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ORIGINAL ARTICLES

Accuracy of 'total counts' of waterbirds from aircraft in coastal waters

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Estimating 'total counts' of waterbirds from aircraft is a widely used survey method, and we assessed the effectiveness of this method for geese, ducks, waders and gulls by comparing the results of counts from aircraft with ground counts in the Danish Wadden Sea during 1984-1998. In total, 47 counts were carried out in 12 counting sites and the results were compared for 18 waterbird species, which varied in abundance, flock size and degree of aggregation. Significantly greater numbers of waterbird species were identified from the ground than from aircraft (mean number: 16.1 vs 10.6 species). Depending on the accuracy of aerial counts compared to ground counts, the species were divided into three categories: a) brent goose *Branta bernicla*, shelduck *Tadorna tadorna*, mallard *Anas platyrhynuchos*, eider *Somateria mollissima* and oystercatcher *Haematopus ostralegus* had a high level of correspondence between densities obtained from ground and aerial counts (detection rate of >80% with no statistical difference between slopes and intercepts of the observed regression lines and the ideal lines (x = y), differences between mean densities of ground and aerial counts being <15%); b) wigeon *Anas penelope*, teal *A. crecca*, grey plover *Pluvialis squatarola*, dunlin *Calidris alpine*, bar-tailed godwit *Limosa lapponica*, black-headed gull *Larus ridibundus*, common gull *L. canus*, herring gull *L. argentatus*, great black-backed gull *L. marinus* and common/arctic tern *Sterna hirundo* and *S. paradisaea* had a medium correspondence between densities obtained from the two platforms (detection rate of >55% with differences between the mean densities of ground and aerial counts of <30%; and c) redshank *Tringa totanus*, greenshank *T. nebularia arquata* and curlew *Numenius arquata* had a low correspondence between the densities obtained from the two platforms (detection rate of <55% and differences between the mean densities of ground and aerial counts of >30%). Species with a high and medium level of correspondence between the two platforms are mostly species that are numerous, of widespread occurrence, and found in large flocks. Species with a low correspondence are minority species, occurring scattered or in small flocks. We recommend to supplement aerial counts with ground counts at sites with mixed flocks of more dabbling duck species present to increase the accuracy of the count results.

Key words: aerial survey, assessment, detection rate, gulls, species identification, waders, waterfowl

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For several decades, counts of waterbirds undertaken from aircraft have been used in North America to map distributions and estimate population sizes on a large scale during both breeding and migration periods (Morrison & Myers 1987, Blohm & Wendt 1993, Bechet et al. 2004). In Europe, aerial counts have been used to a lesser extent due to a long tradition of using ground counts in this area. However, in European countries with long coastlines or large shallow marine waters, counts from aircraft were introduced in the late 1960s and early 1970s, i.e. in Belgium, Denmark, France and Sweden (Joensen 1974, Almkvist & Andersson 1972, Nilsson 1975, Offringa & Meire 1999). During subsequent decades, aerial monitoring of waterbirds became more frequent and improved, and it was introduced elsewhere e.g. Estonia, Norway, Finland, Germany, Lithuania, the Netherlands, Poland and Spain (Haapanen & Nilsson 1979, Follestad et al. 1986, Meltofte 1980, Meissner & Kozakiewicz 1992, Svazas & Vaitkus 1992, Camphuysen & Leopold 1994, Hario 1994, Garcia et al. 1996, Laursen et al. 1997, Nehls 1998).

Surveys from aircraft are thus used in many areas, despite Caughley's (1974) conclusion that aerial survey is an inaccurate method of estimating population size and that it necessitates an estimation of the bias introduced by using aerial counts. However, Caughley (1974) accepted that aerial survey is often the only applicable method, especially where access to a survey area is limited or when time constraints apply. Although aircraft counts have been used for many years in Europe, a standard description of the methodology of aerial surveys appeared late in their development (Pihl & Frikke 1992). In the description, the aerial counts were divided into 'total counts' to be performed with the objective to count all waterbirds or selected waterbird species within a survey area, and 'transect counts', to be performed by sampling counts along lines distributed throughout the survey area (see Rachowicz et al. 2006).

