1986	5	—	0.0 (6)	—	0.1 (41)	0.1 (41)
Apr–Nov 1986	950	0.1 (50)	5.5 (82)	1.5 (252)	1.0 (121)	1.9 (505)
		(N = 715)[4]	(N = 1389)	(N = 1274)	(N = 776)	(N = 4161)

[1] Monterey Bay area includes areas off Santa Cruz, Moss Landing, and Monterey; Half Moon Bay area includes the area between Pigeon Point and Mussel Rock; San Francisco area includes the area between Mussel Rock and Point Reyes; and Bodega Bay area includes the area between Point Reyes and the Russian River.
[2] Number of nets in parentheses.
[3] Dash indicates that no nets were monitored.
[4] Total number of murres observed in gill nets per fishing area.

Program to monitor bycatch (catch of nontarget species). Following a northward shift in fishing effort, this program was extended in 1983 to the Gulf of the Farallones and Bodega Bay areas. Nearshore gill-net fishing was concentrated from Half Moon Bay to Bodega Bay from 1983 to 1986.

Estimates of seabirds killed in gill-net fisheries were: 1) in Monterey Bay, 19,800 birds in 1980 and 1981 combined; and 2) in the Gulf of the Farallones and Bodega Bay areas, 30,000, 7000, 8000, and 5000 birds in 1983, 1984, 1985, and 1986, respectively (CDFG 1981, 1987; see Atkins and Heneman 1987). As 50–97% were Common Murres, over 60,000 murres were netted between 1980 and 1986 (CDFG 1981, 1987). However, mortality was not estimated in Monterey Bay in 1979 or 1982–1987, nor in the Gulf of the Farallones and Bodega Bay prior to 1983 or in 1987, despite known mortality based on beached birds and the gill-net monitoring program (Table 4). An additional 10,000–15,000 murres probably were killed (P. W. Wild, pers. comm.), for a rough total of 70,000–75,000 from 1979–1987.

Gill-net fishing in central California occurred primarily from May to October, with highest fishing effort and seabird mortality occurring from June through September. Murres on South Farallon Islands usually rear nestlings in June, when large numbers of nonbreeders also attend the colony. Feeding murres often aggregate on the outer also frequent nearshore waters to a variable degree (Briggs et al. 1987; Ainley and Boekelheide 1990; Briggs et al. 1988). In July, murres leave the Farallon Islands and many move into nearshore waters. Murres at nearshore colonies in central California appear to remain in nearshore waters through the breeding season and nearer to colonies in June and early July (PRBO, unpubl. data). The loss of 70,000–75,000 murres can be attributed to the consistent spatial and temporal overlap of large numbers of feeding murres and high gill-net fishing effort in nearshore waters in Monterey Bay, the Gulf of the Farallones, and the Bodega Bay area from 1980 to 1986 (Table 4). Similar conditions have led to high mortalities of murres and other alcids in other nearshore gill-net fisheries (e.g., Carter and Sealy 1984, Piatt et al. 1984).

Little data are available regarding age and sex classes of murres killed in nets. In Monterey Bay, both adults and subadults were killed in nets and of 20 adults and 35 subadults examined from May to October 1982, 85.0% and 62.9% were male, respectively (D. A. Croll, unpubl. data). On 21 August 1984, 78% of 37 murres recovered at Point Reyes National Seashore in Marin County were male (R. J. Boekelheide, unpubl. data). The killing of breeding males, which raise chicks at sea, undoubtedly resulted in the death of dependent chicks. This, in association with high chick production by peak populations of murres, probably resulted in higher median numbers of dead HY murres on Monterey Bay beaches in 1980–1982 (see Stenzel et al. 1988).

By assuming that 75% of the 70,000 murres netted in the 1980–1986 survey period (excluding 5000 murres killed in 1979 and 1986 before and after surveys) either were or soon would have been breeding adults, we accounted roughly for 40–45% of the 120,550 murres lost from the central California population from 1980–1982 to 1986 (Table 2). We attribute gill-net mortality to most of this decline.

