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Changes in the distribution of species between two bird atlas surveys: the analysis of covariance after controlling for research activity

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Heterogeneous coverage of data is a serious problem in atlas mappings, because it may bias the interpretation of maps and cause difficulties in statistical tests of distribution changes of species between successive atlas surveys. The areal coverage of the Finnish bird atlases during the years 1974–1979 and 1986–1989 was evaluated by the research grade of 10 × 10-km atlas squares, using six categories (0 = no data, 1 = occasional observations, 2 = fair survey, 3 = satisfactory survey, 4 = well-surveyed, and 5 = thoroughly surveyed square). The research grade of each atlas square was calculated by applying regression analysis on the sum of breeding evidences of species, coded 1 = possible, 2 = probable and 3 = confirmed breeding. Also, the amount of land area, latitude and the presence of coastal habitats in the square were taken into account. The analysis of covariance was applied to analyse changes in the distribution of species, using only such squares that were studied at least fairly well in both atlases. The squares were evened out to represent "equal" research activity by using the research grade as covariate. Statistical significance was calculated for (a) changes in the distribution of each species between the atlas surveys and (b) the areal homogeneity of the change. In 20–25% of Finnish breeding birds the increase in research activity between the atlas surveys biased the analysis. To keep the data comparable, conservatism is suggested for the reforms of atlas methodology.

1. Introduction

Following the pioneering work of Sharrock (1976), numerous distribution atlases of breeding birds have contained species-specific maps. Distributions are presented using squares of regular size, most often 5 × 5 or 10 × 10 km, and include symbols of possible, probable and confirmed breeding. The atlases generally also contain a map of the total number of species which have been found in each square. This map shows geographical trends in species richness that may, however, be masked by variations in research activity. The bias is probably most serious in distant areas with barren habitats and few local observers of birds.

When the breeding bird atlas survey is repeated, one of the main goals is to elucidate the distribution changes of species. A good method for doing this is the comparison of the maps of the two atlases, because the human eye can detect even rather complicated changes. Such a descriptive effort becomes easily cumbersome, however, especially if there are notable areal changes in research activity between the atlas surveys (Högmander 1995, Högmander & Møller 1995). Furthermore, the statistical significance of the changes is often doubtful. These problems imply that we need robust statistical methods to compare the possible changes reliably.

Buckland (1990) has applied such a method to study which bird species showed significant changes between two atlas surveys. For a given species, each square was classified according to whether there was some or no evidence of breeding in each survey. Squares for which there was no evidence of breeding in either survey or some evidence in both were excluded since neither provided evidence of a change. A binomial test indicated whether change between the remaining squares was significant.

In cases where the study effort has been about equal in the two atlases, the method of Buckland (1990) is easy to use. However, it ignores information on the strength of evidence of breeding of the species. Furthermore, differences in research activity can bias comparisons, because the squares studied are not necessarily equally representative in both atlases.

Ideally, one should use only squares that were studied reasonably well in both atlases, even out any differences caused by varying research activity and take into account variations in breeding evidence.

2. The model

The dependent variable is the breeding evidence of a bird species in a square, identified as follows: 0 = not observed (or observed but does not breed in the square), 1 = possible, 2 = probable and 3 = confirmed breeding. The breeding evidence is an ordered variable. Thus, the difference in magnitude between class values 0 and 1 apparently is not identical, say, to the difference between 2 and 3. Anyhow, differences between the successive values are here assumed to be satisfactorily similar so that the breeding evidence is used as a continuous variable.

The mean calculated from such data will be a rough approximation. When the effect of research activity is corrected for from the mean, we obtain an adjusted mean of breeding evidence, which in this paper is also called a distribution index. However, in a demanding statistical test, the basically nonparametric nature of the breeding evidence will be taken into account.

The concept of research grade of an atlas square was developed during the second Finnish bird atlas survey. Basically, it measured the areal coverage of the fieldwork (Väisänen 1989). The original purpose was that distribution maps of species become more informative when the research grade is represented in the background. Observer(s) of each square, together with the regional atlas organiser, evaluated the research grade after each atlas year 1986–1989 using categories: 0 = no data, 1 = occasional observations, 2 = fair survey, 3 = satisfactory survey, 4 = well-surveyed, and 5 = thoroughly surveyed square (more accurate criteria in Väisänen 1989: Table 2).

During the last years of the atlas survey it became apparent, however, that in 20–30% of the squares the research grades were still missing or had not been updated correctly. Accordingly, the first (and more practical) problem of this paper concerns the extrapolation of the missing research grades. These will be predicted on the basis of information on those squares where the research grade is already evaluated, by applying multiple regression analysis.

The formulae are developed separately for each category of research grades (1–5), by using the sum of breeding evidences of species (BS) within each atlas square as a dependent variable (statistically it would be better to use some other information in standardising the census effort — e.g. observation days or hours — but such data were not available from the Finnish bird atlas squares). The amount of land area and latitude are used as independent variables, because the area generally correlates positively with the number of breeding bird species present, and within the boreal zone species richness becomes less from south to north (Järvinen & Väisänen 1979). Furthermore, because sea birds contribute to a notably higher species richness, separate models will be developed for the Baltic coasts.

These regression formulae will be used to estimate research grades for all atlas squares studied in the first (1974–1979) and in the second breeding bird atlas of Finland, and for the combined data of the two atlases.

My second and more theoretical statistical problem concerns how to utilise the research grades by evening out the squares to represent "equal research activity", which would make efficient analyses of distribution changes between the two atlas surveys possible.

In developing the research grades the goal was to have a linear measure of research activity so that the differences between successive grade values are satisfactorily equal. However, the distance from 0 (no data) to 1 (occasional observations) is obscure, and from 1 to 2 (fair survey) rather inaccurate. In the following models it is thus advisable to base calculations on squares which have been studied at least fairly well in both atlases.

