AERIAL SURVEYS FOR SEABIRDS: METHODOLOGICAL EXPERIMENTS

KENNETH T. BRIGGS, Center for Marine Studies, University of California, Santa Cruz, CA 95064
W. BRECK TYLER, Center for Marine Studies, University of California, Santa Cruz, CA 95064
DAVID B. LEWIS, Center for Marine Studies, University of California, Santa Cruz, CA 95064

Abstract: Experiments were conducted off California in 1976 and 1983 to assess the importance of altitude, transect width, and glare conditions in aerial surveys of birds at sea. Observers simultaneously recorded sightings within 50-, 100-, and 200-m strip transects at altitudes of 30 and 60 m. Reported densities generally were highest within the narrowest strip, at 60 m altitude, and without glare. Glare adversely affected narrow corridors but not wider ones. Fifty-meter observers reported proportionately more alcids and other inconspicuous birds, and 200-m observers reported fewer small birds and more of the larger, flocking species.

The use of aerial surveys to study distribution of seabirds at sea during the 1970's greatly increased the rapidity and breadth of coverage that could be achieved by a limited number of observers. Open-ocean aerial surveys now have been reported for the Gulf of Alaska (Gould et al. 1982, Harrison 1982), Pacific Northwest (Vermeer 1981, Wahl et al. 1981), California (Briggs et al. 1981*b*, 1983), the Canadian Arctic (Nettleship and Gaston 1978, Bradstreet 1979, Orr et al. 1982), and the North Sea (Blake et al. 1984). Other regions still are under study. Compared with vessel surveys, those from aircraft are somewhat immune to the effects of rough seas and heavy winds, but incur the disadvantage of less precise bird identifications. Because aerial surveys typically employ narrower strip transects than are searched from vessels, aerial sample sizes are lower per distance travelled. This is compensated for, to some extent, by the larger distances covered per day in aerial surveys.

The aerial surveys reported have used strip transects, but have adopted a variety of protocols concerning speed, altitude, transect width, observer configurations, and recording procedures. LeResche and Rausch (1974), Caughley (1974), and Caughley et al. (1976) investigated several of these factors affecting density estimates of terrestrial mammals, but no work has appeared concerning these variables in the context of bird surveys at sea.

In this paper we present results pertaining to altitude, transect width, and glare as they affect estimates of bird density and species composition. We hope to stimulate further study and to facilitate both comparisons between already completed studies and planning of future efforts.

METHODS

We carried out experiments off California under good or excellent observation conditions (visibility >20 km, wind <5 m/sec, wave height <1 m), from 1000 to 1500 hours local time. Observers with recent survey experience (100–1,400 hours/observer) continuously scanned strip transects, recording sightings orally on cassette tapes. Observers were assigned specific corridors among the overlapping set: 0–50 m, 0–100 m, 0–200 m. The innermost edge of the corridor was defined by the line from the observer's eye along the bottom edge of the window (Fig. 1). Outer boundaries (which determined width) were estimated by inclinometer readings, and observers scanned as far forward as the leading edge of the window (45° relative to head position); the area directly beneath the airplane was not scanned. Altitude was measured by radar altimeter, and speeds were 165
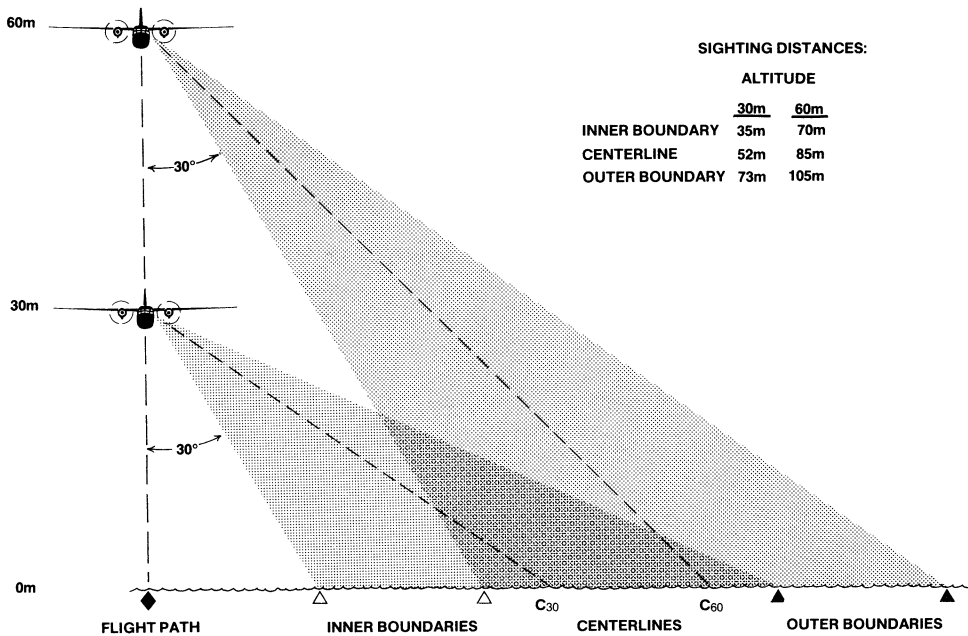
412