Colony Declines

There was a strong connection between areas and periods of gill-net fishing mortality and individual colony declines in central California. Colonies at the South and North Farallon islands and Point Reyes were unchanged or continued to increase from 1980 to 1982 (Table 2). However, colonies at Castle and Hurricane Point rocks declined by 47.2% and 26.0%, respectively. Degree of decline was related to proximity to Monterey Bay, where heavy mortality occurred in 1980 and 1981 (Fig. 1, Table 4). Mortality was greatly reduced in Monterey Bay after 1982–1983, and overall decline from 1980 to 1986 for these two colonies was not as severe (45.8%) as at most other colonies in central California.

From 1982 to 1985, declines occurred at Double Point Rocks, Point Resistance, and South and North Farallon islands, of 52.4%, 49.7%, 46.8%, and 41.7%, respectively (Table 2). These declines reflected high gill-net fishing mortality in the Gulf of the Farallones in 1982 through 1984 (CDFG 1987). The largest decline occurred at Double Point Rocks, which was closest to fishing areas off the Golden Gate and southern Marin County. Declines continued from 1985 to 1986 at Double Point Rocks (42.3%), North Farallon Islands (23.5%), and Point Resistance (20.1%), all near San Francisco and Bodega Bay, where fishing mortality persisted. In this period the Devil's Slide Rock colony disappeared. We associate this with high fishing effort within 1–2 km of the colony. Between 6 and 10 August 1983, 918 murres washed ashore a few kilometers north of Devil's Slide Rock (Stenzel et al. 1988). If all were local breeders, 35% or more of this colony could have been killed in a single event.

Less severe overall declines (50–60%) at Point Resistance, Point Reyes, and North Farallon Islands corresponded with intermediate-sized colonies located farther from gill-net fishing areas. A smaller relative decline at South Farallon Islands may reflect wide dispersal of murres into nearshore waters, but the 46,540 birds lost from this colony almost equaled the total lost from all other central California colonies combined.

Solutions for Gill-Net Fishing Mortality

Species of seabirds killed in gill nets from 1980–1987 included: Common, Pacific, and Red-throated loons (*Gavia immer, G. arctica, G. stellata*), Western and Clark's grebes (*Aechmophorus occidentalis, A. clarkii*), Sooty Shearwater (*Puffinus griseus*), Brandt's and Pelagic cormorants (*Phalacrocorax penicillatus, P. pelagicus*), White-winged and Surf Scoters (*Melanitta fusca, M. perspicillata*), Common Murre, Pigeon Guillemot (*Cepphus columba*), and Marbled Murrelet (*Brachyramphus marmoratus*) (CDFG 1981, 1987; Carter and Erickson 1988). Common Murres accounted for about 50–97% of the mortality during 1980–1986.

In 1982, State Senate Bill (SB) 1475 imposed a permanent ban on gill-net fishing in waters 10 fathoms (18.3 m) or shallower in most of Monterey Bay; the ban was extended to 15 fathoms (27.5 m) in 1984 (Fig. 1). Temporary seasonal closures (May–October) were imposed by CDFG during 1982–1984 in a patchwork pattern to exclude areas of highest seabird and marine mammal mortality. Even so, murre bycatch remained relatively high through 1986 (Table 4). In 1986 and 1987, CDFG, with a cooperative group of gill-net and other fishermen, state and federal agencies (including USFWS) and lawmakers, and private research and environmental groups (including PRBO), attempted to develop a long-term solution to the seabird and marine mammal mortality caused by gill-net fishing. Survey data presented in this report showed that the central California murre population could not sustain continued mortality and that continued existence of individual colonies was threatened.

