Preliminary Assessment of Annual Calf Production in the Gray Whale, *Eschrichtius robustus*, from Pt Piedras Blancas, California

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ABSTRACT

In 1980 and 1981 a census was made of northward migrating gray whales at Pt Piedras Blancas, California to (1) monitor the migration, with special attention to the presence or absence of females with calves, and (2) attempt an assessment of annual calf production based on calf counts. Whales were counted from shore 10 hours/day, 6 days/week for 12 weeks (10 March–31 May) in 1980 and for 16 weeks (9 February–30 May) in 1981. The northward migration was observed to be bimodal, consisting of two distinct pulses of whales temporally spaced. The first pulse (Phase A, February–March), primarily whales other than females with calves, had a mean date of passage in 1981 of 1 March. Phase B (April–May) consisted primarily of females with calves and had a mean passage date of 26 April in 1981. Totals of 1,268 adult and juvenile whales and 228 calves were observed in 1980; 3,087 adult and juvenile whales and 209 calves were observed in 1981. Aerial survey flights conducted in 1981 to verify the accuracy of shore counts yielded 257 adults and juveniles and 27 calves. Estimated total populations were 15,238 ± 1,261 in 1980, containing 691 ± 69 calves; and 15,640 ± 1,227 in 1981, of which 768 ± 106 were calves. Correcting for whales missed prior to the start of the survey brought estimates to 15,725 for 1980, and 16,140 for 1981. Estimated annual calf production (after approximately three months of calf mortality) was not less than 4.7% in 1980 and 5.2% in 1981.

INTRODUCTION

Current estimates of the total population of the eastern-Pacific stock of the gray whale, *Eschrichtius robustus*, include 15,000 at Unimak Pass, Alaska (Rugh and Braham, 1979); 15,647 near Monterey, California (Reilly, Rice and Wolman, 1983); and 18,300 off the Oregon coast (Herzing and Mate, 1981). Each of these estimates was based upon data obtained from systematic shore counts during the southward migration. Shore counts originated at Point Loma, San Diego, California (Gilmore, 1960; Rice, 1961), and were later begun near Monterey, California in 1967 (Rice and Wolman, 1971; Wolman and Rice, 1979). They continued there uninterrupted through the winter of 1979/1980 (Reilly *et al.*, 1983).

In the calving lagoons of Baja California, Mexico, boat and shore surveys have been conducted (Swartz and Jones, 1980a, 1980b; Rice and Wolman, 1979; Mate and Harvey, 1981; Bryant and Lafferty, 1980) as well as aerial surveys (Hubbs and Hubbs, 1967; Gard, 1974; Rice, Wolman, Withrow and Fleischer, 1981).

The spring northward migration has not been studied as much as either the southward migration or the calving lagoons, and certain aspects of the northward migration have remained obscure, such as the migration path followed by females with calves (also called cow/calf pairs) and the number of these pairs (Rice and Wolman, 1971; Hatler and Darling, 1974; Darling, 1977; Herzing and Mate, in press). If both calves and adults can be counted during the northward migration, annual calf production (after some initial mortality) can be determined.

In the springs of 1980 and 1981, I conducted research during the northward migration along the central California coast. This study was based at Pt Piedras Blancas, San Luis Obispo County, California (35° 40′ N; 121° 17′ W; approximately 160 kilometers south of Monterey and 240 kilometers north of Santa Barbara (Fig. 1).

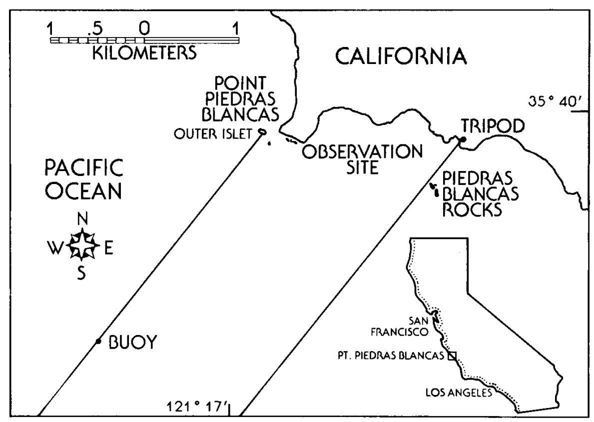

Fig. 1. Shore survey site at Pt Piedras Blancas, California showing observation zone.

One specific objective was to locate the migration corridor of females with calves (Poole, in press). This corridor was postulated to be farther offshore than the path used by the rest of the population (Rice and Wolman, 1971; Scammon, 1874; Townsend, 1887; Jordan, 1887; Starks, 1922). Should the migration corridor of females with calves (cow/calf pairs) be located, an attempt was to be made to assess the rate of annual calf production based on the calf counts.