Let the research grade (G) be used as a covariate in an analysis-of-covariance-model, where variation in the breeding evidence (B) of a certain bird species will be studied. When atlas (A) is also taken into account (1 = the first, 2 = the second breeding bird atlas), we have two continuous variables, B and G, and the class variable A in the mathematical model

eq. 1. $$B_{ij} = \mu + A_i + b\,G_{ij} + e_{ij}$$

$$i = 1, 2 \qquad j = 1, 2, \ldots, n_w$$

where A_i represents atlases, G_{ij} represents research grades of atlas squares, n_w is the number of atlas squares in each atlas (w = 1, 2), μ is the overall mean, β is the regression coefficient of G on B and e is the random error.

Within a bird species, this model evens out the squares to represent "equal" research grade, produces distribution indices (adjusted means of the breeding evidence) for the two atlases and also calculates statistical significance for the distribution change between the atlases.

From this fairly simple model we may advance to more informative ones by adding various class variables of the squares. For example, location (L) of the square can be used, so that 1 = southern and 2 = northern Finland (north of Finnish uniform grid 710). Note that L will not be included as a covariate but as a new class variable, although alternatively L could be used as a regressor, being the south-north uniform coordinate of the square. The interpretation of the adjusted breeding evidence is complicated in the model of two or more covariates.

The mathematical model for these data is

eq. 2. $$B_{ijk} = \mu + L_i + A_j + L\,A_{ij} + b\,G_{ijk} + e_{ijk}$$

$$i = 1, 2 \qquad j = 1, 2 \qquad k = 1, 2, \ldots, n_w$$

where L_i represents location effects, A_j represents atlases and G_{ijk} represents research grades of atlas squares.

Furthermore, as noted above, it is unlikely that in B the successive distances between the four original classes of breeding evidence are equal. To reach statistically better distributions, the breeding evidences of the squares can be transformed into ranks within each species, which produces a new variable BR.

3. Material and methods

The data come from the first (Hyytiä et al. 1983, Koskimies 1989) and the second (Väisänen et al. 1998; field methods in Väisänen 1989) Finnish bird atlases. Finland is about 1 100 km long from south to north and extends through the boreal zone, and contains 3 857 squares of 10 × 10-km . Bird atlas data have been gathered from 3 813 or 99% of the squares.

3.1. Manipulation of data for the calculation of research grades

Land and water areas of the atlas squares were estimated from sc. GT maps (scale 1:200 000) using classes < 1, 1–5, 6–14, 15–24, ..., 85–94, 95–99 and > 99 km². Accuracy was thus generally 10 km², except at the ends of the scale. In the final phase of the project it became possible to check the area estimates from satellite image data, where pixel size was 16 × 16 m.

The sum of breeding evidences (BS) was obtained by giving the following values to species found in the atlas square: 1 = possible, 2 = probable and 3 = confirmed breeding. For comparisons between BS and original research grades (GX) received from the observers and atlas organisers, the atlas squares were divided into three classes: inland squares, which contain at least 50 km² of land inland or at least 85 km^2 of land on the coast; indigent squares, which contain less than 50 km^2 of land either because of extensive coverage of lakes or location on the state boundary, and coastal squares, which contain more than 85 km^2 of sea.

Probably some observers had given unreasonably low or high research grades to their squares, because the original descriptive instructions of the research grades (Väisänen 1989: Table 2) left room for interpretation. The elimination of potential errors from values 2–5 was made in the following way:

1) Such squares were excluded (197 squares out of 2 289; 9% of cases), in which the number of species was relatively low in the second atlas compared with the combined data of the two atlases. The rule of thumb was that in fairly surveyed squares (class 2) the difference in species number was allowed to be at most 40 species, in satisfactorily surveyed (class 3) at most 30 species and in well-surveyed (class 4) or thoroughly surveyed squares (class 5) at most 20 species. This operation eliminated such squares which were studied very differently, e.g. by sampling different habitats in the two atlas surveys. During the second atlas survey, the observers received lists of the accumulation of species in the squares studied by them, and these lists facilitated the detection of habitats that had been studied poorly in the first atlas survey.

2) To exclude coastal squares containing small amounts of land areas, those squares with less than ten bird species found in the second atlas were omitted (21 squares out of 360; 6% of cases). Such squares, which also generally contained less than 0.5 km^2 of land, would have had unreasonable weight, because the area was included in logarithmic scale in the formulae. The exclusion was not based on the land area of the square, because the measure was relatively inaccurate; further, it was difficult to know if these small land areas were proper nesting sites. Also, the classification based on the satellite data could not be applied here. Especially in the northern Gulf of Bothnia there are extensive shallow areas which may be classified into water or dry land depending on the sea level.

The stepwise regression analysis used for the calculation of research grades is described in many textbooks and also in Järvinen and Väisänen (1977).

3.2. Manipulation of data for covariance analyses

In this phase, the research grade values (G) used in statistical manipulations are those estimated by the regression methods.

In the analysis of covariance only those 10-km squares are used that represent at least the research grade category 2, meaning "fair survey" in both atlases. The original minimum requirements for such a standard were (Väisänen 1989): "breeding birds of the most common habitats have been surveyed, but only in a small part of the area; if valuable bird sites (e.g. wetlands) are known to exist in the square, some have been checked".

Data are also eliminated on the basis of the breeding evidence. To exclude squares, where geographical location and habitat scale make the occurrence of the species unlikely, only those squares are included from which there is at least one observation of at least possible breeding from either of the atlases. Thus, those squares are excluded where the breeding evidence is null in both atlases.

The remaining breeding evidences are transformed into ranks, which are corrected for ties, within each species and the covariance analyses will be computed both on the original and the transformed data (SAS Institute 1990). In the results, the adjusted means of breeding evidence are presented from the original data, because these are more understandable than the means based on ranks. Related statistical tests are, however, based on the ranks, because these apparently are statistically more appropriate (see Introduction). The models based on the ranks (BR) generally explain a slightly higher proportion of variation of the dependent variable than the models based on the original values (B).

