Analysis of variance as a statistical method for analysing bird migration patterns

Ralph Tiedemann

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Results from bird counts are often not statistically analysed, though the possibility of biases due to counting errors or high turnover rates can make interpretation difficult. Here, a method is presented whereby counting results may be analysed by using a two-way analysis of variance on data which were transformed by a square root transformation. Using this method in migration studies, statistically significant differences in seasonal and annual (or spatial) migration patterns can be detected. The method assumes that the counts are standardized and the results are Poisson-distributed, at least for short distinct periods. The latter may not always be the case, but it can easily be tested by a Kolmogorov-Smirnov test on the transformed data. Applications of the method are demonstrated for wader migration studies in south-east Iceland.

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INTRODUCTION

Results of bird counts on migration are often not statistically analysed, despite the fact that biases occuring due to counting errors (Kersten et al. 1981; Rappoldt 1983) or high turnover rates (Moser & Carrier 1983), make comparisons of counting results difficult. When standarized counts are carried out during intervals of the study period, a chi^2-test for homogeneity has been suggested to compare interval sums (Niemeyer 1980). However, since many species migrate in flocks rather than as individuals, a single bird is not necessarily a single item in the sense of this test (Sokal & Rohlf 1981), and therefore it is often not suitable for analysis of bird migration patterns. Here, it is crucial to measure the variation in count results within distinct time intervals of the migration season and to compare it with the variation between such intervals. Only in the presence of significant additional variation between the intervals is there evidence for differences in migration patterns between them. Given that the data can be transformed so as to fulfil certain criteria of distribution, an analysis of variance is one possible method for testing such significance.

REQUIREMENTS OF THE DATA

A fundamental assumption is the use of a standarized method of counting in all bird counts to be compared. Then, an analysis of variance requires normal-distributed data. However, data fitting other distributions can often be transformed into normal-distributed data by simple transformation procedures (Sokal & Rohlf 1981). In theory, there is a true parametric mean number of present birds for a given place and a given time interval. Counting results deviate from this mean and it has to be the aim of a counting investigation to estimate this parametric mean (Sokal & Rohlf 1981). In bird counts, one may assume that counting results in a distinct time interval deviate randomly from the true parametric mean of the interval (Fowler & Cohen undated).

In migration studies, one has to choose short time intervals to minimise seasonal effects within the intervals. Following these presumptions, we expect counting results within the intervals to be Poisson-distributed (Figure 1). Poisson-distributed data can be transformed into normal-distributed data by computing their square roots (Sokal & Rohlf 1981). Since counts may include zero values the addition of 0.5 to each value prior to computation of square roots is recommended. If there is doubt about the distribution of data, a Kolmogorov-Smirnov test can assess the goodness of fit of the transformed data to a normal distribution.

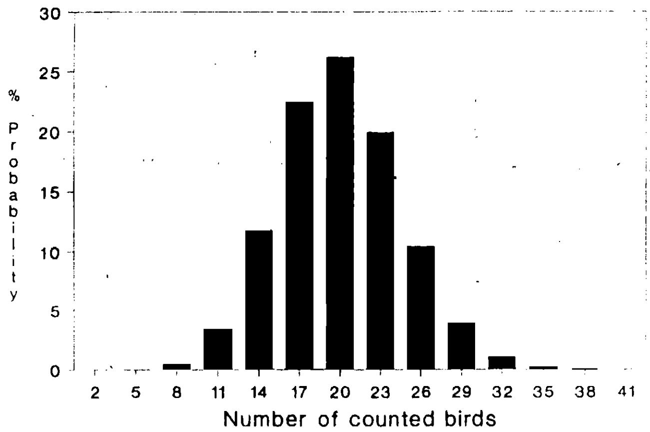


Figure. 1. Probability of different results of bird counts when counting results deviate randomly from the parametric mean 20 (Poisson-distribution).

