Counts of northern elephant seals, *Mirounga angustirostris*, from large-format aerial photographs taken at rookeries in southern California during the breeding season

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Various techniques have been used to count northern elephant seals, *Mirounga angustirostris*, at rookeries in the United States and Mexico. Individuals are customarily counted by observers stationed in observation blinds or on walks atop cliff-tops, along the beach, or among the seals (Le Boeuf, 1974; Stewart, 1989; Stewart et al., 1994; DeMaster et al.[1]). Some rookeries are counted from skiffs nearshore (Stewart et al., 1994). Large-format (228-mm) black-and-white or small-format (35-mm) color-transparency aerial photographs also have been used to count northern elephant seals (Bartholomew and Boolootian, 1960; Carlisle and Aplin, 1966, 1971; Odell, 1971; Antonelis et al., 1981; Stewart, 1989). In addition, counts from aerial photographs have been combined with information on the phenology of haulout behavior to estimate elephant seal abundance when they are not censused at peak haulout periods (Antonelis et al., 1981; Stewart et al., 1994).

In 1985, scientists of the National Marine Fisheries Service began to count northern elephant seals from vertical, color-transparency photographs taken with a large-format camera. A 228-mm-format (cartographic) camera was used in 1985 and 1986, but an improved system was adopted in 1987 which used a 126-mm-format (military reconnaissance) camera adjusted for low altitude photography. This paper describes equipment and procedures used for counting northern elephant seals from photographs taken with these cameras. Counts of northern elephant seals are presented for San Miguel Island (1985–95), San Nicolas Island (1988–95), Santa Rosa Island (1990–95), and Santa Barbara Island (1993–95) off the coast of southern California. The method used to obtain these counts was validated by comparing the precision of counts of northern elephant seals made by biologists on the ground with counts made from large-format aerial color-photographs. The counts of pups that were obtained from photographs taken at each island were then used to estimate the number of births for each year. These birth estimates were then compared with published estimates where other techniques were used in order to evaluate the results obtained by each technique.

Methods

Photography equipment

In 1985 and 1986, vertical photographs of northern elephant seals were taken with a 228-mm-format RC-10 cartographic camera equipped with a 152-mm focal length lens. The resolution of these photographs allowed us to count seals, but the image smear caused by the forward motion of the aircraft reduced image resolution slightly. This problem was solved in 1987 with a 126-mm-format KA-45A or KA-76A (military reconnaissance) camera equipped with a 152-mm focal length lens and image motion compensation (IMC). The IMC and camera firing sequence varied according to ground speed and altitude information to achieve a 66% overlap between adjacent frames (i.e. an object on the ground was photographed three times per pass). In addition, the hyper focal distance of the KA-45A and KA-76A cameras was adjusted to focus at an altitude as low as 129 meters.

The RC-10 camera was mounted in a Cessna 207 aircraft (1985–86) and the KA-45A or KA-76A camera

[1] DeMaster, D. P., R. L. DeLong, B. S. Stewart, P. K. Yochem, and G. A. Antonelis. 1984. A guide to censusing pinnipeds in the Channel Islands National Marine Sanctuary and Channel Islands National Park. Southwest Fisheries Science Center, Natl. Mar. Fish. Serv., NOAA, P.O. Box 271, La Jolla, CA. Admin. Rep. LJ-84-44, 22 p.

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was mounted in a Partenavia P-68 aircraft (1987–95). Both aircraft were flown at an altitude between 244 and 366 meters (typically 259 meters) and at a ground speed of 90 to 110 knots. Kodak Aerochrome MS Film 2448, a very fine-grain, medium-speed, color-reversal film suitable for aerial photography, was used. Photographs also were taken at an altitude of 1,219 meters (at San Miguel Island in 1985) and 1,372 meters (at San Nicolas Island and the western end of Santa Rosa Island in 1989). These high-altitude photographs were used 1) to determine the geographic location of seals shown in low-altitude photographs, 2) to prevent counting the same seals twice that were visible along segments of the coastline in photographs taken during two or more photographic passes (double counting), and 3) to identify segments of coastline that were not photographed during low altitude flights.

Surveys

Two aerial photographic surveys were conducted during the northern elephant seal breeding season (December through February) each year from 1985 to 1995, except 1987 and 1994, when only one survey was conducted. For each year, the first survey occurred when the maximum number of adults was expected to occupy rookery sites (between 18 and 30 January [Stewart, 1989]). These surveys were scheduled for the later part of that period to maximize the number of pups present, but winter storms or scheduling conflicts sometimes resulted in a later starting date (Table 1). The second survey was made late in the breeding-season, between 13 and 22 February, after all pups were born, but before weaned pups had left the beaches (see Odell, 1974; Le Boeuf and Bonnell, 1980; Stewart and Yochem, 1984; Stewart, 1989).