In September 1987, SB 40 was passed, containing much stronger regulations. Gill-net fishing was prohibited year-round in waters north of Point Reyes, in waters 40 fathoms (73 m) or shallower between Point Reyes and Waddell Creek, and within 3 miles of the Farallon Islands and Noonday Rock (just northwest of the Farallon Islands). Area closures were selected to eliminate murre mortality; over 99% of murre mortality observed in nets by CDFG had occurred in waters less than 40 fathoms (73 m) in depth (P. W. Wild, pers. comm.).

These regulations resulted in virtual elimination of the nearshore halibut, shark, and white croaker fisheries north of Monterey Bay, but allowed the offshore rockfish fishery (which caused very low levels of seabird mortality) to continue. In Monterey Bay some gill-net fishing has continued outside 15 fathoms with virtually no seabird mortality (P. W. Wild, pers. comm.). A research advisory committee was formed to investigate and monitor the use of alternative fishing gear.

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APPENDIX

GROUND TRUTHING CORRECTION FACTOR

Aerial counts of murres have been criticized for underestimating actual numbers present, depending on the nature of background habitat, bird activity, and observation distance (but see Gaston and Nettleship 1981). Birkhead and Nettleship (1980) suggested that murres can be counted readily from aerial photographs if the colony is neither indented greatly nor varies greatly in height such that all areas can be seen in photographs.

At all colonies surveyed in California (except parts of SEFI) the vast majority of murres nested in large colonies on gentle slopes and flat areas at the base of slopes or on rounded hilltops. In these habitats, murres were easily photographed and counted. However, to account for birds obscured in tightly-packed groups and those hidden by small rocks and ledges, we determined a ground truthing correction factor (G) on South Farallon Islands, which we applied to aerial survey data from West End and North Farallon islands.

In 1985, we established seven additional plots on SEFI, including one at Tower Point (Fig. 2). Ground counts were conducted at all plots between 11:00–13:00 on 10–15 days between 30 May and 23 June, including the 12 June census day (Table A-1). We compared numbers from the Tower Point and Upper Shubrick Point plots with the mean of 10 counts of the best aerial photographs of these plots. Two versions of G were derived as follows:

$$G_1 = a/g_d \qquad (3)$$

and

$$G_2 = a/g_p \qquad (4)$$

where: a = mean count of birds from aerial photo; g_d = mean count from ground censuses on the census day; and g_p = mean count from ground censuses over the census period. We used G_1 values of 0.764 and 0.917 to adjust numbers of birds counted in aerial photographs, because G_1 minimized possible bias due to daily variation in numbers. G_2 could be used as an alternative when g_d cannot be determined.

The same method was used in 1986 with four plots, but since the aerial survey required two days to complete due to fog, we used either (or both) 4 and 5 June ground counts to derive G_1 values (Table A-1). The Tower Point plot (which was photographed on both days) yielded similar ground counts but quite different means of photo counts, probably a result of differing aerial viewing conditions. Also, in all four plots, mean G_1 values exceeded 1.0 (R = 0.775–1.278) which should have been impossible (disregarding counting error), since all birds were visible from the ground in plots.

TABLE A-1. Numbers of Common Murres Counted in Plots on SEFI, Used to Calculate Ground Truthing Correction Factors (G) in 1985 and 1986