Previous preliminary assessments of the effectiveness of aerial surveys during the non-breeding season have been carried out for waterfowl species (Joensen 1968, Savard 1982, Voslamber & van Turnhout 1999, Bechet et al. 2004). In addition, the effect of the number of species present, visibility, behavioural reaction and flight height have been investigated (Broome 1985, Johnson et al. 1989, Mosbech & Boertmann 1999). However, detailed quantitative multi-species comparisons of total counts from aircraft with ground counts in which all waterbird species (of geese, ducks, waders and gulls) in a survey area are counted have not previously been performed. The aim of our study thus was to evaluate the effectiveness of 'total counts' from aircraft by comparing the results with those of simultaneous ground counts of waterbirds in a study which covered all the common species in a rich waterbird community during the non-breeding season. In any relative assessment of aerial count methods, it must be stressed that the assessment is based on the results of two relatively imperfect registration methods, because ground counts are also associated with errors and bias in relation to the true number of birds (Rappoldt et al. 1985). On the other hand, ground counts are widely used means of assessing avian abundance, so in the absence of an alternative method, the results of ground counts are used for the comparison.

Study area

Our study was performed in the Danish Wadden Sea, which is designated as a Special protected Area (SPA) under the EU-Birds Directive, and is internationally important for several waterbird species during migratory and winter periods (Meltofte et al. 1994). The Danish Wadden Sea comprises the northern part of the Wadden Sea, which is shared by the Netherlands, Germany and Denmark. The Danish

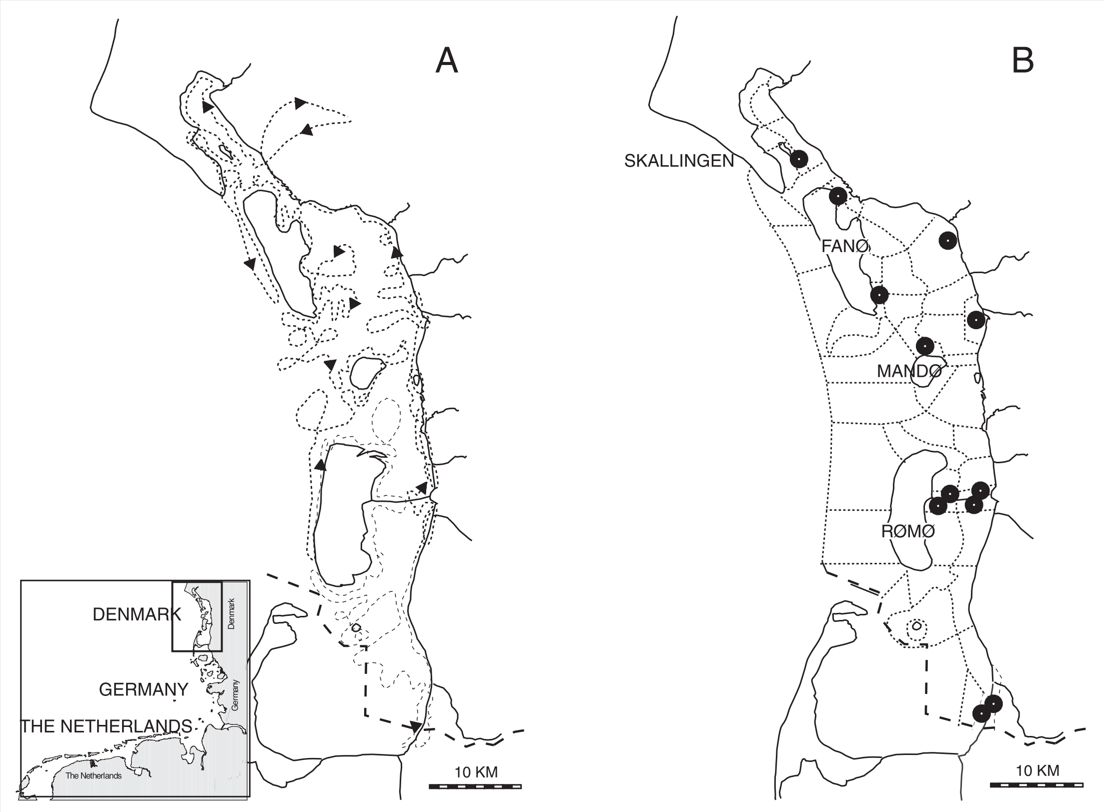

Figure 1. Study area in the Danish Wadden Sea with indication of flying route at high tide, and count areas used for aerial bird surveys (A) and the 12 count sites covered from the ground (•) which were used in the study (B).

part covers about 850 km^2 of which 60% is intertidal with a tidal amplitude of 1.8 m. Three major islands (Fanø, Mandø, Rømø) border the area to the west and separate the Wadden Sea from the North Sea (Fig. 1). Saltmarshes are located along the mainland coast and on the east side of the islands. See Smit & Wolff (1983) for a full description.