Aerial photographic surveys were conducted off southern California at San Miguel Island (34°02'N, 120°21'W) in 1985–95, San Nicolas Island (33°15'N, 119°30'W) in 1988–95, the western end of Santa Rosa Island (34°00'N, 120°14'W) in 1990–95, and Santa Barbara Island (33°29'N, 119°02'W) in 1993–95. A peak breeding-season survey was not conducted at San Nicolas Island in 1988 nor at Santa Rosa Island in 1990. The southern shorelines of San Miguel Island (≈16 km) and San Nicolas Island (≈18 km) were photographed during all surveys. Portions of the northern shorelines of San Miguel Island (≈12 of ≈20 km) and San Nicolas Island (≈4 of ≈16 km) were included in the surveys in 1988 and 1989, respectively. At the western end of Santa Rosa Island, ≈4 km of coastline were photographed, and at Santa Barbara Island ≈0.75 km of 8 km of coastline were photographed. A mosaic of overlapping photographs taken from multiple photographic passes over the hauling grounds at Point Bennett and Cardwell Point (located on the western and eastern ends, respectively, of San Miguel Island) was made to prevent double counting seals that appeared in more than one photograph.

Counts

We counted six categories of elephant seals: 1) pups that were alive or of unknown status (not decomposed, Fig. 1); 2) decomposed carcasses of pups; 3) juveniles; 4) subadult and adult males; 5) adult females; and 6) seals of unknown age and sex category. Color, shape, and behavior (i.e. their tendency to be away from water) distinguished pups from harbor seals, *Phoca vitulina*. No attempt was made to locate decomposed pups in the late breeding-season photographs that were found earlier in peak breeding-season photographs. Juveniles were yellowish in color and generally were not found in the same vicinity as the harems. Adult females were smaller than adult males, were located within a harem, and either attended a pup or appeared parturient. Subadult and adult males were identified as nonparturient animals with a penile opening or proboscis, or as nonparturient animals stationed along the periphery of harems (see Le Boeuf, 1974; Cox, 1983; and McLaren, 1993). Those that could not be classified were included in the "unknown" category. Adult and subadult males were included in the same category because we could not distinguish between them.

Our count of adult females may have contained males that were three to seven years old that (on the basis of our criteria) were not detected in large harems. We believe that the probability of counting males as females when the photographs were taken is very low. Studies of northern elephant seals at Año Nuevo Island indicate that ≤1% of our count of adult females could include young males. (Le Boeuf[2]).

The color-transparency photographs were illuminated with a light table and inspected with a 7–70× zoom binocular microscope. The seals were counted according to each age and sex class category and their numbers were tabulated on a transparent acetate sheet when ten or more were in the photograph to prevent under- or double-counting them. After counting and marking the acetate sheet, the acetate sheet was then placed on an adjacent photograph at the exact location where the count terminated previously.

[2] Le Boeuf, B. J. 1994. Department of Biology and Institute of Marine Sciences, Univ. California at Santa Cruz, CA 95064. Personal commun.

Table 1

Counts of northern elephant seals, *Mirounga angustirostris*, at San Miguel, San Nicolas, Santa Rosa, and Santa Barbara Islands, California, obtained from 228-mm-format (1985–86) or 126-mm-format (1988–95) aerial color transparency photographs (augmented with visual counts from sites that were not photographed during the survey). Juveniles were not counted in 1985 and 1986. No counts are provided for the peak breeding-season survey at San Miguel Island in 1987 and 1992 owing to partial survey coverage that resulted in an incomplete count.