Fig. 1. Geometry of sighting distances in the center of the 50-m corridor at flight levels of 30 and 60 m. The innermost corridor boundary was dictated by the line from the observer's eye along the lower margin of the window, and the outer boundary was determined using trigonometric functions and a hand-held inclinometer. Both sighting distance and time available for detection of seabird targets increase with altitude.

km/hour in 1976 and 185 km/hour in 1983. Locations along transects were fixed with radio navigation aids or with a GNS-500 navigation computer.

In February 1976, a single observer counted birds within a 50-m corridor along each of three parallel transects (2.7-km separation) centered 20 km west of San Clemente Island (33°N, 118°W); lines and direction of travel were selected randomly, and total counting time was 2.5 hours. These counts were made from 60 m altitude in a Cessna 337 Skymaster, a small, high-wing, twin-engine aircraft. On eastbound passes, glare obscured 25–45% of the viewing field.

In June 1983, four observers situated on the same side of a larger Hunting-Pembroke aircraft simultaneously counted birds in 50-, 100-, and 200-m corridors along transects located in Monterey Bay (36.5°N) and the Gulf of the Farallons (38°N). Observers were visually and acoustically isolated from each other and rotated corridor assignments each 2.5 hours to minimize the influence of observer bias. Two observers simultaneously recorded birds in the 200-m corridor; their observations were pooled

after *t* tests (paired comparisons) confirmed that differences were not statistically significant. Due to high clouds, glare was insignificant on 7 June, but on 16 June glare obscured 25–60% of the viewing field on all eastbound counts. We report densities calculated for transect segments of 10′ longitude length (15 km).

Because counts were made serially, it is possible that birds gradually left the survey area to avoid disturbance; the counts, therefore, would not be statistically independent. We believe this not to be the case. Serial counts made in 1976 showed no consistent trend, either between temporally adjacent counts or over the course of the day. In 1983 densities declined an average of 29% through the morning and increased an average of 42% from early to late afternoon. These data are inconsistent with a possible disturbance effect and suggest instead a diel foraging pattern: in both the June (nesting season) 1983 studies and a previous 3-year study throughout central California (Briggs et al. 1983; unpubl. data), bird densities generally appeared to be lowest at midday. The 1976 counts were made during midwinter and farther from island or mainland roosts having large numbers

of birds (>2,000). This may account for lack of an observable diel pattern in numbers at sea. It might be argued that the afternoon increases observed in 1983 were less than would have been observed had not previous airplane activity taken place. We are unable to address this notion directly, but believe that the variance associated with aspects of survey protocols considered below is of greater importance.

In discussions of "inconspicuous" birds, we refer to the small-bodied storm-petrels (*Oceanodroma*), phalaropes (*Phalaropus*), and auklets (*Ptychoramphus* and possibly *Cerorhinca* or *Brachyramphus*) in sightings comprising less than 20 birds, while "conspicuous" birds include all other species, together with large flocks of the above species. No species was seen on more than 85% of all transects during a morning or afternoon; the listed small bird genera were present on an average of 43%. To maximize numbers of comparisons, we lumped all sightings into the two designated size categories, recognizing that additional factors, including plumage characteristics and behavior, also determine conspicuousness.