Background

Within the Trilateral Monitoring Programme for the Wadden Sea, aerial counts and ground counts were performed in the Danish part once or twice annually during 1984-1998 (Blew & Südbeck 2005). A midwinter count took place in January each year, whereas the month of other counts varied from year to year. Use of voluntary ground counters constrained counts to be undertaken at weekends. Aerial counts were performed on or as close as possible to the ground count date. Aerial counts were sometimes postponed due to bad weather conditions and/or high tide conditions (see later), and availability of an aircraft. However, for this study we used counts performed from both aircraft and the ground during the same day, only.

Methods

Numbers of waterbirds counted from aircraft were compared to the numbers obtained from ground counts, a method also used by Joensen (1968), Savard (1982) and Voslamber & van Turnhout (1999). We use the expression 'the two platforms' for ground and aerial counts.

Aerial counts

Total counts from aircraft covered the entire Danish Wadden Sea from the sea walls to a line extending ca 2 km west of the islands. Two observers identified and estimated bird numbers, one from each side of the aircraft. All observations were assigned to 55 counts areas (see Fig. 1). The speed of the aircraft was ca 130 km/hour and it flew at an altitude of ca 60 m. Surveys were initiated 2.5 hours before high tide and lasted 3-3.5 hours. The route was chosen so that the entire Wadden Sea was covered by the observers, including all high-tide roosts and all assemblages of waterbirds. The same team of trained observers (7-8 persons) was used throughout the entire study period. Aerial surveys were only carried out in good weather i.e. when the visibility exceeded 5 km, and the wind speed was <25 km/hour, and it was not raining. The count procedure followed the 'total count' methods as described in Pihl & Frikke (1992). The observers were not informed about which areas were selected for the methodological study.

Ground counts

Ground counts were performed at 18-25 count sites. The counts took place 3-4 hours before and after high tide. All waterbirds species were identified and their numbers were counted at the sites by use of binoculars and telescopes. Each observer covered 2-4 sites during a high-tide period, and was not informed that their results would be used in a methodological study.

Data

We selected 12 sites for the study (see Fig. 1), based on the presence of elevated points (e.g. seawalls or causeways) from which ground counters had a good overall view of the sites and in particular of roosting areas. We performed a total of 47 counts during 1984-1998 from both the ground and aircraft within the selected sites or areas during the same high-water period; six of these counts were performed during winter (December-February), 25 during spring (March-June) and 16 during autumn (July-November).

We included 18 waterbird species (or groups of species) in the study (Table 1). The common tern *Sterna hirundo* and arctic tern *S. paradisaea* were treated as one species (common/arctic tern), because the species were impossible to distinguish from the aircraft. The species chosen for comparison were selected based on the following criteria: 1) all together, they represented the vast majority (93%) of the total number of waterbirds present in the Danish Wadden Sea, 2) they included abundant as well as less abundant species, 3) they included widely distributed species as well as species with a clustered distribution, and 4) they occurred in large as well as in small flocks (see details about the criteria in Appendix I). Most species fulfilled more than one criteria, e.g. shelduck *Tadorna tadorna* (numerous, widespread and occurring in large flocks), teal *Anas crecca* (numerous, confined to few sites and in large flocks) and redshank *Tringa totanus* (in small numbers but widespread and in small flocks).

Table 1. Overall detection rate (in %) of 18 waterbird species recorded in aerial and ground counts, and specific detection rates (in %) of densities at 2, 50 and 100 individuals/km^2 derived from logistic regression. - indicates that the detection rate has not been calculated; $* = P \leq 0.05$; $(*) = 0.05 < P \leq 0.10$; $NS = P > 0.10$.

				Specific detection rate at density		
Species	N	Overall detection rate (%)	Significance of density	2 ind./km^2	50 ind./km^2	100 ind./km^2
Waterfowl						
Brent goose	25	84.0	NS	-	-	-
Shelduck	48	95.8	NS	-	-	-
Mallard	38	84.2	*	78	97	98
Wigeon	24	79.2	*	73	95	97
Teal	20	65.0	*	62	89	93
Eider	23	87.0	NS	-	-	-
Waders						
Oystercatcher	42	92.9	NS	-	-	-
Grey plover	35	82.9	*	78	98	-
Dunlin	41	90.2	(*)	75	91	93
Redshank	36	44.4	NS	-	-	-
Greenshank	23	52.2	NS	-	-	-
Bar-tailed godwit	27	81.5	NS	-	-	-
Curlew	31	35.5	(*)	27	55	-
Gulls & terns						
Black-headed gull	41	95.1	NS	-	-	-
Common gull	34	94.1	NS	-	-	-
Herring gull	38	81.6	NS	-	-	-
Great black-backed gull	26	57.7	NS	-	-	-
Common/arctic tern	23	69.6	NS	-	-	-

When comparing the numbers of a waterbird species counted from the two platforms in each site or area, numbers recorded in adjacent count sites/areas were also taken into account for the aerial counts. We did so because the aircraft typically flushed the birds, which could fly to an adjacent count site/area where they were recorded. In these flush events, the numbers of birds from adjacent sites/areas were added.