Survey date	Survey coverage[1]	Pups		Juveniles	Subadults and Adults		
		Alive and unknown	Decomposed carcasses		♀[2]	♂	Unknown sex
San Miguel Island							
Peak breeding season							
31 Jan 1985	Partial[3]	9,102	71		8,748	1,512	0
1 Feb 1986	Near total	9,622	71		8,651	1,607	0
1–2 Feb 1987	Partial						
1 Feb 1988	Near total	10,146	168	3	10,266	1,705	0
28 Jan 1989	Total	10,114	147	20	10,461	1,663	7
3 Feb 1990	Total	12,185	158	6	10,048	1,990	0
1 Feb 1991	Total	12,883	180	7	11,898	2,065	0
2 Feb 1992	Partial						
29 Jan 1993	Total	13,096	257	22	13,145	2,310	0
28 Jan 1995	Total	10,947	258	25	13,282	2,713	0
Late breeding season							
22 Feb 1985	Partial[3]	9,585	80		1,241	1,308	0
21 Feb 1986	Near total	9,555	67		1,338	1,410	0
15 Feb 1988	Near total	10,901	182	0	4,842	1,493	3
16 Feb 1989	Total	11,117	175	3	3,772	1,648	0
19 Feb 1990	Total	12,241	183	1	2,320	1,779	3
18 Feb 1991	Total	13,029	162	1	3,358	2,084	0
17 Feb 1992	Total	13,116	227	6	4,282	2,272	1
15 Feb 1993	Total	13,720	180	5	5,489	2,292	0
13 Feb 1994	Total	14,616	222	3	8,010	2,403	2
15 Feb 1995	Total	13,012	450	3	7,556	2,411	0
San Nicolas Island							
Peak breeding season							
28 Jan 1989	Total	4,124	50	16	4,313	549	3
3 Feb 1990	Total	4,092	55	5	3,439	475	3
2 Feb 1991	Total	4,053	67	2	4,019	502	0
3 Feb 1992	Total	5,482	78	5	4,745	634	1
29 Jan 1993	Total	4,940	63	23	4,878	554	0
28 Jan 1995	Near total	5,218	62	27	6,232	724	0
Late breeding season							
15 Feb 1988	Near total	3,120	34	0	1,732	430	0
16 Feb 1989	Total	4,688	63	0	1,649	537	0
19 Feb 1990	Total	4,079	52	2	976	425	2
18 Feb 1991	Total	4,547	51	3	1,316	469	0
17 Feb 1992	Partial[4]	5,387	63				
15 Feb 1993	Total	5,171	37	8	1,973	602	0
13 Feb 1994	Total	5,727	63	7	2,998	648	3
15 Feb 1995	Total	6,486	89	2	3,590	673	0
Santa Rosa Island							
Peak breeding season							
2 Feb 1991	Total	86	0	0	86	37	0
3 Feb 1992	Total	67	0	0	68	52	0
29 Jan 1993	Total	110	0	0	119	72	0
28 Jan 1995	Total	143	0	2	175	69	0
Late breeding season							
19 Feb 1990	Total	23	0	0	4	14	0
18 Feb 1991	Total	83	0	0	24	45	0
17 Feb 1992	Total	64	0	0	29	40	0
15 Feb 1993	Total	123	0	0	48	57	0
13 Feb 1994	Total	315	0	0	173	141	0
15 Feb 1995	Total	186	0	0	114	81	0
Santa Barbara Island							
Peak breeding season							
29 Jan 1993	Total	53	0	0	109	9	0
28 Jan 1995	Total	28	0	0	113	18	0
Late breeding season							
15 Feb 1993	Total	34	0	0	21	14	0
13 Feb 1994	Total	47	0	0	45	21	0
15 Feb 1995	Total	27	0	0	113	10	0

[1] Survey coverage: Total = all sites were photographed or visually inspected; Near total = sites not photographed or visually inspected were estimated to have trivial numbers of seals relative to the total count; and Partial = sites inhabited by large numbers of seals were not photographed.

[2] The count of adult females may contain an extremely small percentage (estimated to be ≤1%) of males that are of similar size as adult females.

[3] The counts of pups, adult females, and subadult or adult males include counts made from high-altitude photographs for sites not photographed at low altitude.

[4] Counts of pups from the peak breeding-season survey were substituted for sites, or portions of sites, that were not photographed.

Elephant seals were counted in this manner until the entire photographed coastline was examined.

A subjective evaluation was used to determine the degree of survey coverage after the elephant seal count for each island was completed. A "total" rating was assigned when all sites of the rookery were photographed or visually inspected. A "near-total" rating was assigned when small portions of the rookery were not photographed (the number of seals missed was estimated to be equal to or less than 1% of the total counted). A "partial" rating was assigned when >1% of the total counted were assumed not to have been photographed. Total counts of seals for surveys with a partial rating are normally not provided. However, three partial surveys, two at San Miguel Island in 1985 and one at San Nicolas Island in 1992, were augmented with counts from photographs taken from high altitude (1985) or from the previous peak breeding-season survey (1992).

