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COMPARISON OF SHIP AND AERIAL SURVEYS OF BIRDS AT SEA

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Abstract: Field tests were made off California to compare estimates of seabird density and species composition resulting from simultaneous ship and aerial observations. In controlled survey experiments, significantly higher mean densities were calculated from aerial observations than from the ship. Under variable field conditions, however, densities derived from vessel surveys for five species groups were statistically indistinguishable from corresponding aerial figures. On ship surveys, 95–97% of all birds were identified to species, whereas from the air, specific identifications were made for 77–96% of the birds seen. About the same total numbers of species were noted from the two platforms, and reported species composition was similar.

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During the mid-1970's, the needs of managers for basic population inventories of seabirds led to several large scale, multi-year studies involving both ship- and aircraft-based observations at sea (Briggs et al. 1981, Wahl et al. 1981, Gould et al. 1982, Vermeer et al. 1983, Blake et al. 1984). Survey methodology in open-water habitats previously had received little critical examination, so investigators devised a variety of field procedures and accumulated vast data bases, with only modest standardization between research groups. It has become apparent that aerial and shipboard methodologies should be evaluated and compared.

Qualitative comparisons of strip censuses from vessels and aircraft have been made by Briggs et al. (1981), Wahl et al. (1981), and Gould et al. (1982), whereas limited quantitative comparisons, emphasizing littoral habitats, have been reported by King and Conant (1982) and Savard (1982). Generally, aerial surveys cover wide areas (10^2–10^4 km^2) in a few hours' to a few days' time and have been reported to yield relatively low counts along coastlines when compared to counts from shore or a boat. Due to short sighting times, aerial counts are reported to produce relatively imprecise information concerning species composition. Because ship surveys cover comparable areas more slowly, they introduce the possibility of changes in bird populations during a single survey. However, they yield more precise identifications and have the advantage of facilitating collection of correlative oceanographic information. Both types of survey are thought to have inherent biases leading to error in determination of bird density: (1) birds may be overlooked or their numbers over- or underestimated; (2) on ship transects inclusion of counts of flying birds may exaggerate apparent densities (Tasker et al. 1984); (3) ship-followers (e.g., gulls [*Larus* spp.] and fulmars [*Fulmarus* spp.]) or avoiders (e.g., loons [*Gavia* spp.]) may be represented differently from those that are neutral to the ship's presence. Glare, altitude, and the width of transect corridors can affect density and species composition estimates from airplanes (Briggs et al. 1985).

In this paper we compare some aspects of strip transects made during ship and aerial surveys. We also examine survey data taken off southern California during 1975–78 to compare density estimates under normal (variable) field conditions. Though limited, these appear to be the first direct comparisons reported for the two types of survey in offshore areas.

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METHODS

Controlled Experiments

We made a series of counts simultaneously from ship and airplane during 1975 and 1976 to: (1) compare estimates of bird density and species composition between platforms; and (2) estimate within-sample variance. We limited these "controlled" counts to areas and times having ideal observation conditions: winds <10 km/hour, seas <1.5 m in height, and visibility >10 km. Shipboard observers scanned strips 400 m to each side of a 20-m vessel moving at 18–22 km/hour; observer height was 5 m. Records indicated in which of four distance zones (0–50 m, 51–150 m, 151–400 m, 400+ m) each sighting occurred; the outermost zone was considered "off transect." Estimates of density were made by dividing numbers of birds observed by the area surveyed in transect segments of fixed length. Ship segments were 11.1 km in length during controlled experiments and were 7.4 km during regional surveys under uncontrolled field conditions. Birds following the ship were counted at the start of the segment, then visually rechecked every few minutes to avoid duplicate counts. No corrections were made for flying vs. swimming birds.

Several authors have concluded that under most observation conditions, inconspicuous birds cannot be censused efficiently beyond 100–175 m from a ship (Dixon 1977, Briggs et al. 1981, Tasker et al. 1984). Accordingly, we used overlapping corridors of different widths to estimate density. For large, conspicuous birds, densities were calculated from sightings within the full 800-m corridor (beam to beam, 400 m to each side). For inconspicuous species (which we refer to as "small birds"), including storm-petrels (*Oceanodroma* spp.), small grebes (*Podiceps* sp.), phalaropes (*Phalaropus* spp.), and small alcids (primarily Cassin's auklet [*Ptychoramphus aleuticus*], Xantus' murrelet [*Synthliboramphus hypoleucus*], and rhinoceros auklet [*Cerorhinca monocerata*]), we used only sightings occurring within the first 150 m laterally (300 m total width). At least two experienced observers simultaneously contributed sightings during all ship counts. Lateral transect boundaries were estimated frequently with the aid of a split-image range-finder and probably were accurate to ±10%.