4. Results

4.1. Evaluation of research activity

4.1.1. Inland squares

Data on the different categories of research grades represented the original interpretation made by observers and local atlas organisers in the second bird atlas of Finland. Regression models were developed for the four highest categories: fair survey (536 squares), satisfactory survey (569), well-surveyed (449) and thoroughly surveyed (147).

The total number of breeding species declines with higher latitudes from southernmost Finland to Lapland. Also, the sum of breeding evidences of species in an atlas square decreases with the south-north coordinate values. The curve-fitting procedure applied in Fig. 1A shows that within the research grade categories the change is rather linear, on average. Values 664–740 of a uniform grid can thus be used to predict the dependent variable BS in linear regression within each research grade category. When the east-west coordinate, land area or lake area of the atlas square were added to the linear regression models, the proportion of variation explained did not significantly increase statistically.

North of coordinate 740, the variable BS does not decline anymore with latitude. The right-hand tails of the curves turn slightly upwards in Fig. 1A, although this trend is weak in the two uppermost curves. There are, however, relatively few atlas squares representing well or thoroughly studied squares from northernmost Lapland. These data points do not have enough weight to raise the right-hand tails of the second order polynomials.

The results of various statistical and graphical analyses are presented in simple form in Fig. 1B. By setting a ruler along the y-axis, one may read the minimum BS values needed for different research grades in certain coordinate zones. In the south, the lines depicting the lower limit of the three highest research grades run parallel, so that BS decreases by 1.6 units per 10 km until the northern coordinate 740. In drawing the limits, I assumed that observers and local atlas organisers have generally been modest in giving research grade values for their squares. Thus, the regression lines of BS values run in the upper parts of belts depicting each research category.

Vertical distances between the lines separating the research categories are related to the standard deviations of the variable BS. So, for example, the belt resulting in the satisfactory survey is 50% wider than the belt resulting in a well-surveyed square, because the standard deviation of BS is larger in the former category. The satisfactory survey was the basic goal for all atlas squares. This status had apparently been better accepted for the square than the status of well-surveyed, which is seen in the differences of the variance of BS.

When interpreting the wide vertical dispersal of BS values of fair survey in Fig. 1A, one should remember the biases of the data mentioned above — the largest values, for example, in reality mostly belong to higher research categories. The line depicting the minimum requirement for the fair survey in Fig. 1B could be drawn in the south only rather roughly on the basis of distributions of BS values of the two lowest research grade categories.

4.1.2. Indigent squares

Indigent squares contained less than 50 km^2 of land either because of extensive coverage of lakes or their location on the state boundary. Data of the original research grades were scarce: fair survey (46 squares), satisfactory survey (41), well-surveyed (26) and thoroughly surveyed (4).

The indigent squares represent typical inland squares, where the limits of the research grades may be determined on the basis of a south-north coordinate (Fig. 2). The number of breeding bird species is, however, lower compared with the nearby whole squares. It was compensated for by the following rough method: BS of indigent squares was multiplied by 1.25 and after that the principles of Fig. 1B were applied to calculate the research grades.

4.1.3. Coastal squares

For coastal squares the data of the original research grades were: fair survey (47 squares), satisfactory survey (81), well-surveyed (90) and thoroughly surveyed (66).

The number of species and the sum of breeding evidences of the coastal squares can be predicted by land area (Fig. 3A). South-north or east-west coordinates do not improve the regressions. The total number of breeding bird species is thus rather similar all along the Finnish coasts. Good bird habitats occur along the whole coast. The importance of the latitude is not so great as in inland squares, because the distributions of several south-