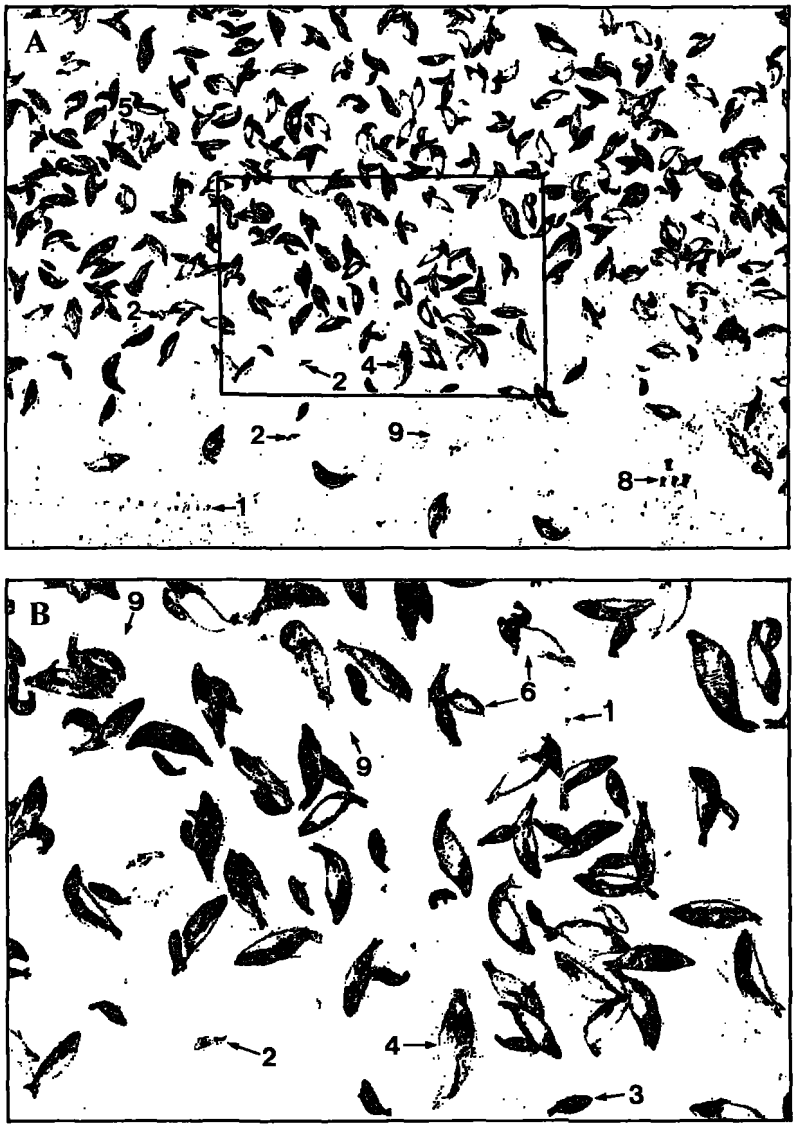

Figure 1

(A) Northern elephant seals, *Mirounga angustirostris*, at Point Bennett, San Miguel Island, California. The photograph was taken with a 126-mm-format camera with IMC from an altitude of 259 meters (850 feet). (B) Enlarged inset from (A). These photographs display the following: 1) gulls (probably western gulls, *Larus occidentalis*) among the elephant seals; 2) decomposed carcasses of pups; 3) pups; 4) adult males; 5) subadult males within the harem; 6) adult females with a pup; 7) adult females that appear parturient; 8) California sea lions, *Zalophus californianus;* and 9) tracks on the sand made by elephant seals.

Precision

Independent counts were made of elephant seals in photographs taken at San Miguel Island, the largest northern elephant seal rookery (Stewart et al., 1994), to examine the precision of the counts obtained from aerial photographs. Three counts were made for each of the two 1988 surveys and four counts were made for each of the two 1989 surveys. Two persons conducted the counts in 1988 and three persons in 1989 (for each year, one person made two counts for each survey, and the other person(s) made one count). The coefficient of variation (CV) of replicate counts was used to compare precision in the counts of all age and sex class categories of seals. Precision was rated excellent, good, acceptable, or unacceptable according to CV's obtained by ground counts at Piedras Blancas (described below). The following ratings, and criteria for defining each rating, are given as follows: 1) excellent when the CV was less than one-half the smallest CV obtained by ground counts; 2) good when the CV was between the smallest CV of ground counts and half that value; 3) acceptable when the CV equaled those obtained by ground counts; and 4) unacceptable when the CV exceeded the largest CV obtained by ground counts.