The impracticality of testing for normality among densities from small replicate sets (7–20 samples in the present study) led us to employ nonparametric statistics. Most samples were paired by time and evaluated by Wilcoxon signed-rank tests or Friedman's randomized block design (Sokal and Rohlf 1981).

RESULTS

Effects of Altitude and Width on Density

Bird density was low in the Farallons Basin on the morning of 7 June (Table 1). At both survey altitudes, densities of both large and small birds calculated for 50-m corridors were greater than those calculated for wider corridors (Friedman's method; observations paired by time; one-tailed $\chi^2_2 = 8.22$–13.85, all $P < 0.025$). Altitude had little effect on reported large bird density, with 30-m samples slightly exceeding those from 60 m, but had a significant effect on reported densities of small birds (Wilcoxon two-sample test; $U_{[12,12]} = 107, 109, 107$ for 50-, 100-, 200-m corridors, respectively; all $P < 0.025$).

During the afternoon of 7 June, large bird density in Monterey Bay was higher than near the Farallons, reflecting the presence of numerous flocks of *Larus* gulls, murres (*Uria*

Table 1. Densities (birds/km²) of birds recorded at two altitudes and using three corridor widths in the Farallons Basin on 7 June 1983.

Altitude (m)	Corridor width (m)		
	50	100	200
Large birds			
60	4.06 ± 5.28 (11)[a]	1.41 ± 1.94 (10)	1.31 ± 1.35 (22)
30	4.09 ± 2.67 (10)	1.99 ± 1.33 (9)	1.33 ± 1.39 (19)
Small birds			
60	5.03 ± 5.64 (11)	2.35 ± 2.89 (10)	1.16 ± 1.40 (22)
30	2.40 ± 2.78 (10)	0.73 ± 0.99 (9)	0.50 ± 0.98 (20)

[a] *N.*

aalge), and shearwaters (*Puffinus griseus* and *P. creatopus*). Small bird density was low, although flocks of up to 50 phalaropes (which we consider with the conspicuous, large bird sightings) also were present. The results of the Monterey Bay counts confirmed the importance of corridor width: at both altitudes 50-m corridor densities of both large and small birds exceeded 200-m corridor densities by more than 50%. Densities obtained at different altitudes were not significantly different.

To ascertain the relative efficiency of observers scanning different parts of the overall 200-m strip, we recorded the lateral location for each large bird sighting on 16 June. The observer of only the innermost strip (the "50-m observer") reported higher densities in the first 50 m than did observers who also covered the outer two strips (Table 2; Friedman's method, time-paired samples; $\chi^2_2 = 9.19$, $P < 0.025$). Similarly, within the 51–100-m strip, the "100-m observer" reported higher densities than the "200-m observers" (Wilcoxon signed-rank test, paired samples; $T_8 = 3$, $P < 0.02$). The outermost 100 m contributed less to total 200-m densities than did the inner 100 m. This indicates that observers of broad corridors are relatively inefficient at reporting birds near the airplane, and that overall efficiency decreases with addition of each successively broader strip.

Densities reported from one altitude were about as variable as those reported at the other altitude. However, the relationship between densities simultaneously recorded in the various corridors was more variable. Correlation coefficients for glare-free observations of large birds

Table 2. Mean densities of large birds (birds/km²) reported in three corridors under glare-free conditions. On 16 June 1983, nine counts were made at 60 m altitude, Monterey Bay, California.

Observer	Corridor		
	First 50 m	Next 50 m	Outer 100 m
50-m observer	25.12 ± 21.80		
100-m observer	21.91 ± 23.02	16.78 ± 14.67	
200-m observers (two, pooled)	14.36 ± 19.16	12.45 ± 12.99	10.86 ± 9.24

in 50- and 200-m corridors ranged from $r = 0.39$ to 0.70 ($P < 0.5$ to $P < 0.01$) for the four morning or afternoon data sets. Greatest disparities existed for two data sets where large flocks appeared at various distances from the airplane.