Plot	Date	Ground count			Aerial photo count	G
		Mean ± SD (N)	Min	Max	Mean ± SD (N)	
1985						
Tower Point	30 May–23 Jun	502.1 ± 79.5 (10)	390	635	375.2 (1)	0.747
	12 Jun	491.0 (1)	—	—	375.2 ± 35.4 (10)	0.764
Upper Shubrick Point	30 May–21 Jun	154.7 ± 9.7 (15)	134	163	138.4 (1)	0.895
	12 Jun	151.0 (2)	149	153	138.4 ± 11.8 (10)	0.917
1986						
Tower Point	28 May–24 Jun	214.6 ± 11.3 (10)	190	244	206.7 (2)	0.963
	4 Jun	225.8 ± 8.7 (5)	218	240	175.1 ± 7.7 (10)	0.775
	5 Jun	224.7 ± 6.3 (6)	215	232	238.2 ± 9.1 (10)	1.060
Cove Point	28 May–24 Jun	159.2 ± 9.7 (10)	141	176	176.5 (1)	1.109
	5 Jun	154.8 ± 3.1 (6)	152	160	176.5 ± 18.5 (10)	1.140
Upper Shubrick Point	28 May–17 Jun	136.1 ± 5.0 (12)	128	143	135.9 (1)	0.999
	5 Jun	131.9 ± 1.6 (7)	129	134	135.9 ± 5.0 (10)	1.030
Lower Shubrick Point	4 Jun–5 Jun	23.7 (2)	21	27	30.3 (1)	1.278
	4 Jun	25.3 ± 1.3 (4)	24	27	30.3 ± 3.4 (10)	1.198

However, it was not possible to synchronize individual ground counts with individual aerial photographs, because the plane made several passes over a period of about 0.5–2.0 h. G_2 values also exceeded 1.0 (R = 0.963–1.109) in 1986.

To get an overall G_1 value for each year, we categorized plots based on numbers of birds, and calculated mean G_1 values of 0.841 and 1.067 for 1985 and 1986, respectively (Table A-2). The large difference presumably resulted mainly from the lower altitude aerial photographs in 1986, which made it easier to distinguish individual birds. In fact, the 1986 value was so close to 1.0 that we felt it was appropriate to apply a G_1 value of 1.0, especially given the small amount of inherent error in the method that resulted in values over 1.0.

Breeder : Non-breeder Ratio

On the census day at the Farallon Islands, we also determined the number of non-breeding sites (i.e., consistently occupied sites where eggs were never observed), numbers of birds attending these sites, and the numbers of "other" birds (i.e., not associated with a specific site) in the Upper Shubrick Point plot (Table 1). All of these birds were considered to be non-breeders even though at some sites eggs may have been laid and lost between site checks (see Gaston et al. 1983) and some may have been off-duty mates. To examine relative differences in the numbers of non-breeding birds between years, we calculated a breeder : non-breeder ratio (BNR) as follows:

$$BNR = n_s(2)/n_{nb}(t_1) \quad (5)$$

where: n_s = total number of non-breeding birds in a plot at time t_1 on the census day. This index does not take into account numbers of non-breeding birds that visit the colony but were absent during the census or younger non-breeding birds that are not yet visiting the colony. BNR varied greatly between years (R = 3.44–42.86).

Breeding and Minimal Non-breeding Population Estimates

To estimate numbers of breeding birds (B) at a colony, we used the following formula:

$$B = N_{ap}(K)/G_1 \quad (6)$$

where: N_{ap} = number of birds counted from aerial photos; K = number of breeding birds/bird counted; and G_1 = ground truthing correction factor. In 1985 and 1986, we added the number of birds counted on SEFI and neighboring islets from boat and ground counts (multiplied by K) to that derived using Equation 6 for West End Island to derive an overall breeding popu-

TABLE A-2. Summary of Ground Truthing Correction Factors (G_1) Used in 1985 and 1986

No. birds per plot	1985 No. plots	1985 G_1	1985 Range	1986 No. plots	1986 G_1	1986 Range
1–99	1	0.917	0.905–0.929	1	1.198	1.122–1.263
100–199	—	—	—	2	1.085	1.030–1.140
200–299	—	—	—	2	0.918	0.775–1.060
500–599	1	0.764	—	—	—	—
Mean	2	0.841	0.764–0.929	3	1.067	0.775–1.263

lation estimate for South Farallon Islands. To estimate minimal numbers of non-breeding birds (NB) at South Farallon Islands, we used the following formula:

$$NB = B/BNR + C \qquad (7)$$

where: C = direct count of birds in non-breeding "clubs" from boat and ground counts. These clubs were excluded from boat and ground counts when determining B.