The counts of elephant seals by people on the ground were compared with counts made from 126-mm-format aerial photographs to ascertain the pre-

cision of each method. Three independent trials were made during two days at the rookery located at Piedras Blancas, California (a 1-1/4 hour interval separated trial 2 and trial 3 on the second day). Three distinct groups of elephant seals were photographed from the air while they were counted on the ground by three persons (each person made two counts of each group). The seals in the photographs were also counted by three persons (each person made two counts of each group). Total counts of all seals were made to eliminate problems associated with classifying a seal to an age and sex class category. The ground count was made from an unobstructed view atop cliffs or sand dunes that were approximately 10–15 meters above the seals.

The Wilcoxon paired-sample test was used to compare CV's obtained from ground counts with photo counts at Piedras Blancas to determine whether the precision of the two methods were equal. The counts were then $\log_{10}$-transformed to meet requirements of homoscedasticity. Analysis of variance (ANOVA) was used to determine whether ground counts and photo counts were equal; the factors tested were method (ground vs. photo), person, group (of seals), trial, and their interactions. An ANOVA was also performed on ground counts and another on photo counts; the factors tested for each test were person, group (of seals), trial, and their interactions.

A comparison of elephant seal counts made at Santa Barbara Island was conducted in 1995 to examine aerial photographic counts, small-vessel and ground counts, and estimates of births for this island. Elephant seals were counted from two aerial photographic surveys (Table 1) and from a small-vessel and ground survey conducted two days after the second aerial survey.

Estimate of births

The number of northern elephant seal births was estimated by summing the counts of pups that were alive or of unknown status and the counts of decomposed pup carcasses. When more than one survey was made each year, the greater count of each category (from either survey) was used. Estimates of births for San Miguel, San Nicolas, and Santa Rosa Islands made by Stewart (1992) were compared with those from this study. Long-term changes in birth rates were examined for San Miguel Island for 1985 through 1991 (data for the other islands were insufficient for this comparison) with log-linear regression analysis (Eberhardt and Simmons, 1992).

Estimates of births at Santa Barbara Island were made from the number of pups counted. The number of adult females counted during the peak breeding-season survey was also compared with the number of pups counted during the three surveys because Stewart (1989) used the count of adult females during peak-breeding season to estimate births for this rookery.

Results

Total or near total survey coverage was achieved for most surveys (90%, Table 1). No counts are available for San Miguel Island in 1987 or for the peak breeding-season survey at San Miguel Island in 1992 owing to missed photographic coverage.

Counts of northern elephant seals at Piedras Blancas, California, from vertical 126-mm-format photographs were more precise than counts made by people at ground-level (Table 2). The CV's of photo counts (between 0.002 and 0.009) and ground counts (between 0.054 and 0.231) were significantly different ($P<0.008$).

The counts obtained from 126-mm-format photographs at Piedras Blancas were significantly different from counts obtained by people on the ground ($P\leq0.001$, Table 3). There was a significant difference between persons for the counts obtained on the ground ($P<0.001$) but not between persons counting the seals from aerial photographs ($P=0.065$). Each method detected a significant difference between the size of the three groups of seals and between the three trials ($P\leq0.002$).

The lowest CV obtained by counting northern elephant seals at Piedras Blancas was 0.054 and the highest CV was 0.231 (Table 2). By our definition, excellent precision would be a CV of <0.027, good precision would be between 0.027 and 0.054, acceptable precision would be between >0.054 and 0.231, and unacceptable precision would be >0.231. Thus, the counts of elephant seals from aerial photographs taken at Piedras Blancas had excellent precision. The replicate counts from the photographic surveys of San Miguel Island in 1988 and 1989 also had excellent precision for counts of pups that were alive or of unknown status, total number of pups, adult females, subadult and adult males, and for total counts of all northern elephant seals (Table 4). The precision for counts of decomposed carcasses of pups was good or acceptable.

Estimates of northern elephant seal births from large-format aerial photographic surveys differed from estimates made from ground surveys at San Miguel and San Nicolas Islands by –8.4% to +11.2% and from small-format aerial photographic surveys at Santa Rosa Island by –14.8% to +17.8% (Table 5). Estimates from aerial photographic surveys were higher than estimates from ground surveys for six of ten comparisons, but the differences were not statistically significant ($P>0.05$). At Santa Barbara Island, the number of pups counted from large-format aerial

Table 2

Ground and aerial photographic counts of three groups of northern elephant seals, *Mirounga angustirostris*, at Piedras Blancas, California. The coefficient of variation (CV) is given for each set of counts. The ground counts and photo counts were made by different persons. Three trials were conducted during a two-day period (trials 2 and 3 occurred on the second day).