Glare Effects

In 1976 we tested the effect of glare on 50-m corridor densities. Density on eight glare-free transects (16.94 birds/km² ± 14.54 SD) was greater than that seen on six glare-affected transects (4.66 birds/km² ± 3.88; Wilcoxon two-sample test; small birds $U_{[8,6]} = 40$, $P = 0.025$; large birds $U = 42$, $P = 0.01$). On 16 June 1983 we separately considered glare effects in each corridor with samples made at 60 m altitude. Matching samples by time, we corroborated the significant 1976 result for the 50-m corridor; mean densities on eight glare-affected passes were 31 and 78% lower than on glare-free lines for large birds and small birds, respectively. Glare-free densities were higher in every case, regardless of order of sampling. In the outermost 100 m, mean glare-free densities were higher by 18 and 46% for large and small birds, but here the differences were not statistically significant.

Effects of Corridor Width on Bird Identifications

The results reported for corridor width strongly suggest that observers using broad corridors will report relatively low densities of both large and small birds. How comparable, then, are bird identifications in the different corridors? During the Monterey Bay counts, there was a clear tendency by observers of broad corridors to report proportionately more shearwaters, but fewer murres, phalaropes, storm-petrels, and small alcids than did the 50-m and 100-m observers (Table 3). Further, within the corridor nearest the airplane (an area scanned

by each observer), the 50-m observer saw a broader mixture of species than did the observers responsible for wider corridors. The disparity between 200-m observers was a function of a consistent tendency of one individual to notice more murres close to the airplane and fewer groups of shearwaters swimming at 100–200 m. Savard (1982) has reported similar compositional differences between observers simultaneously making waterfowl counts in (approximately) 200-m corridors along the British Columbia coast.

DISCUSSION

Our findings demonstrate some of the effects of survey altitude, glare, and corridor width on reported bird density and composition. Our results concerning the disruptive effects of glare contradict the statement by Harrison (1982:245), who made surveys of seabirds in Alaska. Citing the findings of LeResche and Rausch (1974), Harrison apparently considered occasional glare and water turbulence to be unimportant. Neither paper presents data relating to the survey conditions reported here, so we are unable at present to reconcile this discrepancy.

The altitude and corridor width chosen for survey flights appears importantly to affect counts of all species. Doubling of survey altitude from 30 to 60 m leads to an increase in

Table 3. Comparison of taxonomic compositions (percent) reported by observers simultaneously counting in three corridors under glare-free conditions. Nine counts were made in Monterey Bay on 16 June 1983.

Corridor width (m)	Composition percent						
	Murre	Shear-water	Gull	Phal-arope	Pe-trel	Small alcid	Other
50	56.3	21.6	5.0	7.7	1.0	1.4	7.1
100	52.9	18.8	5.3	6.3	0.9	2.0	13.8
200 (a)	45.8	42.3	6.9	2.9	0	0	2.1
200 (b)	29.5	59.7	8.3	0.2	0.1	0	2.1

average distance to a swimming bird (i.e., one in the middle of the search corridor) of 63% for a 50-m-wide transect (Fig. 1) and 23% for a 200-m transect. Simultaneously, under the conditions of our experiment (speed of 185 km/ hour, 0.5-m window diameter, and approximately 90° viewing arc along the transect), the same altitude change increases the period during which a swimming bird remains visible in the center of a 50-m transect proportionately from 2.0 to 3.3 seconds, while in the 200-m corridor potential viewing time increases from 4.8 to 5.8 seconds. We expected these two factors—viewing distance and viewing time—to influence observed density in balanced opposition. However, for small birds within the 50-m corridor, our 7 June data indicate that viewing time at 30-m altitude was too short, whereas at the 60-m flight level, viewing time increased to acceptable levels, and we remained within an efficient sighting range. Our impression from many earlier surveys is that small bird sighting efficiency deteriorates appreciably below 45 m and above 75 m altitude, and large birds may be counted efficiently from at least 100 m.