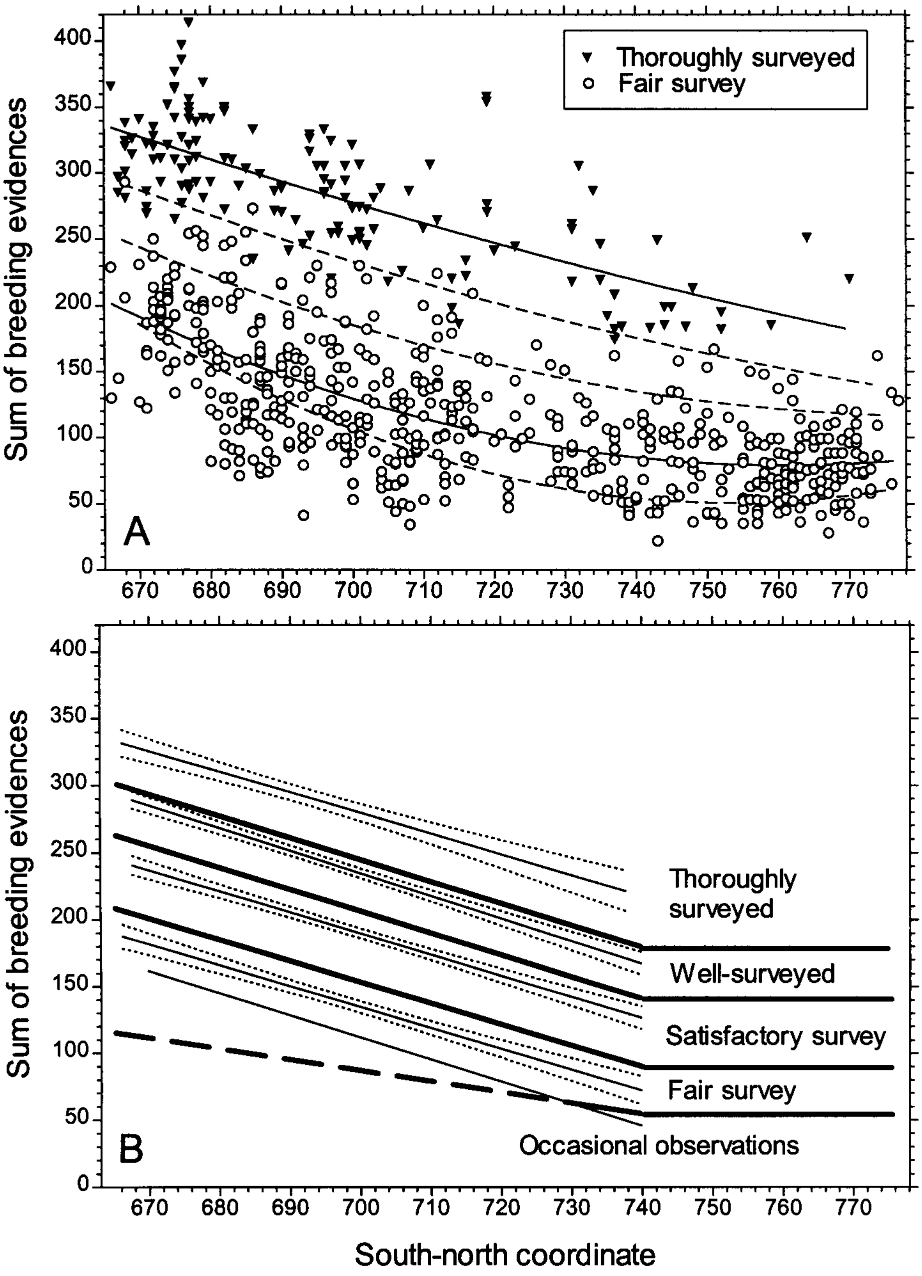

Fig. 1. Relation between south-north coordinate (L) and the sum of breeding evidences of species (BS) of an atlas square in the inland of Finland. A: Curves have been obtained by nonlinear regression, by fitting second-order polynomial equation $BS = \alpha + \beta_1 L + \beta_2 L^2$. To keep the figure understandable, original data points are shown only for thoroughly surveyed and fairly surveyed squares. The curves for these two research grades are shown as solid lines, and those for three others (list in Fig. B) are shown as broken lines. B: Simplified model for estimation of the research grades of an atlas square from the sum of breeding evidences of species. For example, in southern Finland at zone 670, BS values 112–201 (range between thick lines) result fair survey, 202–255 satisfactory survey, etc. Within the four highest research grades, linear regressions with 95% confidence intervals are shown by thin lines. North of the zone 740 the directions of the regression lines change, because the decrease in the number of southern species and the increase in the number of northern species balance each other.

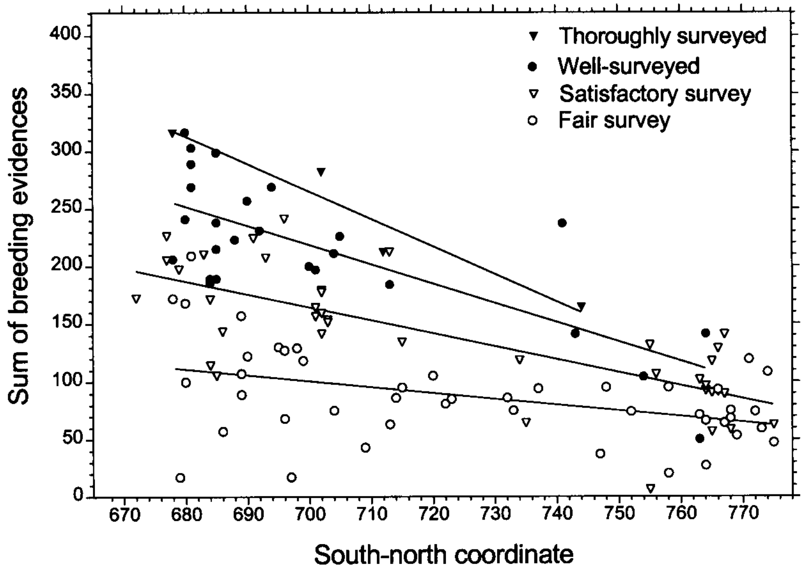

Fig. 2. Relation between south-north coordinate and the sum of breeding evidences of species of indigent atlas squares, which contain less than 50 km² of land. Linear regressions have been calculated separately for the four highest research grades. Indigent squares resemble "impoverished" inland squares.

ern species extend northwards along the coast of the Gulf of Bothnia, where there are, on the other hand, proper habitats for northern species (e.g., Willow Grouse *Lagopus lagopus*, Temminck's Stint *Calidris temminckii* and Red-necked Phalarope *Phalaropus lobatus*).

The species richness and the sum of breeding evidences of the atlas square increase from the outmost archipelago towards the coastline and reach maximum when the proportion of land is about 80%. Maritime and inland habitats are then both present. A rather ordinary coastal area brings about ten sea bird species into the square, and in a square located in a rich archipelago about 20 sea birds may breed. Thus, the limit values of the research grades are even higher in coastal squares with land area of 70–80 km² than in the southernmost inland squares (cf. Figs. 1B and 3B). Coastal squares with 90 km² of land are already included in inland squares, because their nature mainly has an inland character, e.g., the avifauna of large bays resembles that of lakes.

4.1.4. Special squares and final distribution of research grades

Research grades calculated by the same formal principles do not necessarily fit for all atlas squares. Preliminary results of the classification were sent for evaluation to the local atlas organisers. On the basis of the inspection of maps and bird atlas observations, they corrected the research grades of 229 squares (6% of the total) that have especially rich or poor composition of habitats. These are called special squares.

Final distributions of research grades were rather similar in the first and the second bird atlas of Finland (Table 1). A satisfactory standard or better was reached in about half of the squares in both atlases. In the second atlas, the observers were asked to pay special attention to those squares that had been studied poorly in the first atlas. So the fieldwork was conducted partly in different squares in the two atlases. In their combined data, a satisfactory or better standard is reached in about 2 900 squares or 77% of all cases, and even one out of three squares has the highest research grade. If the distribution of a species has not changed notably between the atlases, the distribution map based on the combined atlas is most informative.