METHODS

Shore surveys

Methods for shore-based data collection were similar to those described by Rice and Wolman (1971) and Reilly, Rice and Wolman (1980). Whales were counted from

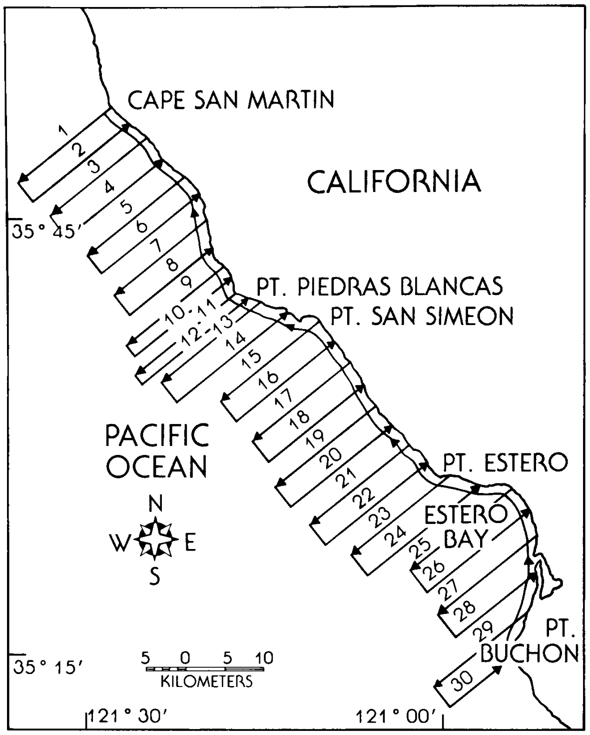

Fig. 2. Aerial survey transects from Cape San Martin to Pt Buchon.

shore 10 hours/day, 6 days/week for 12 weeks in 1980 (10 March–31 May), and for 16 weeks in 1981 (9 February–30 May). Work days consisted of two five-hour shifts (0700–1200, 1200–1700 PST) with two observers per shift. The observers monitored the movements of whales passing a 1.6-km length of coastline (Fig. 1). Boundaries of the study zone were demarcated using natural landmarks, a large tripod, and a Coast Guard buoy. Using 7 × 50 binoculars, a 20 ×–60 × spotting scope, engineer's compasses, and on occasion a rangefinder or surveyor's transit, the number of whales in a pod, relative positions of individuals (if determinable), and distances offshore were recorded. Individuals with distinctive scars and markings were photographed for future identification purposes. Behavior of the whales was also recorded. Wind velocity, sea state, and visibility conditions were noted at least hourly. The visibility code ranged from 1 (excellent) to 6 (terrible) and was similar to that used by Reilly *et al.* (1980; 1983).

Aerial surveys

Aerial survey flights were conducted in support of the shore-based observations from 3–11 March and 21–29 April, 1981. Methods for the aerial surveys were modified from those of Reilly *et al.* (1980; 1983) and Swartz and Jones (1980a). During the March flights a Cessna 172 high-wing aircraft flew at an altitude of 330 m at an average ground speed of 128 kmh^{-1} over a series of 30 transect lines lying perpendicular to the axis of the coastline between Cape San Martin and Pt Buchon (Fig. 2). The interval between transects was 3.2 km, except at Pt Piedras Blancas, where the interval between transects was shortened to 1.6 km for five transects along 6.4 km of coastline. All transect lines extended 16 km out to sea.

During the April flights, the scarcity of whales along the 96 km of coastline, and their proximity to shore, made the method used in March costly and unproductive. A series of transects parallel to the coastline were substituted for the perpendicular transects, except off Pt Piedras Blancas, where the five perpendicular transects 1.6 km apart were conducted in the same manner as in March, extending 16 km out to sea during the first run of the day. Any subsequent runs that same day were flown 8 km out to sea. For the parallel transects between Cape San Martin and Pt Buchon, flights were flown at 400-, 800-, and 1200-meter intervals offshore, following the contour of the coastline. This modified method proved to be cost-effective and productive during the April flights.

Biases

Experiments conducted by Reilly *et al.* (1980; 1983) revealed that several different types of bias affected estimates of the number of whales present in a pod or group at the Monterey station. There was a significant reduction in visibility when the weather was Code 5 (poor) or worse. There was also a consistent bias in estimating the number present in a pod even under ideal visibility conditions. Specifically, estimates of single individuals and of pods containing 4 or more whales were significantly lower than the number actually present. Estimates of pods containing 2 or 3 whales were more accurate. A correction factor was used here as calculated by Reilly *et al.*:

$$f(n_i) = n_i + b_n = \begin{array}{ll} n+0.350 & n=1 \\ n+0 & n=2,3 \\ n+0.333 & n=4 \text{ or more} \end{array} \qquad (1)$$

where $f(n_i)$ is the bias correction factor for n_i, n_i is the number of whales estimated to be in the ith pod, and b_n is the mean bias correction factor. The variance is estimated as

$$\mathrm{var}\,[f(n_i)] = \begin{array}{ll} 0.474 & n=1 \\ 0 & n=2,3 \\ 0.612 & n=4 \text{ or more} \end{array} \qquad (2)$$

The third area of bias investigated by Reilly *et al.* was that due to the offshore distance of the whales. A consistent bias was observed for whales passing beyond 2.4 km offshore. A correction factor $h(k)$ was introduced for the proportion of whales missed;

$$h(k) = C_s/C_p \qquad (3)$$

where C_s = the cumulative proportion of whales within 2.4 km of shore as observed from shore, and C_p = the cumulative proportion of whales within 2.4 km of shore as observed from the plane.