Preliminary analyses showed that the size of areas (range: 3.4-13.1 km^2) explained part of the variance in bird numbers at sites. As data tended to deviate from a normal distribution, we standardised the abundance of birds between count areas by conversion of the numbers to densities and log-transformed ($\log(x+1)$) them. We carried out the following comparison between aerial and ground counts in two steps.

First, we analysed the presence or absence of the species recorded from aircraft in relation to their densities obtained by ground counts, using logistic regression. In this way, we were able to estimate the probability that a given species would at least be observed from aircraft as a function of their densities, assuming that observers counted all birds from the ground. Second, we took the bird densities from the areas where a given species was actually present during an aerial count and compared them with the ground count densities (>0 individuals/km^2) in a regression analysis. The reason why we excluded ground data of 0 individual/km^2 (birds observed in the aerial counts but not in the ground counts), was that these data introduced a systematic source of error to the analysis as the intercept of regression lines would automatically be high, because these data were not balanced by observations of birds observed in the ground counts but not in the aerial counts (these observations were analysed in

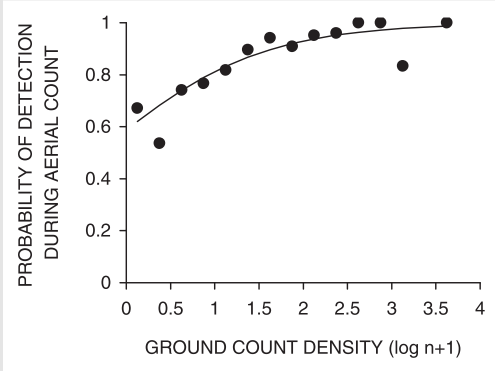

Figure 2. Probability of detection during aerial counts for all observations of the 18 waterbird species compared to ground counts; N = 575.

Table 2. Results of regression analyses for 18 waterbird species recorded from the ground (independent parameter) and from aircraft (dependant parameter) for observations of >0 individuals/km^2 for both ground and aerial counts. Test results are also given for analyses of slopes and intercepts between the observed regression lines and the ideal line representing x = y. - indicates that the F-values have not been calculated; NS = P > 0.05.

	Regression analysis				Test of slope		Test of intercept	
Species	Parameter estimate	R^2	P	N	F-value	P	F-value	P
Waterfowl								
Brent goose	0.667	0.378	<0.01	17	2.27	NS	1.10	NS
Shelduck	0.891	0.739	<0.0001	44	1.90	NS	2.85	NS
Mallard	0.756	0.444	<0.001	26	1.99	NS	0.42	NS
Wigeon	0.686	0.545	<0.01	15	3.25	NS	6.20	<0.05
Teal	0.656	0.460	<0.05	9	1.64	NS	0.96	NS
Eider	0.907	0.746	<0.0001	13	0.34	NS	0.01	NS
Waders								
Oystercatcher	0.894	0.693	<0.001	36	1.08	NS	0.56	NS
Grey plover	0.631	0.484	<0.0001	25	7.34	<0.05	-	-
Dunlin	0.929	0.545	<0.0001	33	0.22	NS	1.42	NS
Redshank	0.483	0.400	<0.05	13	8.35	< 0.05	-	-
Greenshank	0.222	0.101	NS	8	8.31	<0.05	-	-
Bar-tailed godwit	0.710	0.648	<0.0001	19	5.21	<0.05	-	-
Curlew	0.512	0.462	<0.05	11	6.98	<0.05	-	-
Gulls & terns								
Black-headed gull	0.844	0.699	<0.001	33	2.47	NS	7.91	<0.01
Common gull	0.450	0.245	<0.01	27	12.12	<0.05	-	-
Herring gull	0.572	0.490	<0.0001	26	12.88	<0.05	-	-
Great black-backed gull	0.880	0.638	<0.01	10	0.28	NS	0.03	NS
Common/arctic tern	0.599	0.554	<0.05	10	4.45	NS	0.00	NS

the logistical regression above). Specific regression lines were then compared with the ideal regression line (equal densities in aerial and ground counts, x=y) in order to test the efficiency of aerial counts, once a species was actually identified in a count site.