4.2. Analysing distribution changes

Three common birds from the family of thrushes are first analysed as examples (Fig. 4). Distributions of evidence of their breeding are presented in Table 2. For the Redstart, the number of probable breedings increased and possible breedings

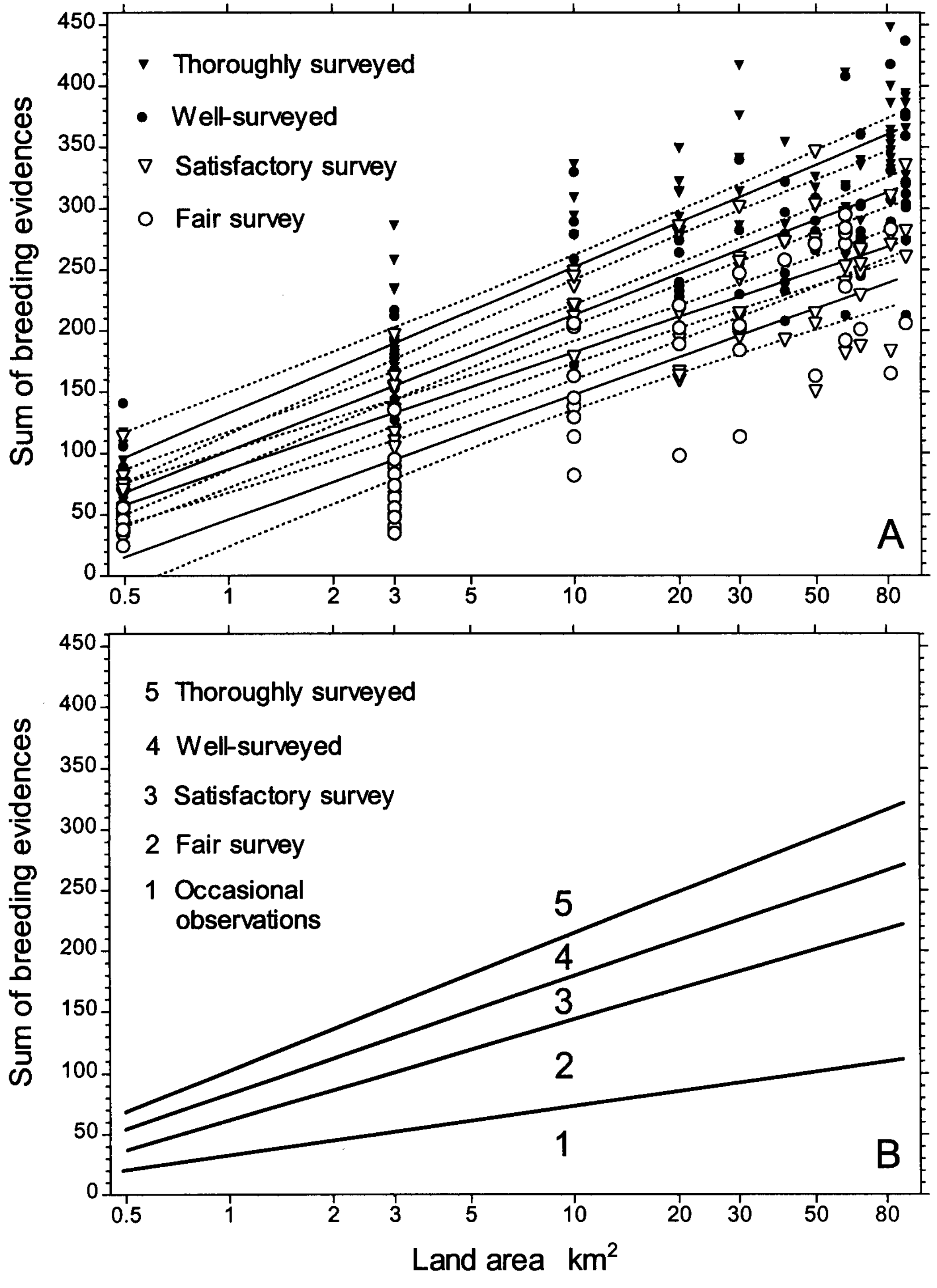

Fig. 3. Relation between land area and the sum of breeding evidences of species of an atlas square on the coast of Finland. A: Regression lines with 95% confidence intervals in the four highest classes of the research grade of the squares (note the logarithmic scale of the x-axis). B: Simplified model for estimation of the research grade of an atlas square from the sum of breeding evidences of species (cf. Fig. 1B). The result is rather inaccurate, if the land area is 0.5 km² or less. If the land area is more than 85 km², use Fig. 1B.