The variance of $h(k)$ was estimated (assuming covariance terms = 0) as

$$\mathrm{var}\,[h(k)] = [-C_p/C_s^2]^2\,\mathrm{var}\,[C_p] + (1/C_p)^2\,\mathrm{var}\,[C_s] \qquad (4)$$

where

$$\mathrm{var}\,[C_p] = (C_p)(1-C_p)/n_p$$
$$n_p = \text{number within 2.4 km as observed from the plane} \qquad (5)$$

and

$$\text{var}[C_s] = (C_s)(1-C_s)/n_s$$
n = number within 2.4 km as observed from shore. (6)

Presently there are no data to test for a change in migration rate at night (Rice and Wolman, 1971; Reilly *et al.*, 1980). Most previous population estimates have assumed a constant 24-hour rate; this paper does likewise. The use of radio telemetry has been demonstrated on gray whales (Mate and Harvey, 1981) and may provide data which will clarify this issue.

Total population estimate

The total population estimates have been produced by first grouping all observations into weekly periods, Monday through Saturday, yielding 12 weeks of data in 1980 and 16 weeks in 1981. All whales observed in Code 5 or 6 visibility conditions were then removed. Only those whales observed in Code-4 conditions or better were utilized for the population estimates. Estimates were then corrected for the pod-size bias for all pods of 1 or of 4 or more individuals and summed as weekly totals. Each weekly total was then divided by the weekly total number of hours with Code 4 or better visibility, to yield an average hourly rate of whales passing Pt Piedras Blancas for that week. This hourly rate was multiplied by 168 to produce a new weekly estimate. The next step was to correct the weekly estimates for whales missed due to their distance offshore, using the correction factor $h(k)$. Due to the nature of the northbound migration, this correction factor was used to correct only those weeks through 21 March, as all whales observed after that time were within 2.4 km of the shore. It should be noted that the formulation of the distance correction assumes that during periods of fair or better visibility (Codes 4 or better) all pods passing within 2.4 km were sighted. The final step in producing a total population estimate was to sum the corrected weekly totals. Notation was modified from Reilly *et al.*, (1980; 1983) as follows:
The weekly estimate after pod size bias correction is

$$\hat{n}_j = [\sum_i f(n_i)/t_j](168) \quad (7)$$

where n_i = the original estimate of the number of whales present in the ith observation, $f(n_i)$ = the bias correction factor for n_i, t_j = the total observational time during the jth week in Code 4 or better visibility conditions, and $\hat{n}_j$ = the number of whales estimated for 168-hour week corrected for pod-size bias in n_i.

The variance for $\hat{n}_j$ was estimated as

$$\text{var}[\hat{n}_j] = (168/t_j)^2(\Sigma\,\text{var}[f(n_i)]). \quad (8)$$

The total population estimate for year k is

$$\hat{N}_k = \sum_j [(\hat{n}_j)_a\, h(k)] + \sum_j (\hat{n}_j)_b \quad (9)$$

where $(\hat{n}_j)_a$ = the corrected weekly estimates through 21 March, $(\hat{n}_j)_b$ = the corrected weekly estimates after 21 March, and $h(k)$ = the distance-bias correction factor.

The variance for $\hat{N}_k$ (assuming covariance terms are 0) was estimated as:

$$\text{Var}[\hat{N}_k] = \text{var}[\sum_j (\hat{n}_j)_a\, h(k)] + \text{var}[\sum_j (\hat{n}_j)_b] \quad (10)$$

where

$$\text{var}[(\hat{n}_j)_a \cdot h(k)] = h(k)^2\,\text{var}[\Sigma(\hat{n}_j)_a] + [\Sigma(\hat{n}_j)_a]^2\,\text{var}[h(k)] \quad (11)$$

and

$$\text{var}[\Sigma n_j] = \Sigma\,\text{var}[n_j]. \quad (12)$$

Estimate of number of calves

The adjusted number of calves (or cow/calf pairs) was estimated using percentages of the weekly totals. For each week in which calves were observed, all calves in Codes 5 or 6 visibility conditions were removed. The remaining number of calves was then divided by the total number of whales observed in that week during Code 4 or better conditions to yield the percentage makeup of calves per total observed. The resulting percentage was then multiplied by the corrected weekly total after adjustment for pod-size bias to yield the corrected number of calves for that particular week. Since all calves were observed within 2.4 km of the shoreline, the offshore-distance correction factor $h(k)$ was not utilized. The final step was to sum the corrected weekly totals to yield an estimate of the total number of calves in the population passing Pt Piedras Blancas. The weekly estimate of the number of calves passing during the jth week is

$$\hat{n}_{cj} = (n_{ci}/n_i)\,\hat{n}_j = (p_i)\,\hat{n}_j \quad (13)$$

where p_i is the proportion n_{ci}/n_i and n_{ci} = the original estimate of the number of calves present in the ith observation in Code 4 or better conditions, n_i = the original estimate of the number of whales present in the ith observation in Code 4 or better conditions, and $\hat{n}_j$ = the number of whales estimated for 168 hour week corrected for pod size bias in n_i.