Results

Number of species observed

On average, we recorded fewer species from aircraft than from ground during the 47 counts (aircraft: 10.6 ± 0.56 species (mean number ± SE) versus ground: 16.1 ± 1.40 species). The difference between the number of species observed from the two platforms was statistically significant (T-test on log-transformed data: $P < 0.005$; $N = 47$).

Detection rate

The logistic analysis showed a high variability between species in the detection rates obtained from aircraft compared to ground counts (see Table 1). In total, 11 waterbird species showed an overall detection rate from aircraft of >80% compared to that of ground counts. For the rest of the species, wigeon *Anas penelope*, teal, greenshank *Tringa nebularia*, great black-backed gull *Larus marinus* and common/arctic tern had a detection rate from aircraft of 50-80%, and for redshank and curlew *Numenius arquata* the detection rates were <50% of those obtained in observations from the ground.

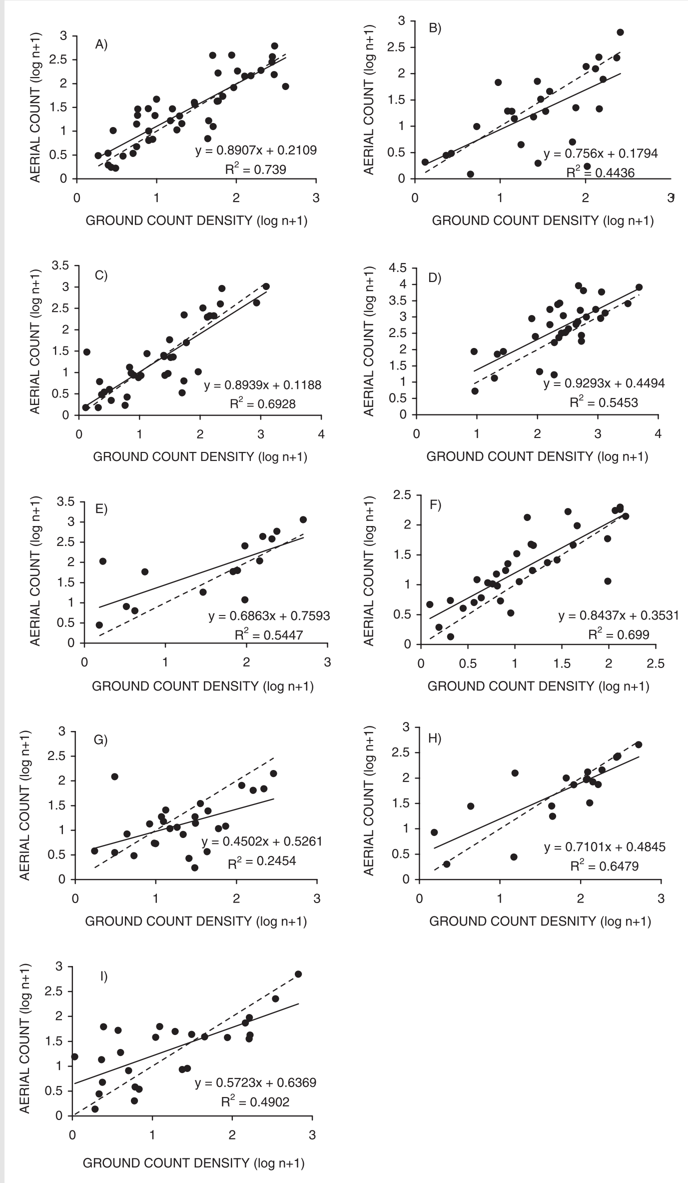

Figure 3. Relationships (full line) between density of waterbird species recorded from the ground and from aircraft (number/km^2) for shelduck (A), mallard (B), oystercatcher (C), dunlin (D), wigeon (E), black-headed gull (F), common gull (G), bar-tailed godwit (H) and herring gull (I). The dotted line shows the ideal relationship (x=y).

In general, the logistic regression analysis of all species showed that waterbirds occurring at low densities had a lower detection rate from aircraft compared to ground counts than birds occurring in larger densities (Fig. 2). A statistically significant relationship between detection rates and densities was shown for six species, and for these species the detection rates are given for densities at 2, 50 and 100 individuals/km^2 (see Table 1). For all these species, the detection rates increased with increasing bird densities.