Aerial counts were made from a Cessna 337 "Skymaster," flying at 60 m altitude and 165 km/hour; observations were recorded orally on cassette tapes. The transect corridor was 50 m wide and was determined by inclinometer measurements and trigonometric functions; appropriate marks were drawn on the aircraft window. During the controlled experiments, transects for both ship and aircraft were oriented east and west. By altering seating arrangements, the aerial observer scanned a glare-free field of view in either direction of travel. Aerial segments were 18.5 km in length. One experienced observer made all aerial counts.

In experiments during February 1976, the vessel and airplane surveyed over two parallel lines separated by 1.9 km; initial line selection and direction of travel were determined at random, and the two platforms met six times within 4 hours. In December 1975 and January 1976, the vessel and airplane each surveyed a single transect, passing near the midpoint. References to "replicate" counts indicate that a given platform resurveyed exactly the same line, to the extent allowed by navigational accuracy.

Regional Comparisons

The results of standardized ship and air surveys made every few weeks by the same observers were used to compare density estimates under normal field conditions. Data were selected from surveys in the area bounded by 33° and 34°N latitude and by 119° and 120°W longitude, in the central portion of the California Bight. Mean densities for each species or group were calculated for all transect segments in each cell of a 10′ by 10′ latitude–longitude grid; grid-cell averages then were combined into regional survey means. Comparisons were limited to surveys occurring not more than 10 days apart, during which at least 10 of the possible 36 grid-cells were visited both by ship and aircraft, under at least moderate observation conditions (maximum seas 3 m, maximum winds 30 km/hour, minimum visibility 4 km). Each survey sampled both across and along gradients of

Table 1. Comparison of mean densities of birds during near-simultaneous air and ship counts. For each ship sample, six segments were surveyed, totalling 66.6 linear km, and aerial samples included six samples totalling 111 km, California Bight.

Date	Mean density ± SD		Average time separation (hours)	Correlation (r) between ship–air segment counts		Significance of Wilcoxon test	
	Large birds	Small birds		Large bird	Small bird	Large bird	Small bird
16 Dec 1975							
Ship	1.79 ± 1.47	0.29 ± 0.31	2.2	−0.09	0.39	0.016	0.016
Air	5.42 ± 3.48	1.81 ± 1.51					
6 Jan 1976							
Ship	2.20 ± 1.64	3.78 ± 5.59	1.9	0.22	0.28	0.016	0.039
Air	9.94 ± 5.93	13.96 ± 12.56					
12 Feb 1976							
Ship	4.73 ± 4.54	0.84 ± 0.72	0.2	0.56	0.77	>0.10	0.016
Air	15.41 ± 13.11	5.38 ± 4.81					

water depth, distance from shore, and water temperature; we excluded all segments within 8 km of land to minimize possible bias associated with close approach to active seabird colonies. Within the area of regional comparisons, minimum and maximum monthly distances surveyed from the air were 185.2 and 667.2 linear km and from the ship were 88.9 and 244.5 km.

Because of small sample sizes, we used nonparametric Wilcoxon signed-rank tests to assess significance of differences in the controlled experiments. For the larger samples in regional comparisons, we used mixed-model, two-way ANOVA, with unequal but proportional sample sizes (Sokal and Rohlf 1981). Unequal variances calculated for some surveys were eliminated by square-root transformation.