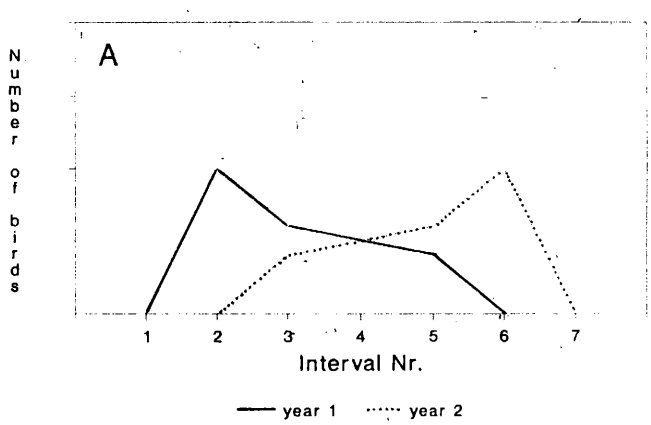
DIFFERENCES IN MIGRATION PATTERNS DETECTED BY AN ANALYSIS OF VARIANCE

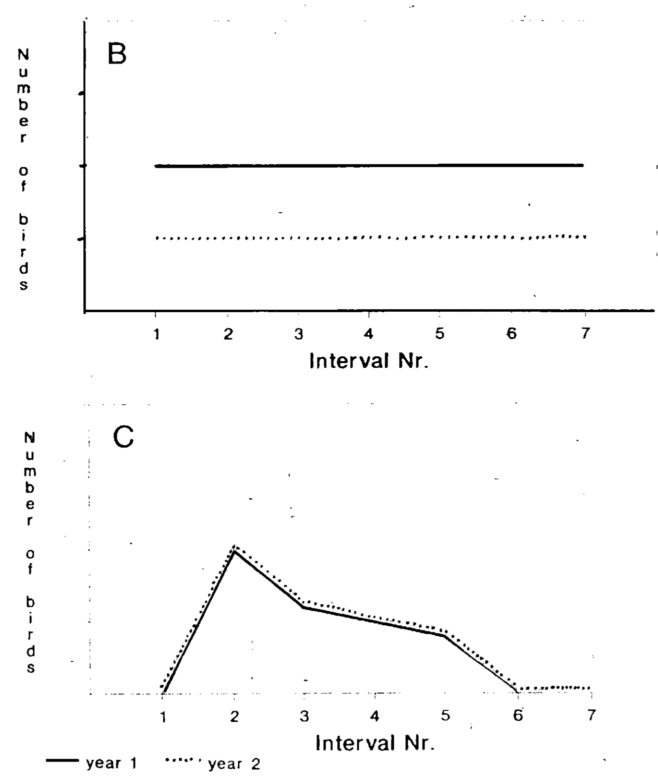
To explain how a statistical analysis on bird count data may function one can imagine a bird migration study based on counts lasting over a certain season of the year. The season has been divided into time intervals of equal length, and an equal number of standarized counts (at least two) has been carried out in each time interval. The study has been repeated for at least two years (alternatively at two places). Count results within a time interval are supposed to deviate by random from the true parametric mean. Hence the variation within intervals is defined as error. In this case one can apply a two-way-analysis of variance (ANOVA) having the different intervals of a season as factor A and the years (or places) as factor B. The two-way ANOVA will address three questions (see examples in Figure 2):

1. *Is there a significant difference in the migration phenology of different years (or places) (significant interaction between years (or places) and time intervals) ?*
2. *Is there a significant difference in bird numbers between the years (or places) ?*
3. *Is there a significant difference in bird numbers between the intervals ?*

All of these possible patterns of differences may occur in all possible combinations in bird migration.

Figure. 2. Examples for possible patterns of difference in bird migration: (A) difference in migration schemes between years, (B) difference in bird numbers between years, (C) difference in bird numbers between time intervals of the migration period.





Bird count analysis by a two-way analysis of variance: examples from wader migration studies in south-east Iceland

Here, the use of a two-way analysis of variance (ANOVA) is demonstrated on the results of wader counts carried out in south-east Iceland in spring 1988 and 1989 (Tiedemann 1990). The study period was from 21 April to 30 May in both years. Each study period was divided into 5-day-intervals (pentades) according to the scheme of fixed annual 5-day periods given by Berthold (1973). Therefore the study lasted for 8 pentades, beginning at pentade no. 23 (21-25 April) and ending with pentade no. 30 (26-30 May). Two counts were

Table 1. Count results for Black-tailed Godwit *L. limosa* from spring migration studies in south-east Iceland after square root transformation.