Comparison of densities in ground and aerial counts

Regression analyses for observations of species recorded from both platforms showed that for 17 species, there was a significant positive relationship between observations from ground and aerial counts, which suggests some compliance between ground and aerial counts (Table 2). Only for greenshank, no significant relationship between counts from the two platforms existed. Examples of the observations and regression lines are given for nine selected species in Figure 3A-I.

For nine species, the comparisons between the regression lines representing the observed densities from the two platforms and the ideal lines (x = y) showed good agreement (i.e. no statistical differences) between the slope and the intercept for the two lines for brent goose *Branta bernicla*, shelduck (see Fig. 3A), mallard *Anas platyrhynchos* (see Fig. 3B), teal, eider *Somateria mollissima*, oystercatcher *Haematopus ostralegus* (see Fig. 3C), dunlin *Calidris alpine* (see Fig. 3D), great black-backed gull and common/arctic tern (see Table 2). For wigeon and black-headed gull *Larus ridibundus* (see Fig. 3E and F), the slopes of the two lines do not differ, but the intercepts are statistically different (see Table 2), and the results indicate that densities for these two species were overestimated from aircraft at low densities recorded from the ground (see Fig. 3E and F). For grey plover *Pluvialis squatarola*, redshank, greenshank, bar-tailed godwit *Limosa lapponica*, curlew, common gull *Larus canus* and herring gull *L. argentatus*, the slopes of the observed and the ideal lines (x = y) were statistically different (see Table 2). These species were underestimated from aircraft at high densities recorded from the ground (see Fig. 3G for common gull), except for bar-tailed godwit and herring gull, which were overestimated at low ground count densities (see Fig. 3H and I).

Mean densities

We calculated log-transformed mean densities and relative differences (in %) for the 18 waterbird species including all ground and aerial counts (Table 3). Of these species, 12 had < 15% difference between mean densities recorded from the two platforms, and for four other species, the differences between the two platforms were < 30%. For the last two species (redshank and greenshank), the differences between the two platforms were 36 and 73%, respectively.

Table 3. Log-transformed mean density (log (n + 1)) and difference (% ± S.E.) for 18 waterbird species recorded in ground and aerial counts. See Table 1 for details on numbers of each species.

	Mean density at		Difference	
Species	Ground	Aircraft	%	S.E.
Waterfowl				
Brent goose	0.963	0.931	0.7	± 14.7
Shelduck	1.803	1.345	3.7	± 6.4
Mallard	1.055	1.006	2.7	± 10.7
Wigeon	1.039	1.252	10.2	± 15.3
Teal	0.729	0.838	5.0	± 23.3
Eider	0.945	0.894	1.1	± 19.0
Waders				
Oystercatcher	1.261	1.163	4.7	± 9.9
Grey plover	0.816	0.731	9.9	± 9.8
Dunlin	2.036	2.325	21.3	± 6.8
Redshank	0.77	0.249	36.4	± 7.5
Greenshank	0.535	0.263	73.0	± 15.8
Bar-tailed godwit	1.391	1.315	4.4	± 9.6
Curlew	0.845	0.168	24.0	± 14.5
Gulls & terns				
Black-headed gull	0.902	1.143	22.2	± 10.3
Common gull	1.098	1.039	5.3	± 9.5
Herring gull	0.956	1.002	10.5	± 10.0
Great black-backed gull	0.335	0.288	13.1	± 18.8
Common/arctic tern	0.632	0.373	22.9	± 16.1

Discussion

The ability of the observers to identify species and estimate flock size from the ground and from aircraft is quite different. The advantage of aerial surveys is that an aircraft can be manoeuvred so that birds can be observed in good light conditions and at a close distance. The disadvantage is that time is a limiting factor, and observers often have only few seconds to identify species and estimate flock size. Furthermore, the aircraft can displace birds, potentially from one count site/area to another. In addition, flocks of mixed species often occur, and the proportion of different species has to be estimated as well. For ground counters, the advantage is that they have more time at each counting site, often several minutes, to identify the species and estimate or even count the individuals in the flocks. The disadvantage of using ground counts is that birds are often observed at great distance, so heat haze or backlight may reduce the possibility of identifying species and estimating their numbers accurately.

Species account

We found that 52% more species were identified from ground than from aircraft counts. The overlooked species in the aerial counts were in particular those which occurred in small numbers or solitary as ringed plover *Charadrius hiaticula*, common sandpiper *Tringa hypoleucos* and little tern *Sterna albifrons* or species that often mixed with large flocks of other species such as little stint *Calidris* *minuta*, curlew sandpiper *Calidris ferrugineus* and ruff *Philomachus pugnax*. Joensen (1968) and Savard (1982), who compared surveys of waterfowl species counted both from ground and aircraft, also found that more species were identified in ground counts than in aerial counts. Savard (1982) found that species number identified in ground counts were four times higher than the number of species identified from aircraft.