The variance of $\hat{n}_{cj}$ was estimated (assuming covariance terms = 0) as

$$\text{var}[\hat{n}_{cj}] = (n_{ci}/n_i)^2\,\text{var}[\hat{n}_j] + (\hat{n}_j)^2\,\text{var}[n_{ci}/n_i] \quad (14)$$

where

$$\text{var}[n_{ci}/n_i] = (1/n_i)^2\,\text{var}[n_{ci}] + (n_{ci}/n_i^2)^2\,\text{var}[n_i]. \quad (15)$$

The total estimate of the number of calves passing Pt Piedras Blancas is

$$\hat{N}_{ck} = \Sigma\,\hat{n}_{cj}. \quad (16)$$

The variance for $\hat{N}_{ck}$ was estimated as

$$\text{var}[\hat{N}_{ck}] = \text{var}\,\Sigma[\hat{n}_{cj}] = \Sigma\,\text{var}[\hat{n}_{cj}]. \quad (17)$$

Annual rate of calf production

The annual rate of calf production is defined as the number of new individuals (calves) added to the population per unit time:

$$R_k = \hat{N}_{ck}/(\hat{N}_k - \hat{N}_{ck}\Delta t) \quad (18)$$

where $\hat{N}_{ck}$ = estimated total number of calves passing Pt Piedras Blancas, $\hat{N}_k$ = estimated total population passing Pt Piedras Blancas, and Δt = one year.

The variance for R_k was estimated (assuming covariance terms = 0) as

$$\text{var}[R_k] = (1/\hat{N}_k - \hat{N}_{ck}\Delta t)^2 \cdot \text{var}[\hat{N}_{ck}] + [\hat{N}_{ck}/(\hat{N}_k - \hat{N}_{ck}\Delta t)^2]^2 \cdot \text{var}[\hat{N}_k - \hat{N}_{ck}\Delta t]. \quad (19)$$

RESULTS

Raw counts

A total of 1,496 gray whales was observed during 659 data-collecting hours between 10 March and 31 May 1980; 228 were calves (Table 1). Five hundred seventy-seven (577) hours of observation were in Codes 1–4, during which 1,488 whales were seen passing the shore site; 227 were calves.

Table 1

1980 weekly raw and adjusted counts of (1) all whales except cow/calf pairs ('others'); (2) cows; and (3) calves

	Raw			Adjusted		
Week	Others	Cows	Calves	Others	Cow	Calves
3/10–3/16	390	0	0	1,815	0	0
3/17–3/23	307	0	0	1,505	0	0
3/24–3/30	146	4	4	598	16	16
3/31–4/06	69	2	2	216	6	6
4/07–4/13	38	5	5	119	16	16
4/14–4/20	25	12	12	85	49	49
4/21–4/27	24	71	71	69	204	204
4/28–5/04	23	63	63	69	188	188
5/05–5/11	8	55	55	21	160	160
5/12–5/18	8	15	15	24	47	47
5/19–5/25	2	1	1	12	5	5
5/26–6/01	0	0	0	0	0	0
Totals	1,040	228	228	4,533	691	691

Between 9 February and 30 May 1981, 3,296 northbound whales were seen during 755 hours of observation; 209 were calves. Weather conditions in 1981 were more harsh than in 1980, resulting in 638 hours of Codes 1–4 visibility conditions with 3,159 whales recorded passing Pt Piedras Blancas, of which 194 were calves (Table 2).

Table 2

1981 weekly raw and adjusted counts of (1) all whales except cow/calf pairs ('others'); (2) cows; and (3) calves

	Raw			Adjusted		
Week	Others	Cows	Calves	Others	Cows	Calves
2/09–2/15	218	0	0	942	0	0
2/16–2/22	387	0	0	1,602	0	0
2/23–3/01	704	0	0	3,297	0	0
3/02–3/08	498	0	0	2,922	0	0
3/09–3/15	395	0	0	2,165	0	0
3/16–3/22	385	0	0	1,888	0	0
3/23–3/29	145	0	0	690	0	0
3/30–4/05	84	1	1	332	5	5
4/06–4/12	6	4	4	33	23	23
4/13–4/19	20	21	21	90	81	81
4/20–4/26	13	42	42	52	164	164
4/27–5/03	9	56	56	35	185	185
5/04–5/10	9	64	64	32	211	211
5/11–5/17	4	17	17	18	79	79
5/18–5/24	1	4	4	4	20	20
5/25–5/31	0	0	0	0	0	0
Totals	2,878	209	209	14,602	768	768

Phase A

The migration in both 1980 and 1981 contained two separate and distinct pulses that were temporally spaced and that were comprised of different subsets of the gray-whale population. I have termed these two pulses Phase A and Phase B. The first wave (Phase A) comprised whales other than females with calves. It occurred between 1 February and 1 April in 1981 and represented approximately 89% of the total population. The mean date of passage (1981) was 1 March and the median date was 3 March. Rice and Wolman (1971) found that the northward migration is segregated by age and sex, although they had no data on cow/calf pairs. They found that first to pass were recently impregnated females, then adult males, adult females, immature females, immature males, and lastly some postpartum females that had apparently lost their calves. These animals comprised Phase A.

Phase B

The remainder of the migration (Phase B) occurred between 1 April and 25 May, comprising mainly females with calves, which migrated much closer to shore than the rest of the population (Poole, in press). The first well-supported sighting of a female with calf was on 24 March in 1980 and on 1 April in 1981. Although small whales were observed in the presence of larger whales prior to these dates, they could not be positively identified as calves and were therefore not counted as such. An animal was determined to be a calf by (1) its size (and the disparity in size between it and the accompanying whale); (2) the absence of the numerous barnacles and scars of previous barnacles found on adult whales; and (3) the 'darkness' of its pigmentation.