Pentade number		23	24	25	26	27	28	29	30
Year:									
1988	1.count	8.2	16.8	15.8	5.3	1.2	7.2	3.5	4.9
	2.count	8.2	8.2	10.7	9.6	5.3	6.2	0.7	0.7
1989	1.count	9.8	12.9	4.5	2.1	1.2	0.7	0.7	0.7
	2 count	11.0	3.5	4.2	4.5	0.7	0.7	0.7	0.7

Table. 2. Computation of a two-way-ANOVA on the numbers of Black-tailed Godwits *Limosa limosa* migrating through south-east Iceland in spring (SS = sums of squares; df = degrees of freedom; MS = mean squares).

Source of variation	SS	df	MS	F_S
Factor A (pentades)	376.82	7	53.83	$4.87 > F_{0.05[7,7]}{}^{*}$
Factor B (years)	90.93	1	90.93	$11.28 > F_{0.01[1,16]}{}^{**}$
Interaction between pentades and years	77.39	7	11.06	$1.37 < F_{0.05[7,16]}$ns
Within subgroups (Error)	129.00	16	8.06	

ns = p>0.05; * = p<0.05; ** = p<0.01

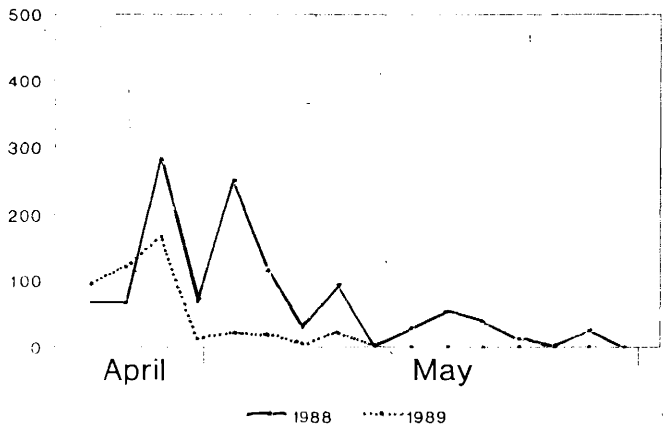


Figure 3 shows the numbers of Black-tailed Godwits *Limosa limosa* migrating through the study area in south-east Iceland. In Table 1, the same data are given after square root transformation.

carried out in each pentade. The computation of a two-way-ANOVA is shown in Table 2, using the transformed data from Table 1.

Prior to significance testing one has to determine whether the degrees of the factors A and B are fixed (Model I-type) or choosen by random (Model II-type). Here, the pentades were fixed since the aim of the investigation was to study wader migration in spring in these certain pentades. Years, on the other hand, were choosen by random without prior knowledge of their attributes (e.g. weather conditions), and theoretically any other year could have been choosen for such a study. Therefore a mixed model-ANOVA (Sokal & Rohlf 1981; Weber 1986) is computed with factor A fixed and factor B choosen by random. Hence the mean square of factor A was compared to the interaction mean square, the mean square of factor B and the interaction mean square were compared to the error mean square by computing their ratios (Fs-values).

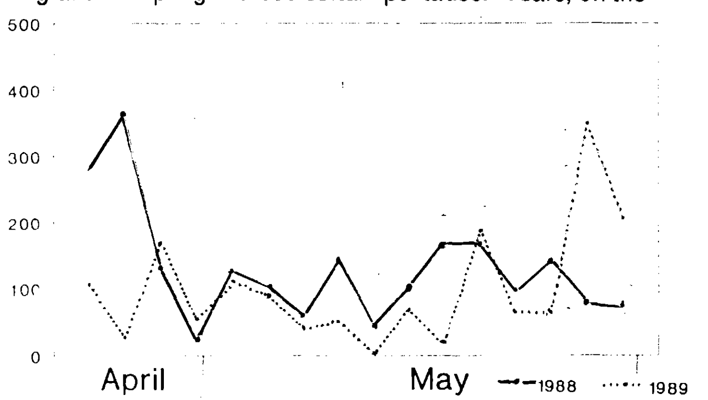


Figure. 4. Spring migration of the Ringed Plover *Charadrius hiaticula* through South-east Iceland.

Table 3. Computation of a two-way-ANOVA on the numbers of Ringed Plover *Charadrius hiaticula* migrating through south-east Iceland in spring (SS = sums of squares; df = degrees of freedom; MS = mean squares).