We reported higher bird densities from narrow corridors than from broad ones. Estes and Gilbert (1978) found much the same situation with counts of walrus (*Odobenus rosmarus*); animal detection in water declined significantly beyond 0.23 km, whereas for more visible animals on ice the detection function was flat to at least 0.93 km. Similarly, we and others (Dixon 1977, Briggs et al. 1981*a*, Rees 1985) have found that under most conditions, alcids and other inconspicuous seabirds are not reliably censused from a ship beyond 150–175 m; for more visible species 300 m, 400 m, or more may not be excessive. These findings suggest that aerial observers attempting to estimate densities for a mixed fauna in corridors of 100 or 200 m probably seriously underestimate the proportion of inconspicuous birds. Several means could be employed to alleviate this problem. First, as we have done off California, investigators might employ a narrow corridor, wherein even the least detectable of species are counted reliably. This procedure involves the fewest assumptions and requires few observers, but is sensitive to glare conditions. Reported densities of birds of all sizes are higher than those that might be reported using unmodified data from broad corridors; as is the case with all altitude/width combinations, coefficients of variation from replicated counts are high. Second, multiple observers and multiple search corridors might be employed, appropriate to the ranges of detection of the various species groups. Or, third, one could experimentally determine an appropriate detection coefficient for each species under each set of observation conditions, then use a corridor of any reasonable breadth (Wiens et al. 1978). These procedures require multiple observers or determination of detectability curves (Wiens et al. 1978), but they increase the number of sightings for all species, which may facilitate statistical analyses (especially for infrequently detected species).

We did not specifically address questions of flight speed but have found the effects to vary in the manner of changes in altitude. At 30–60 m altitude, flight speeds exceeding 200 km/hour lead to difficulty in bird detection and counting. The same speed is not excessive at altitudes of 75–90 m, because (large) birds can be seen for longer periods in the linearly extended viewing field. In the absence of quantitative tests, we recommend initial use of the slowest attainable survey speed and gradual increases in speed until observers report subjective difficulties with detection.

LITERATURE CITED

BLAKE, B. F., M. L. TASKER, P. HOPE-JONES, T. J. DIXON, R. MITCHELL, AND D. R. LANGSLOW. 1984. Seabird distribution in the North Sea. Nature Conservancy Council, Huntingdon, U.K. 429pp.

BRADSTREET, M. S. W. 1979. Thick-billed murres and black guillemots in the Barrow Strait area, N.W.T., during spring: distribution and habitat use. Can. J. Zool. 57:1789–1802.

BRIGGS, K. T., E. W. CHU, D. B. LEWIS, W. B. TYLER, R. L. PITMAN, AND G. L. HUNT, JR. 1981*a*. Distribution, numbers, and seasonal status of seabirds of the southern California Bight. Pages 1–212 *in* Summary report 1975–1978: marine mammal and seabird surveys of the southern California Bight area. Vol. III. U.S. Natl. Tech. Inf. Serv. Publ. PB-81-248-197, Springfield, Va.

———, D. B. LEWIS, W. B. TYLER, AND G. L. HUNT, JR. 1981*b*. Brown pelicans in southern California: habitat use and environmental fluctuations. Condor 83:1–15.

———, W. B. TYLER, D. B. LEWIS, AND K. F. DETTMAN. 1983. Seabirds of central and northern California, 1980–1983: status, abundance, and distribution. Final Proj. Rep., Pacific OCS Reg., U.S. Minerals Manage. Serv., Los Angeles, Calif. 246pp.

CAUGHLEY, G. 1974. Bias in aerial survey. J. Wildl. Manage. 38:921–933.

———, R. SINCLAIR, AND D. SCOTT-KEMMIS. 1976.

Experiments in aerial survey. J. Wildl. Manage. 40:290–300.

DIXON, T. J. 1977. The distance at which sitting birds can be seen at sea. Ibis 119:372–375.

ESTES, J. A., AND J. R. GILBERT. 1978. Evaluation of an aerial survey of Pacific walruses (*Odobenus rosmarus divergens*). J. Fish. Res. Board Can. 35:1130–1140.