		Group 1		Group 2		Group 3	
Trial	Counter	Ground	Photo	Ground	Photo	Ground	Photo
1	A	271	310	712	753	762	852
	A	294	302	726	755	749	856
	B	292	305	645	750	681	857
	B	303	305	686	756	711	858
	C	321	305	812	756	857	862
	C	339	308	844	754	820	857
	CV	0.079	0.009	0.103	0.003	0.086	0.004
2	A	239	297	616	634	878	934
	A	245	297	649	642	818	919
	B	262	297	538	634	741	936
	B	248	294	576	646	776	933
	C	380	299	699	636	963	946
	C	376	296	660	637	879	934
	CV	0.231	0.006	0.094	0.008	0.096	0.009
3	A	303	320	625	665	852	969
	A	299	323	615	668	865	967
	B	300	319	552	661	795	952
	B	313	320	544	665	798	953
	C	338	321	648	667	986	964
	C	332	323	683	668	959	974
	CV	0.054	0.005	0.089	0.004	0.092	0.009

photographs differed from that of the small-vessel and ground survey by –36%, and the number of adult females counted during peak breeding season differed from the number of pups counted 18 days later by small-vessel and ground survey by +157% (Table 5).

Analysis of the trend in pup production over time for San Miguel Island, based on counts obtained from aerial photographic surveys or from ground surveys, showed that 1) a log-linear relationship between count and year (Fig. 2) fits counts from photographs better (R^2=0.979) than counts from the ground (R^2=0.788); 2) the standard errors of the constant and the slope from each regression indicated that the counts from photographs were less variable; 3) each had a significant slope and intercept (P<0.03); and 4) there was no significant difference between the slopes (P=0.66) or the elevations of the regressions (P=0.32).

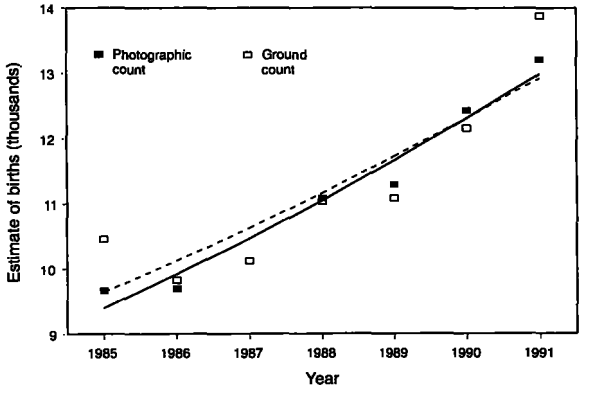

Figure 2

Comparison of northern elephant seal, *Mirounga angustirostris*, birth estimates from 1985 to 1991 for San Miguel Island, California, based on large-format aerial color photographs with estimates based on ground surveys (Stewart, 1992). The solid line represents the regression line for photographic counts (R^2=0.979) and the dashed line represents the regression for ground counts (R^2=0.788).

Discussion

Large-format color transparency photographs were useful for obtaining accurate and precise counts of northern elephant seal pups and adults. The preci-

Table 3

Results of three separate analysis-of-variance (ANOVA) tests with $\log_{10}$-transformed counts of northern elephant seals, *Mirounga angustirostris*, from Piedras Blancas, California. The first ANOVA is for ground and photo counts (emphasis on differences between methods), the second ANOVA is for ground counts, and the third ANOVA is for photo counts (the latter two emphasize differences between persons). Method refers to counts made at ground level and counts made from 126-mm-format aerial color photographs. Only first-order interactions are presented.

Category	Sum of squares	df	Mean square	*F*-value	*P*-value
Ground and photo counts					
Method	0.018	1	0.018	174.929	<0.001
Person	0.037	2	0.019	179.633	<0.001
Group	4.053	2	2.027	19480.595	<0.001
Trial	0.008	2	0.004	38.954	<0.001
Method * person	0.034	2	0.017	161.846	<0.001
Method * group	0.006	2	0.003	30.720	<0.001
Method * trial	0.000	2	0.000	1.388	0.258
Error	0.006	54	0.000		
Ground counts					
Person	0.071	2	0.035	177.694	<0.001
Group	1.890	2	0.945	4731.476	<0.001
Trial	0.004	2	0.002	9.286	0.001
Person * group	0.010	4	0.002	12.270	<0.001
Person * trial	0.004	4	0.001	5.588	0.002
Error	0.005	27	0.000		
Photo counts					
Person	0.000	2	0.000	3.021	0.065
Group	2.169	2	1.085	130915.433	<0.001
Trial	0.005	2	0.002	282.652	<0.001
Person * group	0.000	4	0.000	0.734	0.577
Person * trial	0.000	4	0.000	1.348	0.278
Error	0.000	27	0.000		

sion and accuracy of the counts, respectively, were demonstrated by the small CV's between multiple counts of seals at a large rookery (Table 4) and between counts made from photographs and those by persons on the ground (Fig. 1; Tables 2 and 3).