From 5 April 1981 until the end of the migration, an adjusted count of 1,790 whales passed Pt Piedras Blancas. Of these, 254 (14%) were not cow/calf pairs. They may have been postpartum females that had lost their calves. They were almost always in the presence of a female with calf.

The mean dates of passage for cow/calf pairs were 24 April in 1980 and 26 April in 1981. The median dates were 28 April 1980 and 30 April 1981. These dates are approximately two months later than those of Phase A. Similar temporal segregation has been observed off the Oregon coast (Herzing and Mate, 1981), and occasional observations of females with calves near shore and late in the migration have been previously reported (Morejohn, 1968; Leatherwood, 1974; Baldridge, 1974).

Aerial surveys

During the 3–11 March 1981 flights, 225 northbound whales were observed (Poole, in press). Flights conducted along transects #9–13 yielded 119 whales. During the 21–29 April flights, 59 whales (27 cow/calf pairs, one duo, and 3 'solos') were observed between Cape San Martin and Pt Buchon.

Analysis of the aerial-survey data at Pt Piedras Blancas yielded a value for C_p (the cumulative proportion of whales passing within 2.4 km of the shoreline as observed from the plane) of 0.737 for the March flights, with a variance of 0.0034. The April flights yielded a value for C_p of 1.0, as all whales were observed within 2.4 km.

Distance bias

Analysis of February and March shore data yielded a value for C_s (the cumulative proportion passing within 2.4 km as observed from shore) of 0.942, with a variance of 0.00002. Therefore the resulting value for $h(k)$ is

$$h(k) = C_s/C_p = 0.942/0.737 = 1.28$$
$$\text{var}[h(k)] = 0.0023.$$

The value for C_s in April and May was 1.0, as all whales were within 2.4 km.

Total population estimate

1981. As stated previously, 3,296 whales were observed in 755 hours of observation in 1981, including 209 calves. Removing all sightings in Code 5 or 6 visibility conditions left a total of 3,159 whales in 638 hours of observation, of which 194 were calves. These data were grouped in weekly sets and used in the equations given previously to calculate the adjusted weekly counts and associated variances (Table 2).

Summing these adjusted weekly counts yielded a total population estimate:

$$\hat{N}_k = 15{,}640 \quad \text{var}[\hat{N}_k] = 391{,}648 \quad 95\% \text{ CI} = \pm 1{,}227$$

Therefore, the 95% confidence interval is 15,640 ± 1,227.

This estimate does not contain a correction for those whales missed prior to the start of the survey. The first sighting of northbound whales at Pt Piedras Blancas in 1981 was in the first week of February (J. Bodkin, pers. comm.). I have postulated an additional 500 whales passing prior to the survey, approximating the value of 471 whales derived from the slope of a line extended backwards from 942 whales to 0 whales in a one-week period prior to the survey. The addition of 500 whales resulted in a total population estimate of 16,140 whales passing Pt Piedras Blancas in the spring of 1981. The previous variance is not applicable here.

1980. The 1,496 whales observed during the 659 data-collecting hours were adjusted for visibility conditions, which left 1,488 whales in 577 hours of observation. These data were pooled into weekly sets and then adjusted for the various biases to yield adjusted weekly counts with associated variances (Table 1). Summing these adjusted weekly counts yielded a total of 5,922 whales, with a variance of 28,931 and a 95% CI of ±333. These adjusted data, however, were insufficient to provide a total population estimate for 1980, as much of Phase A had been missed. An alternative method was used.

A comparison of the adjusted counts for both years during the last eight weeks of the survey, Phase B, revealed a ratio (1981/1982) of 0.9743. This value was then used to derive a total population estimate for 1980, by utilizing the total population estimate for 1981 calculated earlier, with the assumption that $\Sigma \hat{n}_{1980B}/\hat{N}_{1980} = \Sigma \hat{n}_{1981B}/\hat{N}_{1981}$. The total population estimate for 1980 was therefore

$$\hat{N}_{1980} = \hat{N}_{1981} \cdot (\Sigma \hat{n}_{1980B}/\Sigma \hat{n}_{1981B}) \quad (20)$$

where $\hat{N}_{1981}$ = adjusted total population estimate for 1981, $\hat{n}_{1980B}$ = the sum of the adjusted counts for Phase B 1980, and $\hat{n}_{1981B}$ = the sum of the adjusted counts for Phase B 1981.

The variance for $\hat{N}_{1980}$ was estimated (assuming covariance terms = 0) as:

$$\text{var}[\hat{N}_{1980}] = (\Sigma \hat{n}_{1980B}/\Sigma \hat{n}_{1981B})^2 \text{var}[\hat{N}_{1981}] + (\hat{N}_{1981})^2 \text{var}[\Sigma \hat{n}_{1980B}/\Sigma \hat{n}_{1981B}] \quad (21)$$

where

$$\text{var}[\Sigma \hat{n}_{1980B}/\Sigma \hat{n}_{1981B}] = (1/\Sigma \hat{n}_{1981B})^2 \text{var}[\Sigma \hat{n}_{1980B}] + (\Sigma \hat{n}_{1980B}/\Sigma \hat{n}^2_{1981B})^2 \text{var}[\Sigma \hat{n}_{1981B}]. \quad (22)$$

The resulting estimate for the total population passing Pt Piedras Blancas in the spring of 1980 was

$$\hat{N}_{1980} = 15{,}640 \quad (\times 0.9743) = 15{,}238$$
$$\text{var}[\hat{N}_{1980}] = 413{,}864 \quad 95\% \text{ CI} = \pm 1{,}261.$$

Therefore, the total population estimate for 1980 with 95% CI was 15,238 ± 1,261 whales. It should be noted that this estimate was produced using the 1981 estimate without correction for whales missed prior to the survey. Using the population estimate of 16,140 for 1981, the resulting estimate for 1980 is 15,725 whales. The value of 0.0257 may be construed to be the net rate of increase for the population between 1980 and 1981.