In our data, a single flock of 12,000 bar-tailed godwits was overlooked in an aerial survey, probably due to a local rainfall. In such circumstances, the visibility is restricted, and as bar-tailed godwits often flush in front of the aircraft at a distance of about one kilometre, such flocks can easily be overlooked. This example illustrates the importance of maintaining consistency in the survey condition, including a visibility of several kilometres and avoiding conditions of local rainfall which increases the inaccuracy of aerial counts.

We found that the accuracy of recording wigeon and teal from aircraft differed from that of other waterfowl species with respect to detection rate (for teal), slope of regression line between observations and the ideal line (x = y; for wigeon), and differences in mean densities recorded from the two platforms (for both species). For teal, the reason was that the species was overlooked especially at low densities, but probably also when occurring in larger numbers in mixed flocks with other dabbling duck species. For wigeon, it appears from Figure 3E that the numbers were overestimated in aerial counts compared to ground counts at low densities. The reason for this might be that males are more conspicuous than females, and other dabbling duck species, such as teal and pintail *Anas acuta*, may be included in the numbers recorded as they may be taken for females wigeon.

Detection rate

Our results showed that the detection rate in aerial counts increased with increasing bird densities; in general, a species with a density of 2 individuals/km^2 had a detection rate of ca 65% which increased to ca 78% for a density of 10 individuals/km^2 and to 90% for a density of 100 individuals/km^2 (see Fig. 2). In aerial counts, this circumstance favours the detection of species that are naturally occurring in large flocks such as most dabbling duck species and the wader species oystercatcher and dunlin, whereas species that occur in small flocks are most likely to be overlooked. Joensen (1968) also reported that species generally occurring in small numbers and/or widely scattered were often overlooked, particularly when they constituted a small proportion of the birds present.

Comparison of densities during ground and aerial counts

For 17 out of the 18 examined species, we found a significant relationship between bird densities recorded from the two platforms. Amongst aerial counts in Australia, involving 13 species of primarily waterfowl, a significant correlation was also found between count results from ground and aircraft (Broome 1985). Off the coast of North America, Savard (1982) found that ground observers saw and registered approximately twice as many birds as was done from aircraft. Savard found that loons *Gavia* sp., grebes Podicipedidae and cormorants Phalacrocoracidae were seen more often in ground surveys than in aerial surveys, except for arctic loon *Gavia arctica*, which was easier to locate in aerial counts. Furthermore, dabbling and diving ducks occurred in consistently smaller numbers in aerial than in ground surveys. Savard's results for dabbling and diving ducks were not confirmed in our study as we did not find significant differences for dabbling ducks in the results from the two platforms, except for wigeon (see Table 2). We do not know the reason for this difference in the results, but there may have been species-specific differences in the two studies.

We divided the species into three categories with respect to how well they were recorded in aerial compared to ground counts. Category A included species with a high level of correspondence between densities obtained from ground and aerial counts. These species had a general detection rate of > 80%, no statistical difference between slope and intercept between the observed regression line and the ideal line (x = y), and differences between the mean densities of ground and aerial counts of < 15%. The category A species were: brent goose, shelduck, mallard, eider and oystercatcher. Category B included species with a medium correspondence between densities obtained from ground and aerial counts, and they had a detection rate of > 55% with differences between the mean densities of ground and aerial counts of < 30%. The category B species were: wigeon, teal, grey plover, dunlin, bar-tailed godwit, black-headed gull, common gull, herring gull, great black-backed gull and common/arctic tern. Category C included species with a low correspondence between the densities obtained from ground and aerial counts, and they had a detection rate of < 55% with differences between the mean densities of ground and aerial counts of > 30% for most of the species. The category C species were: redshank, greenshank and curlew.

According to the species description criteria presented in Appendix I, most species with a high and medium level of accuracy between the densities obtained from ground and aerial counts are species that are numerous, of widespread occurrence and are found in large flocks. Exceptions are teal and great black-backed gull, which are neither numerous nor widespread. However, the mean flock size of teal is relatively large, which increases the detectability of the species from an aircraft, and great black-backed gull has a large body size and a colour that differs from the other gull species. For species with a poorer accuracy between the densities obtained from ground and aerial counts, the characteristics are that they are minority species and occur scattered or in small flocks.