This study was the first to use a large-format camera with fine-grain, color transparency film and a camera equipped with IMC. Image interpretation is improved because colors that print as the same shade of gray in a black-and-white photograph can be differentiated in a color photograph. Large-format cameras have better resolution than medium-format (70-mm) or small-format (35-mm) cameras (Glegg and Scherz, 1975) that are commonly used for aerial photographic surveys of pinnipeds (e.g. Stewart, 1989; Hanan et al.[3]). The IMC mechanism improves the resolution in photographs taken with a large-format camera (compared with one not equipped with IMC) by eliminating the forward motion of the aircraft when the photograph is taken. The result is that color photographs taken with a large-format camera equipped with IMC record more detail in the photograph and, thus, make it possible to interpret what is on the ground precisely and accurately.

Elephant seal births are used as a relative index to measure population growth and to estimate population size (Laws, 1994; Stewart et al., 1994). It is not possible to determine the absolute number of births for large rookeries because pup mortality prior to the census can only be estimated. Stewart et al. (1994) describes various methods to estimate northern elephant seal births. Where comparisons in estimates are possible with the various methods described by Stewart et al. (1994), large within-year discrepancies exist (Table 5). These differences can be attributed to several factors: 1) the large variance associated with ground counts of pups and with phenological studies; 2) differences between the dates each census was conducted (storms are a known

[3] Hanan, D. A., E. S. Konno, and M. J. Beeson. 1991. Harbor seal, *Phoca vitulina richardsi*, census in California, May–June 1990. Southwest Fisheries Science Center, Natl. Mar. Fish. Serv., NOAA, La Jolla, CA. Admin. Rep. LJ-91-05, 68 p.

Table 4

Replicate independent counts of northern elephant seals, *Mirounga angustirostris*, found in 126-mm-format aerial color photographs taken at San Miguel Island, California, made by three persons. The mean and coefficients of variation (CV) of the counts are also shown.

		Pups				Sub-adults and adults			
Date of survey	Counter	Alive and unknown	Unnown carcasses	Total	Juveniles	♀[1]	♂	Unknown sex	Grand total
1 Feb 1988	A	10,146	168	10,314	4	10,266	1,705	0	22,289
	A	10,207	180	10,387	15	10,173	1,731	0	22,306
	B	10,053	118	10,171	5	10,220	1,684	15	22,112
	Mean	10,135	155	10,291	8	10,220	1,707	5	22,236
	CV	0.008	0.212	0.011	0.760	0.005	0.014	1.732	0.005
15 Feb 1988	A	10,901	182	11,083	0	4,842	1,493	3	17,421
	A	10,851	154	11,005	0	4,832	1,526	1	17,364
	B	10,595	161	10,756	4	4,778	1,527	14	17,093
	Mean	10,782	166	10,948	1	4,817	1,515	6	17,293
	CV	0.015	0.088	0.016	1.732	0.007	0.013	1.167	0.010
28 Jan 1989	A	10,114	147	10,261	20	10,461	1,663	7	22,412
	A	10,183	129	10,312	9	10,461	1,740	2	22,524
	B	10,048	186	10,234	2	10,398	1,719	5	22,363
	C	10,217	181	10,398	23	10,518	1,748	3	22,691
	Mean	10,140	161	10,301	14	10,459	1,717	4	22,497
	CV	0.007	0.170	0.007	0.722	0.005	0.022	0.522	0.006
16 Feb 1989	A	11,117	175	11,292	3	3,772	1,648	0	16,715
	A	11,266	145	11,411	3	3,697	1,685	4	16,800
	B	11,237	171	11,408	2	3,685	1,657	3	16,756
	C	11,142	156	11,298	4	3,692	1,675	0	16,669
	Mean	11,191	162	11,352	3	3,712	1,666	2	16,735
	CV	0.006	0.086	0.006	0.272	0.011	0.010	1.178	0.003

[1] The count of adult females may contain an extremely small percentage (estimated to be ≤1%) of males that are of similar size as adult females.

cause of pup mortality [Le Boeuf and Reiter, 1991; Stewart and Yochem, 1991]); 3) differences in estimates of precensus pup mortality; and 4) the inferior resolution of small-format (35-mm) photographs (Glegg and Scherz, 1975) when they are used in aerial surveys to estimate total number of births. While differences exist between estimates of the number of births, at this time there is no significant difference in the long-term trend between estimates derived from ground counts or from counts made from large-format aerial color photographs.