Estimate of number of calves

1980. A total of 228 calves was observed in 1980. After deleting those observed in Code 5 or 6 visibility conditions, 227 were left with which to produce a total estimate. Using Equation 13 these data were adjusted into weekly estimates with associated variances (Table 1, Fig. 3). These adjusted weekly estimates were then summed to yield the total number of calves:

$$\hat{N}_{c1980} = 691 \quad \text{Var}[\hat{N}_{c1980}] = 1231 \quad 95\% \text{ CI} = \pm 69$$

Therefore, the estimate for the number of calves passing Pt Piedras Blancas in the spring of 1980 is 691 ± 69 calves.

1981. A total of 209 calves were observed in 1981. Deleting those observed in Code 5 or 6 visibility conditions left 194 with which to produce an estimate. Adjusted weekly estimates were calculated with variances (Table 2, Fig. 4). These in turn were summed to produce a total estimate for 1981 of:

$$\hat{N}_{c1981} = 768 \quad \text{var}[\hat{N}_{c1981}] = 2{,}942 \quad 95\% \text{ CI} = 106.$$

Therefore the estimate for the number of calves passing Pt Piedras Blancas in the spring of 1981 is 768 ± 106 calves.

Annual rate of calf production

1980. Using Equation 18, the annual rate of calf production was

$$R_{1980} = 691/(15{,}238 - 691)\,1 = 0.0475$$

= 4.7% estimated rate of annual calf production as observed at Pt Piedras Blancas after three months of mortality

$$\text{var}[R_{1980}] = 0.000009 \quad 95\% \text{ CI} = 0.0059.$$

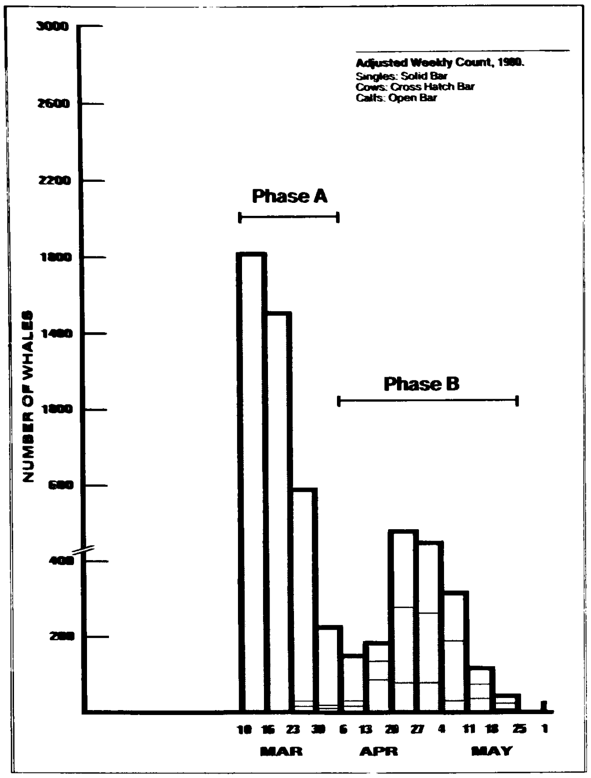

Fig. 3. Adjusted weekly counts, 1980.

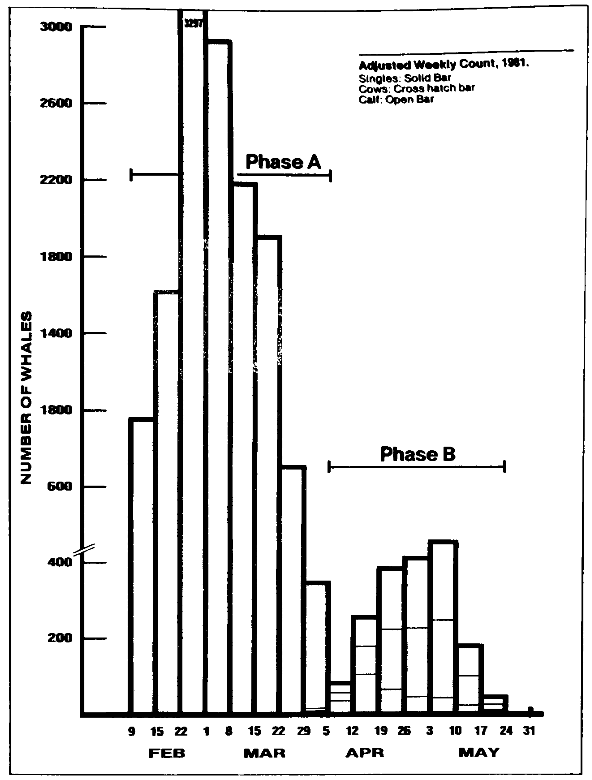

Fig. 4. Adjusted weekly counts, 1981.