RESULTS

Controlled Experiments

Nearly simultaneous counts were made in 1975 and 1976 in areas having ideal conditions and low or moderate bird densities (average densities all <25 birds/km^2). Gulls (*Larus* spp. and black-legged kittiwake [*Rissa tridactyla*]) and alcids (especially common murre [*Uria aalge*], Cassin's auklet, and rhinoceros auklet) predominated numerically in this wintering avifauna. Among transect segments paired by time (six segment pairs on each date, 0–4.0 hours separation between platform passes), we found that aerial observers reported considerably higher mean densities than did ship observers (Table 1). For gulls, pelicans (*Pelecanus* spp.), fulmars, and other large species, mean ship densities averaged less than one-third aerial densities, whereas for smaller, difficult-to-detect species, ship densities were only one-fourth as high. In December and January, density differences between platforms for both large and small birds were highly significant (Wilcoxon tests, $P < 0.025$). In February, the aerial counts yielded higher small bird figures ($P = 0.0156$), whereas for large birds, the between-platform difference was not significant ($P > 0.10$). By considering ship observations made only in the innermost 150 m of the surveyed strip, calculated densities of large birds increased by 46%, but still fell well below densities from the narrower aerial corridor. Similarity between platforms in densities calculated for individual segments varied inversely with delay between counts; correlations were as poor as $r = -0.09$ for large birds at average delays of 2.2 hours (Dec) and as high as $r = 0.77$ for small bird counts at an average delay of 0.2 hours. We detected no consistent trend toward lower densities with increasing numbers of replicate aerial counts, nor did ship counts decline in the minutes after aircraft passes. Either condition might imply interference, or statistical dependency, between survey modes.

In both types of survey, we found moderate to large standard deviations among replicate counts. Coefficients of variation for two to six aerial replicates ranged from 3.8 to 89.4%; this variation was independent of mean density, time delays, and number of replications (Table 2). Because of relatively slow speed, immediate replications of counts along fixed transects are more difficult to obtain using ships than airplanes. However, for the February experiment (one line traversed six times in 3.5 hours) the CV was 85.2%; Table 3). Increased delays be-

Table 2. Coefficients of variation from replicated aerial counts made with time delays (start of first count to start of last) of 0.2–2.2 hours, California Bight.

Date	Transect length (km)	*N* replicates	Time delay (hours)	$\bar{x}$ density (birds/km²)	CV
23 Jan 1976	24.0	2	0.2	13.5	3.8
	27.7	2	0.6	9.7	14.6
12 Feb 1976	18.5	2	0.6	5.0	60.0
	18.5	2	1.5	4.0	89.4
	18.5	6	2.2	20.8	76.4
8 Jan 1977	18.5	6	2.1	190.5	26.0

Table 3. Effect of time delays on coefficient of variation from replicated ship counts. Transects were 7.4 km in length and featured 150-m lateral strips (300 m total width) for inconspicuous birds and 400-m lateral strips (800 m total width) for conspicuous birds, California Bight.

Date	Time delay (hours)	*N* counts	$\bar{x}$ density (birds/km²)	CV
12 Feb 1976	3.5	6	5.6	85.2
	6.3	2	6.7	5.1
	7.4	2	9.5	53.2
	8.3	2	3.2	25.6
	9.3	2	5.9	1.9
	10.1	2	4.3	4.7
12–13 Feb 1976	23.9	2	6.0	15.6
	23.9	2	5.2	15.6
	23.9	2	5.0	20.7
	23.9	2	11.7	23.7
	24.0	2	5.7	11.9

tween ship counts (6–24 hours) yielded CV's in about the same range as for immediate aerial replicates (1.9–53.2%). Due to changes in survey conditions, replicate aerial counts with delays of this length (24 hours) were not obtained. Mobile bird populations easily might change in density, flock locations, or composition within 2–3 hours, and it may be impossible to precisely duplicate survey line coverage at sea. Because of this, it is not at all clear whether the precision of density estimates from either platform can be improved (i.e., reduce variance) by making additional replicate counts in a specified area.

Ship observers were more precise in bird identifications. On average, 95.7% of all birds were identified to species from the ship, whereas in aerial counts the comparable average was 86.7% (Table 4). About the same numbers of total taxa (including "unidentified" categories) were noted, though ship observers recorded more individual species in December.

The composition of counts made from the two platforms was similar on a percentage basis, although aerial densities for each species group were somewhat higher than those from the ship (Table 5). Ship observers consistently reported higher proportions of gulls, probably resulting from attraction of gulls to the vessel and our inability to completely eliminate recounts of ship-followers. Among the inconspicuous seabirds, aerial observers reported a higher proportion and higher density of small grebes. Densities of alcids were highest among aerial

Table 4. Comparison of densities (birds/km², SE in parentheses) of eight groups of birds derived from ship and aerial counts over the same transects. The geographic unit of calculation is the transect segment. Data here include the more limited sample in Table 1, California Bight.