Source of variation	SS	df	MS	F_S
Factor A (pentades)	119.18	7	17.03	$0.63 < F_{0.05[7,7]}$ns
Factor B (years)	24.32	1	24.32	$2.76 < F_{0.05[1,16]}$ns
Interaction between pentades and years	188.42	7	26.92	$2.98 > F_{0.05[7,16]}{}^{*}$
Within subgroups (Error)	144.61	16	9.04	

ns = p >0.05; * = p<0.05.

In the case of the spring migration of the Black-tailed Godwit through south-east Iceland there were significant differences in numbers between pentades (p<0.05) and between years (p<0.01), but the migration scheme was not significantly different between study years, i.e. there was no significant interaction. These results thus indicate that migration maxima mainly occured in the same pentades in both study years, but significantly more Black-tailed Godwits migrated through the study area in 1988 than in 1989.

As another example, counting results for the Ringed Plover *Charadrius hiaticula* through south-east Iceland in spring are given in Figure 4. Here, a two-way-ANOVA (see Table 3) indicated a significant difference in the migration scheme between the study years (significant interaction between years and pentades, p<0.05).

CONCLUSION

It has been shown that counting results may be statistically analysed by ANOVA when the data fullfil certain requirements. It is important that bird migration studies based mainly on counts should be designed in a way allowing statistical analysis. A design with repeated standard counts may distinguish between differences in counting results caused by counting errors or high turnover rates and real differences in present bird numbers. As shown for the migration of the Black-tailed Godwit through south-east Iceland the differences in numbers between subsequent counts can exceed the differences between different periods due to high turnover rates, making an interpretation of such data difficult without statistical analysis. Moreover, these differences between subsequent counts indeed show the possible random effect, when only one count is carried out to investigate bird numbers of a certain period. However, there may be true differences in migration patterns between periods (or places) though the test did not indicate them. The probability of such type II errors decreases with an increase in the number of counts within subgroups (here within one pentade in one year), making the estimation of the counting error more reliable.

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The diaries of William Mudge, wildfowler

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There are few printed sources from which to reconstruct the size and variability of estuarine bird populations before modern systematic counting began. Hunters' records of the numbers of birds killed seasonally are a possible source of such information, but most such records have deficiencies which confound analysis. This article attempts to interpret the seasonal kills of William Mudge, a wildfowler (= hunter) who punt-gunned in Southampton Water and the Beaulieu River estuary on the central south coast of England between 1897-98 and 1952-53. A distinctive pattern of numerical change is evident, although it does not occur with equal strength in every species. Its main features are high kills associated with the First and Second World Wars and a low kill in the 1930s. Since the final entries in William Mudge's diaries the numbers of most species in the area have become much larger than those suggested by the diaries for the first half of the 20th century. It is tentatively proposed that these changes are in the main related to changes in hunting pressure, although it is not suggested that this was the sole influence on the changing status of every species.

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INTRODUCTION

The ornithological literature contains few direct indications of the size and variability of estuarine wader and wildfowl populations before the modern era of systematic counting began. In Britain wildfowl counts effectively began in 1952-53 and counts of all estuarine birds in most estuaries began in 1970-71 with the inception of the British Trust for Ornithology Birds of Estuaries Enquiry (BoEE), though in a few estuaries regular counts began in the 1950s or 1960s. Reconstruction of numbers and population changes in earlier times depends on piecing together fragments of evidence embedded in the literature and in unpublished manuscripts. In such sources most relevant allusions are of a general, qualitative kind. An interest in absolute numbers is a relatively recent phenomenon except in one particular respect: hunters often felt impelled to record the numbers of birds which they shot. Most such records are of limited value because they are inconsistent as to locality, selective, irregularly kept, summed over periods of years, unrelated to shooting effort, or possess other defects which confound analysis. This article is about the shooting records of a particular wildfowler (= estuarine hunter) which are remarkable because they lack most such defects and moreover span a long period of time.

William Mudge shot waders, ducks, Brent Geese *Branta bernicla* and other birds from ashore and from a gunning punt in Southampton Water, the Beaulieu River estuary and adjoining parts of The Solent, on the central south coast of England (Figure 1), from the summer of 1897 until at least February 1952. He maintained a diary of his activities which for the most part is a daily narrative, although 1906-1920 is contained in a single long entry for the latter year (following his return from the First World War) and the period of 1920-