Therefore, the rate of production is 4.75% ±0.59%. The range is

$$(691 \pm 69)/[(15{,}238 \pm 1{,}261) - (691 \pm 69)] = 3.9\text{–}5.7\%.$$

1981. The rate of production for 1981 was

$$R_{1981} = 768/(15{,}640\text{–}768)\,1 = 0.516$$

= 5.2% estimated annual rate of calf production as observed at Pt Piedras Blancas after three months of mortality.

$$\text{var}\,[R_{1981}] = 0.000018 \quad 95\%\ \text{CI} = 0.0078.$$

Therefore, the rate of calf production was 5.16% ± 0.78%. The range is

$$(768 \pm 106)/[15{,}640 \pm 1{,}227) - (768 \pm 106)] = 4.1\text{–}6.5\%.$$

It should be noted that in determining the variances for R_{1980} and R_{1981} it was assumed that covariance terms equaled zero. As an unknown but assumedly substantial amount of covariance probably exists, these estimates of variance for R_{1980} and R_{1981} are negatively biased and should be looked upon as minimum estimates.

DISCUSSION

The population estimates presented here are reasonably close to estimates of Reilly *et al.* (1980; 1983), Reilly (1981), Rugh and Braham (1979), and Herzing and Mate (1981). Reilly's 'best estimate' for 1980 is 15,587, obtained from an exponential regression line through 13 estimates from the Monterey shore censuses. My own estimate for 1980 is 15,238 whales; 15,725 if postulated whales missed prior to the survey are included. Reilly also stated that the annual rate of increase of the population was 2.5% (Reilly *et al.*, 1983). My own data suggest an annual increase of 2.6%, in agreement with his figures. My estimates for the number of calves (691 in 1980; 768 in 1981), however, are substantially less than might have been expected.

Rice and Wolman (1971) made an estimate of the maximum theoretical birth rate of the population in the late 1960s of no more than 0.13, based upon an equal sex ratio, an adult population of less than 0.56 of the whole, and an adult-female pregnancy rate of 0.46. Using my 1981 population estimate of 15,640, this would yield 2,033 calves. The actual birth rate may be considerably lower, however, as recent studies in the calving lagoons indicate.

Rice *et al.* (1981) counted 557 calves in Laguna Ojo de Liebre, Baja California, Mexico, which they stated may represent approximately half of the total calves produced. Swartz and Jones (1982) examined boat surveys of Guerro Negro, Laguna Ojo de Liebre, and Laguna San Ignacio taken in 1980–1982. They arrived at an average annual gross calf production for all three lagoons combined of 865 calves, which included 46 dead ones. This represents a mortality rate of 5.3% in the lagoons. Rice *et al.* (1981) determined that these three lagoons produced 73% of all calves born. Therefore, Swartz and

Jones (1983) arrived at a total gross calf production of 1,185 calves for the entire 1982 population, with a mortality of 63 deaths before the migration, leaving a 1982 calf total of 1,122. Using a 1981 population of 15,942 (derived from Reilly *et al.*, 1983) this yields a calf total of 1,097 as the net calf production before the migration, and mortality along the route between the calving areas and Pt Piedras Blancas of

$$1-(768/1{,}097) = 30\%$$
$$1-(874\text{–}662/1{,}097) = 20\%\text{–}40\% \quad [768 \pm 106]$$

Therefore calf mortality along the migration route would be 30%, with a range of 20%–40%.

The low number of calves on the migration can be explained in at least two ways: calves were missed as they passed Pt Piedras Blancas, or they died enroute, perhaps from the stress and rigors of the migration or from attacks by predators, such as killer whales (*Orcinus orca*). In 1980 I examined a dead calf that had been attacked by killer whales. It washed ashore at Pismo Beach, approximately 85 km south of Pt Piedras Blancas. Mortality from other causes has also been documented (Brownell, 1971).

One factor to consider is that the end of Phase A is comprised of primarily smaller juveniles (Poole, in press; Rice and Wolman, 1971) along with some adult whales. As Phase A ended and Phase B began, it is probable that some calves with females were mistaken for imatures in the presence of adults. Small whales in the presence of larger whales were observed just prior to the first sightings of cow/calf pairs. But these smaller whales could not be positively identified as calves. This may not have been a major factor, however. When the first 'definite' cow/calf pairs were sighted, the size disparity between the female and calf, and between the calf and previous 'small' whales, was quite evident and very striking.

Calves can be difficult to spot. Their relatively small size and often close proximity to the female can 'hide' them from view, especially if the calf is on the opposite side of the female from the observers. Due to the nature of the migration corridor at Piedras Blancas, this too was probably not a major factor. Phase B whales most often approached the observation site head on, allowing both sides of a large whale to be observed at times. And 95% (1980) and 92% (1981) of all Phase B whales passed within 200 meters of the shoreline (Poole, in press).