			Densities (birds/km²) (SD)							
Month	Type	Linear distance covered (km)	Loons	Small grebes	Fulmars and shearwaters	Pelicans, cormorants	Jaegers	Gulls	Alcids	Others
Dec 1975	Ship	118.6	0.02 (0.02)	0.01 (0.01)	0.12 (0.05)	0.37 (0.18)	0.04 (0.02)	3.95 (1.57)	0.51 (0.21)	0.13 (0.11)
	Air	216.0	0.95 (0.48)	1.20 (0.86)	0	1.12 (0.51)	0.09 (0.08)	7.74 (1.41)	0.34 (0.17)	0
Jan 1976	Ship	88.9	0.03 (0.02)	0	0.04 (0.02)	0.01 (0.01)	0.03 (0.02)	3.06 (0.94)	3.38 (2.17)	0
	Air	99.6	1.01 (0.48)	0	0.60 (0.41)	0	0	8.43 (2.29)	10.44 (4.82)	0
Feb 1976	Ship	88.8	0.04 (0.04)	0	0.04 (0.02)	0.11 (0.08)	0.18 (0.06)	2.80 (0.38)	0.79 (0.31)	0
	Air	148.16	0	0	0.81 (0.28)	0.27 (0.27)	0.41 (0.28)	10.12 (3.77)	4.59 (1.55)	0

Table 5. Precision of identifications attained by ship and aerial observers over the same survey tracks, California Bight.

Month	Platform	Taxa seen	Total species identified	Total birds identified to species level	Total identified at genus or family	% specific identifications
Dec 1975	Ship	21	17	441	22	95.2
	Air	18	12	838	33	96.2
Jan 1976	Ship	13	9	676	35	95.1
	Air	14	9	82	25	77.3
Feb 1976	Ship	13	11	349	12	96.7
	Air	14	11	144	22	86.7

counts for two of three dates, but alcids were proportionately more prominent in ship counts on one date, in air counts on one date, and were about equal in the January counts. Shipboard observers noted that even under conditions of low swells and excellent visibility, some small alcids probably were being hidden from view in the outer portions (>100 m) of the searched corridor. The aerial corridor was narrow enough (50 m) that habitat screening was not a significant factor, and under the ideal conditions prevailing during these tests, the splashing that is characteristic of avoidance (diving) behavior of alcids actually called the observer's attention to the birds' presence.

Regional Comparisons

Seldom is it feasible to limit surveys over broad offshore areas to observation conditions as benign as those described for our controlled experiments. How comparable, then, are data taken by ship and aerial observers under conditions of changing light, surface weather, and observer fatigue? We sought an answer among the results of surveys made during 1975–78 in a well-sampled area lying at the eastern edge of the California current.

Data are presented for five species or groups that were relatively numerous and that represent a spectrum of plumage and behavioral characteristics affecting conspicuousness and thus relative detection distances (Wiens et al. 1978). By virtue of large size, light adult body plumage, and aerial foraging habits, western gulls (*Larus occidentalis*) are the most conspicuous of the species, followed by the similar-sized but predominantly dark shearwaters (primarily *Puffinus griseus*). Phalaropes, storm-petrels, and small alcids represent a range of conspicuousness among small seabirds (50–150 g), from the light-colored phalaropes to the primarily dark, primarily swimming and diving alcids. We expected density to be most variable geographically and potentially most dissimilar between platforms for shearwaters and phalaropes, because these species form extremely large flocks and migrate rapidly through the region. The gulls, storm-petrels, and alcids exhibit less seasonal variation in population numbers (Briggs et al. 1981), do not form such large flocks, and maintain modest nesting populations (10^2 to 2×10^3 birds) near the surveyed area. Regional densities are compared by ANOVA for 7–10 months (Table 5). Three major sources of variation in bird density are present in each analysis: error mean squares were not tabulated but include primarily the variance due to the degree of clumping and geographic concentration of birds during a given survey. Between-platform (ship vs. air) and between-month variation (i.e., changes in mean density in accordance with stage of annual cycle) are the two main treatments.

Geographic variation in density during a given survey and variation in density between months were almost always greater than variation between platforms in a given month. Monthly variation related to annual cycles was significantly greater than variation within the region during a given survey (i.e., high F ratios of mean squares for months: error mean squares). In no case was there a significant difference between platforms in a given month. A significant interaction between platforms and months was obtained for ship data on storm-petrels. Ship observers saw more petrels in April–June when the birds formed conspicuous flocks numbering 5–50 individuals.

If ship and aerial observers perceive bird densities equally during regional surveys, we should expect a regression of ship and air densities matched by time to approximate a slope of 1:1. In fact, 95% confidence limits of slopes of regressions calculated by Bartlett's three-

Table 6. Analysis of variance (*F* ratios) in mean regional densities of five species or groups of species. Surveys occurred off southern California in 1975 and 1976.