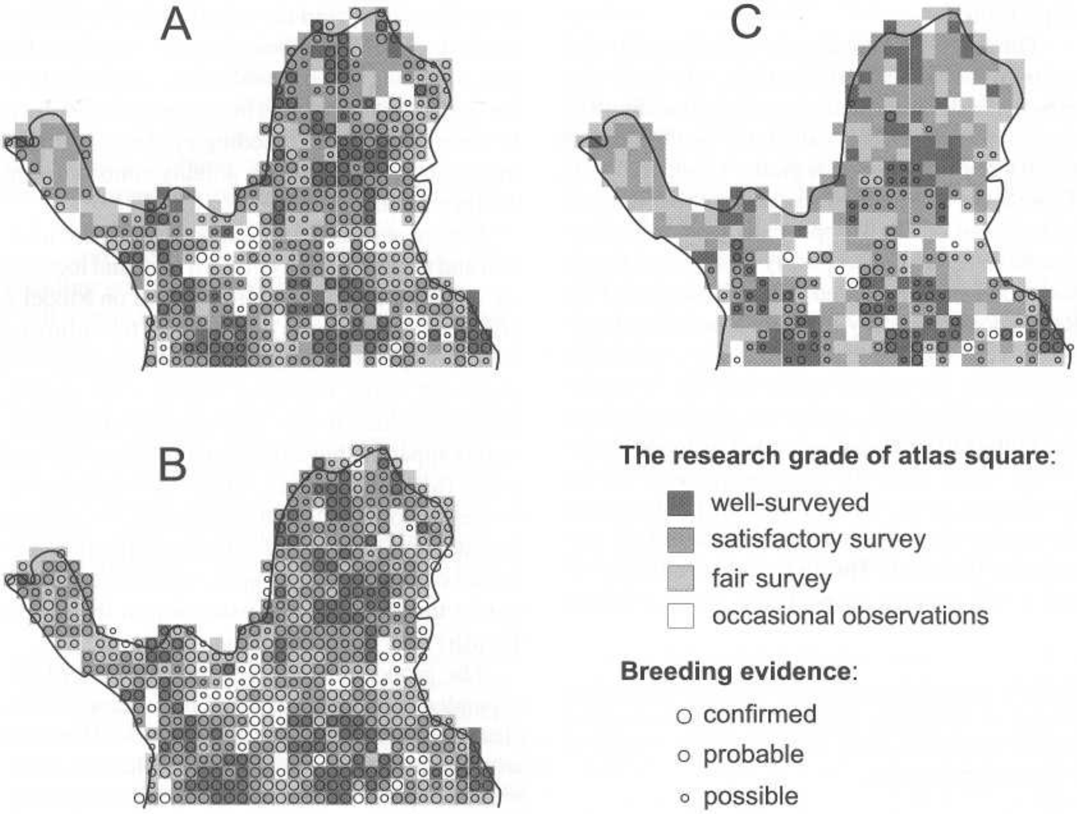

Fig. 4. Part of the atlas maps of the Redstart *Phoenicurus phoenicurus* (A), Redwing *Turdus iliacus* (B) and Mistle Thrush *T. viscivorus* (C) from north Finland, showing the combined data of the two atlas surveys (1974–1979, 1986–1989). Breeding evidence indicates the certainty of nesting of a species within a 10 × 10-km square. The three categories are shown by circles (explained by the maps), and they indicate (from smallest to largest) possible, probable and confirmed breeding. One should relate these to the research grade of the square, which measures the quality of the coverage of the data. The research grade is shown by background shades of grey of the atlas square, which are also explained by the map. Thus, the paler the squares are, the less information is available, and most of the species have low indices of breeding evidence. The darker the squares are, the better the whole avifauna is known, and most of the species have high indices of breeding evidence. Most distribution gaps of these species are situated in areas where survey activity has been insufficient. There are real gaps in the distribution of the Redstart and the Redwing only in treeless areas of the northernmost mountains. The Redwing is one of the most widely distributed species in Finland. It may breed even in tiny birch scrub. Thus, it has a wider distribution in mountain areas than the Redstart.
The numbers of the Mistle Thrush decrease towards the north and the bird is almost lacking in the birch zone of northernmost Lapland. It favours barren pine forests in Finland, which are often situated in poorly studied, distant areas. Because the bird is, as measured by the number of breeding squares, about 30% rarer than the two other examples, one may detect more details from the distribution map.
Atlas maps and their interpretation are from Väisänen et al. (1998), which also includes the maps of the second survey (1986–1989), together with density maps.

decreased between the atlas surveys. For the Redwing, the number of squares with confirmed breedings decreased, but the number of squares of probable breedings increased. However, the total number of breeding squares indicate a significant change only in the Mistle Thrush ($P < 0.001$; Chi-square test), which strongly extended its area between the atlas surveys. Movements of the centres of gravity of the breeding squares proved to be ineffective indicators of changes in distribution (Table 2).

The analysis of covariance was first computed using Model 1 (see Introduction), where the distribution index (adjusted mean of the breeding evidence) in the atlases is calculated by eliminating the effect of the research grade. Compared with Table 2, the amount of data decreases but its quality increases (Table 3: upper part), because squares that have been studied poorly in either of the atlases have been excluded. The distribution of the Redstart expanded by 0.07 units between the atlas surveys, but the change was not statistically significant. The distribution of the Redwing decreased highly significantly (new observation) and that of the Mistle Thrush extended, as found above.

To verify how the average increase of the breeding evidence by 0.27 units in 1 630 squares accumulated, cf. Table 2. In the first and the second atlas the Mistle Thrush was observed in 1 342 and 1 642 squares, respectively. Some of these were discarded from the calculations for Table 3 on the basis of low research grade. Anyhow, the data contained several hundreds of squares, where the species was observed in the second atlas only. In these squares the breeding evidence changed from 0 to 1, 2 or 3, which notably contributed to the increase of the mean.

New useful details appear when the terms location and the interaction between atlas and location are added in the computations based on Model 2 (Table 3: lower parts). Note that the adjusted means of the whole of Finland are averages of north and south, thus they may deviate slightly from the values above. The stability of the Redstart is apparent, but strong interactions are found in the two other species. Adjusted breeding evidences of north and south and related P-values of the interaction terms indicate that northern populations changed more abruptly (accelerated reduction in the Redwing and extension in the Mistle Thrush) than the southern ones.

The proportions of the total variation of the dependent variable accounted for in these examples generally range from 15% to 20%. These are around the median (17%) among the 203 common bird species of Finland in which these calculations were repeated. Whole models and the slopes of the covariate were in most tests highly significant ($P < 0.001$). In seven species, the whole model was not significant ($P > 0.05$). In six cases, this was related to the small amount of data (6–10 squares) from the north or from the south. The seventh case was the Golden Eagle *Aquila chrysaetos*, for which the majority of the atlas data was taken from an extensive national monitoring project (in Model 2 test 203 squares from the north and 39 squares

Table 1. Relative distributions (%) of the research grades of 3813 atlas squares in two breeding bird atlases of Finland (1976–1979 and 1986–1989) and in their combined data.