In addition, few lone adult whales were observed in Phase B. Rather, adults without calves were most often observed in the presence of cow/calf pairs, traveling together as a trio. It is possible that a second calf could be overlooked in such a situation. Observations of what appeared to be a single calf with two adults may have been observations of two calves surfacing at different intervals next to the females. Again, this probably was not a major factor, due to the proximity to shore of Phase B whales and the length of time they were under observation.

However, a reasonable upper limit to the number of calves may be estimated by assuming that all adult Phase B whales had calves. In 1981 this would add 254 calves, bringing the total to 1,022, which is only 6.8% less than the total net production of 1,097 suggested by Swartz and Jones (1982) for all calving areas.

It should be noted that the last eight weeks of the northward migration, Phase B, has the 'correct' number of females (within 6.8%); only the number of calves is significantly different. If my own Phase-B figure of 1,022 is used as the net calf production before the migration, then mortality along the migration route to Piedras Blancas was

$$1-(768/1{,}022) = 25\%$$
$$1-(874\text{–}662/1{,}022) = 14\%\text{–}35\% \quad [768 \pm 106]$$

Therefore calf mortality enroute would be 25%, with a range of 14%–35%. These data are supported by other research efforts. Herzing and Mate (in press) estimated that 534 calves were present in a total population of 11,962 whales passing within 4.8 km of Yaquina Head, Oregon in 1980. This represents an annual rate of calf production (Equation 18) of 4.7%, in agreement with my figures. Aerial surveys conducted between Pt Conception, California and the Oregon border during the northward migration (February through May) yielded rates of calf production of 6.0% in 1980, 6.3% in 1982, and 4.2% in 1983 (Tom Dohl, pers. comm.).

This suggests that either equivalent percentages of calves were missed in three very separate and distinct research efforts, or that some validity exists for these lower-than-expected calf counts. An inescapable question arises: Where are the dead calves? One would expect to find a fair number washed ashore. Records of strandings in California south of Pt Piedras Blancas do not support mortality of this level. But where would the highest degree of calf mortality during the migration occur?

Swartz and Jones (1983) suggested two critical periods for gray whale calf mortality: one at and just following birth, and a second period at the *beginning* of the northward migration. This predicts that a large proportion of calves that have died during the initial stage of the migration and washed ashore would be found along the coast of Baja California, Mexico, rather than the coast of California, USA.

Marilyn Dahlheim (pers. comm.) reported that her field assistant, Michael Symons, found numerous remains of gray whales at Miller's Landing during a recent visit to Baja California (19–28 July 1983). Forty-three whales were judged by their state of decomposition to have recently died, during the winter–spring 1982–83 season. Of these 43, 17–18 (40%) were calves. An additional 12 skulls were observed and judged to have been whales from previous seasons, as they were 'considerably eroded away'. This finding indicates that, indeed, some calves do die off the coast of Baja California and wash ashore where they would normally remain undetected.

If my estimates of total abundance of 15,238 ± 1,261 (1980) and 15,640 ± 1,227 (1981) whales and estimates of 691 ± 69 (1980) and 768 ± 106 (1981) calves are reasonably accurate, then calf mortality is greater than has been previously suspected, but the rate of increase for the population as a whole has been maintained at approximately 2.5%. If a proportionally equivalent number of calves was missed in both 1980 and 1981, the rate of increase would not be altered, but calf mortality would be less than suggested here. Clearly, more data are needed.

CONCLUSIONS

(1) The northward migration of the California gray whale along the central California coast occurs in two distinct and separate phases which are temporally spaced and segregated by age and sex.

(2) Phase A, the migration of whales other than females with calves, occurs in February and March, and has a mean date of passage of approximately 1 March.

(3) Phase B, the migration of primarily females with calves, occurs in April and May and has a mean date of passage of 26 April, approximately two months later than Phase A.

(4) An estimated 15,238 ± 1,261 whales (15,725, after correction for whales missed prior to the start of the survey) passed Pt Piedras Blancas during the northward migration in 1980. This population contained an estimated 691 ± 69 calves, and had an annual rate of calf production of not less than 4.7% after approximately three or four months of mortality.

(5) An estimated 15,640 ± 1,227 whales (16,140 after correction for whales missed prior to the survey) passed Pt Piedras Blancas during the northward migration in 1981. This population contained an estimated 768 ± 106 calves, and had a rate of calf production of not less than 5.2% after approximately three or four months of mortality.

(6) The annual rate of increase for the population between 1980 and 1981 was 2.6%.

(7) If 1,022 calves is considered to be the net total calf production before the northward migration, then calf mortality between the calving areas in Baja Calilfornia, Mexico and Pt Piedras Blancas, California in 1981 was 25%, with a range of 14–35%.

(8) Calf counts may be biased downward by at least two factors:

(*a*) Calves may be mistakenly identified as yearlings during the latter part of Phase A and the beginning of Phase B; and

(*b*) Pods containing two cow/calf pairs may be mistakenly identified as 'trios' containing two adults and a single calf.

(9) A reasonable upper limit to the number of calves passing Pt Piedras Blancas may be estimated as 1,022. A reasonable lower limit of calf mortality during the migration would then be 6.8%.

The results of this report are preliminary. However, the basic patterns and numbers of whales remained rather consistent for the two year period. Further data collection could be quite beneficial. It is recommended that an additional three years of research be undertaken to provide a larger data base from which more reliable conclusions can be drawn.

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