Source	Small alcids (4 spp.)	Storm-petrels (4 spp.)	Western gull	Phalaropes (2 spp.)	Shearwaters (3 spp.)
Platform type	0.01	0.03	0.40	2.30	0.40
Month	13.20***[a]	244.71***	3.61**	8.44***	5.88***
Interaction	1.41	4.00***	0.89	1.33	0.52
Sample size (months)	7	7	8	10	9

[a] *** $P < 0.001$, ** $P < 0.01$.

group method (Sokal and Rohlf 1981) from the regional data all overlap the theoretical value of 1.0. Thus, during our regional surveys of densities of these five species groups, ship and aerial results were statistically indistinguishable.

DISCUSSION

Our findings provide a first, quantitative indication of differences and similarities between open-ocean surveys from vessels and aircraft. The data were drawn from limited samples obtained under restricted circumstances. In simultaneous survey experiments, we used rested, experienced observers and sought out ideal observation conditions and low or moderate densities of birds. Additionally, the tests were made away from land and in winter. For many pelagic, wintering species, these last limitations preclude periodic visits by birds to shoreline roosts and, thus, the accompanying diel pattern in offshore habitat occupancy that might confound density analyses at different times of day. Regional comparisons were made under conditions more closely approximating normal survey operations, but also occurred away from colonies and roosts and where overall bird density was low or moderate. To the extent that the imposed limitations influence survey efficiency, our findings may generalize to only a subset of possible survey conditions. Clearly, a great deal of additional work in this area will be required before the strengths and limitations of the two types of survey are fully understood.

We obtained conflicting results regarding comparability of density estimates from the two platforms. In controlled experiments, ship densities generally were significantly lower than aerial densities. This result is surprising, in view of the short detection times available to aerial observers. The most important consideration here appears to be sighting inefficiency in the outer portions of the ship corridor. This results from the combined deleterious effects of habitat screening (especially of swimming alcids) and decreasing target size with distance. To the unaided eye, sightings at the outer edge of the 400-m ship corridor are four times more distant than birds at the extremity of the 50-m aerial strip (400 vs. 105 m). We have found corridor width to significantly influence reported bird density from an airplane (Briggs et al. 1985), and we suspect that as more data become available (e.g., Dixon 1977, Tasker et al. 1984), this effect will be documented for vessel surveys as well.

In contrast to the simultaneous experiments, the regional comparisons indicated that density differences between platforms in a given month were not significant compared to variance attributable to annual cycle, geographic patchiness, or sampling error. Bird densities reported in geographically broad surveys were independent of the sampling method.

Because other aspects of the experiments and the regional surveys were constant, we surmise that the discrepancy was a function of observers and viewing conditions. We had ideal sighting conditions and used rested observers in test periods of <4 hours. We also experienced changeable conditions leading to observer fatigue a few hours into successive 7-hour work days. Apparently, fatigue and suboptimal conditions in regional surveys combined to limit aerial observer efficiency to levels characteristic of ship observers. If correct, this interpretation reinforces the notion that survey efficiency is critically dependent upon protocols and assumptions (Wiens et al. 1978, Tasker et al. 1984, Briggs et al. 1985).

Levels of precision in identification reported here are higher than those reported by Savard (1982), who employed unbounded (broad) search corridors on both sides of an airplane.

This appears to be one effect of declining average target size with increasing width of the searched corridor.

The present knowledge of offshore survey characteristics allows for some general guidelines for sampling design. Except for studies of single species of conspicuous birds (albatross [*Diomedea* spp.], pelicans, large gulls), it seems that highest reported densities are obtained from both platforms using the narrowest practicable search corridor. Under the present protocols, the two types of survey produce similar regional density and composition figures, but at different levels of precision and at different sampling rates. Thus, the speed and breadth of coverage afforded by the airplane may best be used to obtain synoptic views of population density and distribution, to assess general species composition, and to ascertain areas of bird concentration and rarity. Because of longer viewing times, rare birds, and groups such as storm-petrels, gulls, terns, and alcids having plumages that are difficult to discriminate, are most efficiently identified from a ship. A ship might best be used to collect biological materials, to make detailed observations of species composition and behavior, and simultaneously to gather hydrographic information in areas of special interest, such as seabird feeding grounds. On this basis, the investigator may choose the platform that optimizes cost, operating range, and time constraints, and that achieves the desired level of specific identifications and requirements for correlative environmental information.

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