Joensen (1974), who surveyed waterfowl in Danish marine waters, concluded that species identification from aircraft presents no major problems in general, because the birds are observed at close range and from a favourable angle. Joensen also considered waterfowl to generally occur as separate groups, although dabbling ducks occasionally are aggregated in mixed flocks, which makes the proportion of each waterfowl species difficult to estimate. Our results confirm Joensen's result concerning waterfowl species, and are in particular valid for wigeon and teal. Caughley (1974) argued that detectability from aircraft is inversely related to scanning time, i.e. the probability of accurate estimations of birds from aircraft decreased when the bird density increased. Broome (1985) did not find any relative decrease in detectability of duck species from aircraft when they occurred in densities of up to 1,500 birds/km^2. However, Martinson & Kaczynski (in Broome 1985) found that bird numbers counted from aircraft on small inland ponds decreased as duck densities increased to 20-30 birds/km^2. Joensen (1968) also reported that dabbling duck species could be overlooked from aircraft when they occur in large densities, due to the short time available to estimate bird numbers. However, the different results in these studies indicate that other circumstances than of those that were examined in our study, e.g. structure of habitat, experience of the observers, and specific circumstances for each aerial count due to weather conditions are likely to influence counting results.

Ground counts

In our study, we used ground counts to compare with results from aerial counts. However, ground counts can also be inaccurate as shown in a large-scale study that evaluated shorebird counts in the Dutch Wadden Sea by comparing the count results of the same bird flocks made by several observers. For roosting shorebirds, the result showed a stochastic error of 37%, and for flying flocks of shorebirds a stochastic error of 17%. A systematic error for both cases could not be quantified accurately in the study, but it was evaluated to be smaller than "some tens of percent" (Rappoldt et al. 1985). It should be noted that these results for most species are within the same range as our comparison of ground and aerial counts.

Conclusion and recommendation

'Total counts' of waterbirds from aircraft is a useful method to obtain an overview of numbers of waterbird species that occur widespread, numerously and in large flocks. We recommend that aerial surveys should be performed only during optimal weather condition; even local rainfalls can cause overlooking of large flocks. In areas with mixed flocks of dabbling ducks (e.g. wigeon and teal), it may be necessary to combine aerial and ground counts to identify and estimate the dabbling duck species composition accurately.

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Appendix I

Total number of 18 selected waterbird species recorded in 12 total counts performed from aircraft in the Danish Wadden Sea during one year (1984; one count per month), relative number of species (total number: 2,473,835 individuals) and the relative number of subareas in which the species occur (subareas with only one observation were excluded). The species' mean flock size and the number of flocks recorded are also shown, calculated from at least 30 total counts in the Danish Wadden Sea.

The seasonal distribution of these counts matched the distribution of counts used in the study. The following definitions of occurrence are used in the body text: A species was defined as occurring numerously if its numbers made up $>1\%$ of the total number of waterbirds counted in the Danish Wadden Sea on an annual basis (a minority species made up $<1\%$ of the total number of waterbirds counted in the Danish Wadden Sea at a yearly basis); a species was defined as occurring widespread if it occurred in $>30\%$ of the count areas and in large flocks if it's mean flock size is >30 individuals (a species was defined as occurring scattered if it occurred in $<30\%$ of the count sites, and in small flocks if it's mean flock size was <30 individuals).

Appendix I.

	Number		Occurrence	Flock size	
	Recorded	% of total	% of all sites	Mean	N
Brent Goose	70912	2.9	66.7	161.9	1173
Shelduck	86014	3.5	86.0	73.8	6396
Mallard	37485	1.5	71.9	66.4	2418
Wigeon	102040	4.1	61.4	200.5	2002
Teal	14409	0.6	26.3	96.2	565
Eider	184374	7.5	80.7	122.0	3245
Oystercatcher	181060	7.3	80.7	266.0	2157
Grey Plover	6555	0.3	61.4	19.1	1046
Dunlin	1200375	48.5	64.9	1721.0	2250
Redshank	7048	0.3	52.6	16.3	514
Greenshank	1548	0.1	28.1	9.7	287
Bar-tailed Godwit	63526	2.6	61.4	265.3	907
Curlew	1394	0.1	29.8	25.8	475
Black-headed Gull	107742	4.4	94.7	96.9	3047
Common Gull	83334	3.4	98.2	90.1	2581
Herring Gull	154768	6.3	100.0	109.5	3796
Great Black-bagged Gull	3964	0.2	71.9	7.7	1109
Common & Arctic Tern	2971	0.1	26.3	19.5	703
Total of selected species	2309519	93.4	-	-	-