GOULD, P. J., D. J. FORSELL, AND C. J. LENSINK. 1982. Pelagic distribution and abundance of seabirds in the Gulf of Alaska and eastern Bering Sea. U.S. Fish Wildl. Serv. Publ. FWS/OBS-82/48, Anchorage, Alaska. 294pp.

HARRISON, C. S. 1982. Spring distribution of marine birds in the Gulf of Alaska. Condor 84:245–254.

LERESCHE, R. E., AND R. A. RAUSCH. 1974. Accuracy and precision of aerial moose censusing. J. Wildl. Manage. 38:175–182.

NETTLESHIP, D. N., AND A. J. GASTON. 1978. Patterns of pelagic distribution of seabirds in western Lancaster Sound and Barrow Strait, Northwest Territories, in August and September, 1976. Can. Wildl. Serv. Occas. Pap. 39. 40pp.

ORR, C. D., R. M. P. WARD, N. A. WILLIAMS, AND R. G. B. BROWN. 1982. Migration patterns of red and northern phalaropes in southwest Davis Strait and in the northern Labrador Sea. Wilson Bull. 94:303–312.

REES, E. I. S. 1985. Estimation of population densities of auks at sea. Seabird. In Press.

SAVARD, J-P. L. 1982. Variability of waterfowl aerial surveys: observer and air-ground comparisons—a preliminary report. Can. Wildl. Serv. Prog. Notes 127:1–6.

SOKAL, R. R., AND F. J. ROHLF. 1981. Biometry. 2nd ed. W. H. Freeman and Co., San Francisco, Calif. 859pp.

VERMEER, K. 1981. Food and populations of surf scoters in British Columbia. Wildfowl 32:107–116.

WAHL, T. R., S. M. SPEICH, D. A. MANUWAL, K. V. HIRSCH, AND C. MILLER. 1981. Marine bird populations of the Strait of Juan de Fuca, Strait of Georgia, and adjacent waters in 1978 and 1979. U.S. Natl. Tech. Inf. Serv. Publ. EPA-600/7-81-156, Springfield, Va. 789pp.

WIENS, J. A., D. HEINEMANN, AND W. HOFFMAN. 1978. Community structure, distribution and interrelationships of marine birds in the Gulf of Alaska. Pages 1–178 *in* Environmental assessment of the Alaskan continental shelf. Final reports of principal investigators. Vol. 3. Biological studies. U.S. Dep. Commer. and Dep. Inter., Boulder, Colo.

DOES CLUTCH SIZE VARY WITH COHORT IN LESSER SNOW GEESE?

C. SCOTT FINDLAY, Department of Biology, Queen's University, Kingston, Ontario K7L 3N6, Canada

ROBERT F. ROCKWELL, Department of Biology, The City College of New York, 138th St. at Convent Ave., New York, NY 10031

FRED COOKE, Department of Biology, Queen's University, Kingston, Ontario K7L 3N6, Canada

A question of major interest to biologists is the extent to which environmental conditions during prereproductive growth and development influence subsequent reproductive performance. If, for example conditions during a particular breeding season were exceptionally mild or severe, we might expect that subsequent reproductive success of the young hatched in that season might be influenced by those conditions throughout life. One way to investigate this question is to compare various demographic parameters among cohorts for evidence of cohort-specific differences. Such differences, if found, could indicate differences in the conditions under which these cohorts were produced, or differences in the genetic composition of the cohorts, or both. Using the long-term study of

lesser snow geese (*Chen caerulescens*) at La Pérouse Bay, Manitoba, in which large numbers of individually marked geese of known age (i.e., banded as goslings) are available, we investigated demographic attributes of the cohorts.

Because demographic models in population ecology often assume constant birth and death rates (i.e., vital rates), we attempt here to investigate this assumption, which may be tenuous under certain conditions. These conditions include populations for which the vital rates are functions of some: (1) extrinsic environmental variable such as temperature, humidity, or phenology, which varies over breeding season (Hodder 1963, Walburg 1972, Rockwell et al. 1983); (2) intrinsic environmental variable, such