A problem with ground surveys is that counts of pups are repeated when they differ by 5% to 10% (Stewart, 1989; Stewart et al., 1994). Large-format aerial color photography makes it possible to obtain accurate and precise counts of northern elephant seals without additional survey effort. In addition, the aircraft did not appear to disturb elephant seals and other sympatric species of pinnipeds (no animals abandoned the haulout area).

The topography at San Miguel Island, San Nicolas Island, and the western end of Santa Rosa Island is ideal for conducting vertical aerial photographic censuses of northern elephant seals because the coastlines of these islands lack tall vertical cliffs. High vertical cliffs that are adjacent to beaches obscure elephant seals by their overhangs and by the shadows that they create. The topography at Santa Barbara Island is not ideal for aerial photographic censusing because cliffs that range up to 122 meters in height obscure elephant seals at the haulouts below them. Counts obtained from aerial photographs at Santa Barbara Island may result in an underestimate of the number of pups present (Table 5).

Counts of northern elephant seals obtained from ground and small-vessel surveys require calibration against counts obtained from vertical aerial color photographs taken with a large-format, IMC-equipped camera. These calibrations are needed for each rookery to evaluate the effects of rookery size

Table 5

Estimates for births of northern elephant seals, *Mirounga angustirostris*, at San Miguel, San Nicolas, Santa Rosa, and Santa Barbara Islands, California, obtained from large-format aerial photographic surveys in comparison with ground surveys or small-format aerial photographic surveys from data presented in Stewart (1992).

	Estimate of births			
Year	Large-format aerial photographic survey (LF)	Ground survey (G)[1]	Small-format aerial photographic survey (SF)[1]	Percent difference (PD)[2]
San Miguel Island				
1985	9,665	10,459		−7.6
1986	9,693	9,824		−1.3
1988	11,083	11,035		+0.4
1989	11,292	11,079		+1.9
1990	12,424	12,152		+2.2
1991	13,209	13,884		−4.9
1992	13,343			
1993	13,900			
1994	14,838			
1995	13,462			
San Nicolas Island				
1988	3,154	3,366		−6.3
1989	4,751	4,466		+6.0
1990	4,147	4,101		+0.5
1991	4,614	4,082		+13.0
1992	5,560			
1993	5,234			
1994	5,790			
1995	6,575			
San Rosa Island				
1990	23		27	−14.8
1991	86		73	+17.8
1992	67			
1993	123			
1994	315			
1995	186			
Santa Barbara Island				
1993	53 (109)[3]			
1994	47			
1995	28 (113)[3]	44[4]		−36 (+157)

[1] From Stewart (1992).
[2] $PD = [(LF - G)/G] \times 100$ or $[(LF-SF)/SF] \times 100$.
[3] The number of adult females counted is enclosed within parentheses; Stewart (1989) used the number of adult females to estimate births.
[4] This study.

and topography on the counts obtained by ground and small-vessel surveys.

Northern elephant seal rookeries at San Miguel and San Nicolas Islands cover many miles of coastline. Observers counting northern elephant seals on the ground at these rookeries require an entire day or several days to complete a census at just one island (Stewart et al., 1994). They have the advantage of being able to spend more time to perform the count, repeat it if necessary, or to determine the sex and age class of a seal correctly, but they can cause a great deal of disturbance to elephant seals and pinnipeds sympatric with them (DeMaster et al.[4]) and their counts lack precision and accuracy. Aerial photo-

[4] DeMaster, D. P., R. L. DeLong, B. S. Steward, P. K. Yochem, and G. A. Antonelis. 1984. A guide to censusing pinnipeds in the Channel Islands National Marine Sanctuary and Channel Islands National Park. Southwest Fisheries Science Center, Natl. Mar. Fish. Serv., NOAA, P.O. Box 271, La Jolla, CA. Admin. Rep. LJ-84-44, 22 p.

graphic censuses, on the other hand, provide a nearly instantaneous look at a population that is spread over a wide coastal area with little, if any, disturbance to these pinnipeds and produce counts that are very precise and accurate.

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