Survey category	1st Atlas	2nd Atlas	Combined Atlas
No data	2	2	0
Occasional observations	22	23	6
Fair survey	28	21	17
Satisfactory survey	22	23	25
Well-surveyed	13	16	18
Thoroughly surveyed	13	15	34
Totals	100	100	100

Table 2. Number of 10 × 10-km squares in which the Redstart, Redwing and Mistle Thrush were observed in the first (1974–1979) and in the second breeding bird atlas survey (1986–1989) of Finland. Average coordinates of the squares in the national uniform grid in south-north and west-east directions are shown below (in km ± sd).

	Redstart		Redwing		Mistle Thrush	
Atlas	1st	2nd	1st	2nd	1st	2nd
Confirmed breeding	1406	1428	2419	1887	404	481
Probable breeding	595	833	485	856	311	570
Possible breeding	663	468	409	415	627	591
Total no. of squares	2664	2729	3313	3158	1342	1642
North km	706 ± 28	706 ± 28	707 ± 29	707 ± 30	697 ± 23	702 ± 26
East km	44 ± 13	44 ± 13	44 ± 13	44 ± 13	44 ± 13	44 ± 13

from the south). Here, the slope of the covariate was not significant and the whole model performed poorly ($R^2 = 0.9\%$).

The extent of the distribution of species can be compared on the basis of the number of qualified squares (column N in Table 3). The minimum requirements for such squares were that they had been studied at least fairly well in both atlases, and that for each species at least possible breeding was found in either of the atlases.

By applying Model 1, the analysis of covariance was computed separately in 235 bird species breeding annually in Finland, and the resulting adjusted breeding evidences were plotted against the numbers of qualified squares (Fig. 5). Although the breeding evidence is on average higher in common species than in rare species, it varies too much to reliably reflect differences in distribution among species. The group of extreme species is presented in the box (see Fig. 5, upper left corner). Categories of high breeding evidence, which can easily be recorded for the common seabirds along the Finnish coasts (symbols of several other seabirds are below the box), do not necessarily indicate a wide distribution of these birds.

The number of qualified squares is an abstract number. A more understandable index can be obtained by relating the number of qualified squares to the most common bird. In Finland, the White Wagtail *Motacilla alba* has apparently occupied almost all atlas squares. With 2 322 qualified squares it deserves an index value of 100. The most rare regular breeder of the atlases, the Barnacle Goose *Branta leucopsis*, was found in seven qualified squares, which resulted in an index value of 0.3.

For raptors, which experienced increased research activity between the atlas surveys, a corre-

Table 3. Distribution indices (adjusted breeding evidences from the analysis of covariance) for three bird species in the first and the second bird atlas of Finland and in their combined data. N depicts the number of 10-km squares enclosed. These have been studied at least fairly well and belong to the breeding area of the species (at least possible breeding has been noticed). In the first part (whole Finland) is a simple test of distribution change within each species between the atlas surveys (P = statistical significance). The analyses below (Redstart, Redwing, Mistle Thrush) show the development in northern, southern and whole Finland. There the lower P-value indicates change in whole Finland between the atlas surveys and the upper P-value warns of areal interactions. R^2 means the proportion of the total variation of the dependent variable (BR) accounted for by the model.

	Atlas combined	(N)	Atlas 1st	Atlas 2nd	Change	P	R^2 %
Whole Finland							
Redstart	2.19	(2187)	2.15	2.22	+ 0.07	0.196	22.8
Redwing	2.63	(2266)	2.72	2.53	− 0.19	0.000	15.5
Mistle Thrush	1.41	(1630)	1.28	1.55	+ 0.27	0.000	13.0
Redstart							
North	2.19	(730)	2.17	2.22	+ 0.05	} 0.419	
South	2.19	(1457)	2.15	2.23	+ 0.08		
Whole Finland	2.19	(2187)	2.16	2.22	+ 0.06	0.339	22.9
Redwing							
North	2.50	(764)	2.65	2.35	− 0.30	} 0.000	
South	2.69	(1502)	2.76	2.63	− 0.13		
Whole Finland	2.63	(2266)	2.70	2.49	− 0.21	0.000	18.2
Mistle Thrush							
North	1.30	(481)	1.04	1.57	+ 0.53	} 0.000	
South	1.46	(1149)	1.38	1.54	+ 0.16		
Whole Finland	1.41	(1630)	1.21	1.55	+ 0.35	0.000	14.0

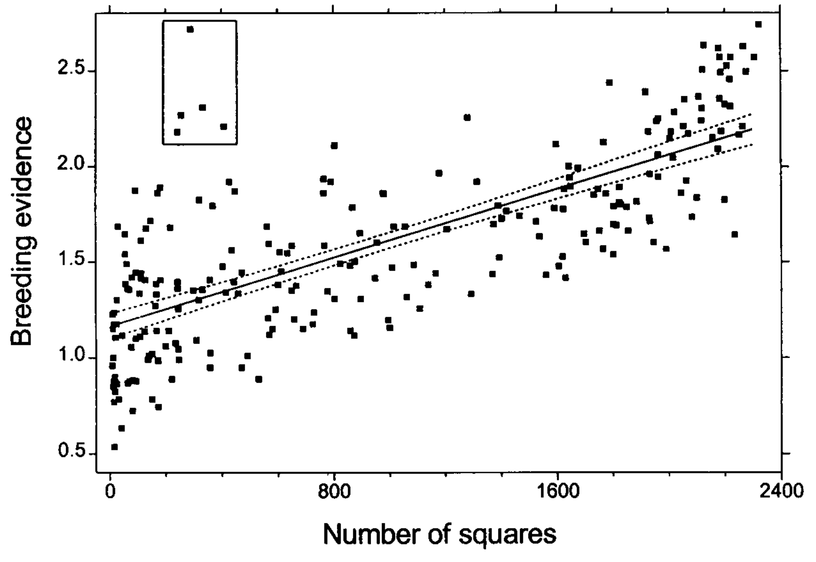

Fig. 5. Relation between the number of breeding squares and the distribution index (adjusted breeding evidence, mean of the values of two Finnish atlases) in 235 species. Regression is y = 1.16 + 0.000448x, meaning that on average the distribution index increases 0.45 units when the number of squares increases by 1 000. The box depicts five outliers (from top: *Somateria mollissima, Arenaria interpres, Cygnus olor, Haematopus ostralegus* and *Cepphus grylle*).

sponding increase in the distribution indices was apparent and was most prominent in rare species (Fig. 6).

5. Discussion

5.1. Quality of research grades

Biases in research grades are most probable in the following types of atlas squares:

1. Squares with very rich avifauna may be given too high research grades. If the atlas square contains a diversified selection of habitats and bird sites, even a rapid inspection may result in a rather high sum of breeding evidences of species. A research grade calculated from it would probably be an overestimate.

2. Squares with very poor avifauna may be given too low research grades. If the square has a poor selection of habitats and no bird sites, even a thorough inspection results in a rather low sum of breeding evidences of species. A research grade calculated from it would probably be an underestimate of research activity. The same may hold true for coastal squares with limited land areas and for the smallest indigent squares on state borders.

3. Research grades of the coastal squares may easily be under- or overestimates. A mechanical classification based on land area and on the sum of breeding evidences of species may result in an overestimate, if the square contains, e.g. bird islands, rich wetlands, rich forests and cultural landscapes. The result may be an underestimate, if the land area comprises islands with pines or a barren piece of coast. Research grades of coastal squares thus probably contain more errors than those of inland squares.

Despite my reservations, I believe that the majority of the research grades calculated here for the atlas surveys are correct. Errors of plus or minus one category are possible, but those of two categories would hardly have passed through the checking. This conclusion is also based on the fact that large, homogenous habitat blocks, which would cause difficulties in classification, are rare in Finland. Most 10 × 10-km atlas squares contain a mixture of four main habitats (forests, peatlands, fields and lakes). This was seen in the scarcity of "special squares" (6% of cases), for which the calculated research grades were clearly not correct.

Preliminary versions of the research grades presented here were incorporated into image analysis, where Högmander (1995) and Högmander and Møller (1995) estimated the ranges of some breeding birds in central Finland. They showed that efficient modelling of atlas maps becomes possible by using Monte Carlo methods.

5.2. Measures of distribution

In this study, the distribution of a species was equalised with the number of bird atlas squares occupied in Finland. The geographical location of the occupied squares was analysed only coarsely by dividing the country into two parts. Furthermore, data on the number of pairs living in each occupied square were lacking. Thus, the possibilities of elucidating the two facets of the term distribution — the extent of occurrence ('gross range') and the area of occupancy (number of sites occupied) (Gaston 1994) — were limited. However, strong support for such a generic usage of the term distribution is received from the fact that among British birds there is an extremely tight relationship between a species' abundance and distribution (Newton 1997), and that for most Finnish land birds changes in abundance and distribution have showed a similar trend from the 1970s to the 1980s (Väisänen et al. 1998).

Distribution indices, from which the research activity has been eliminated, are promising. These make possible versatile analyses of distribution changes within species, in which the significance of the changes is also tested. The appending of new environmental variables to the covariance models is easy, like those based on satellite data. For example, one could add a habitat variable by classifying the 10-km squares into two categories on the basis of absence or presence of a certain level of habitat, and study the occurrence and changes of birds known to be dependent on that habitat in the atlas data. The use of habitat variables as covariates also offers interesting possibilities.

Some reservations must be expressed on the index suggested in this paper for comparisons of distributions between species: the number 'qualified squares' calculated as a percentage of the square number of the most common species. First, the index is dependent on the distribution of the squares studied at least fairly well in both atlases. In the Finnish atlas survey, data on such squares are underrepresented in distant areas with low human populations, especially in the northern and eastern parts of the country. Second, because only such squares were included, where at least possible breeding of the species was found in either of the atlases, the detectability of the species affects the index. Thus, the index will somewhat favour easily detectable birds in southern agricultural areas.

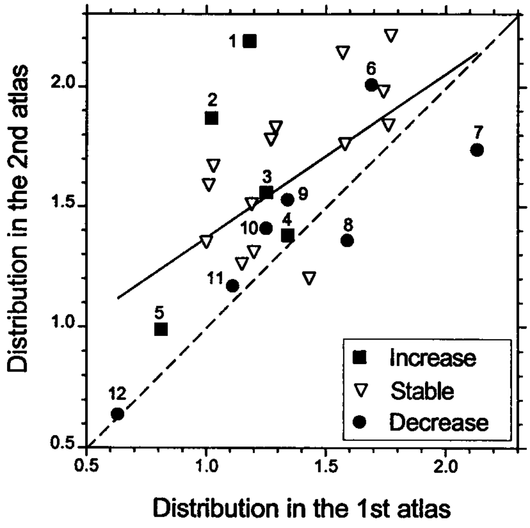

Fig. 6. Change in the distribution index of 26 raptor species between the two atlas surveys. Regression is y = 0.69 + 0.682x (P < 0.001). Dashed line shows the 1:1 change. Because research activity on raptors increased between the atlas surveys, the indices show a strong increase. The change was largest in rare species. On the basis of other monitoring data and faunistical records, one can point to the real changes. Species 1–5 really increased: 1 = *Bubo bubo*, 2 = *Haliaeetus albicilla*, 3 = *Circus aeruginosus*, 4 = *Aquila chrysaetos*, 5 = *C. pygargus*. Species 6–12 really decreased: 6 = *Accipiter gentilis*, 7 = *Strix aluco*, 8 = *Falco tinnunculus*, 9 = *F. subbuteo*, 10 = *Pernis apivorus*, 11 = *F. columbarius*, 12 = *Milvus migrans*.

5.3. Comparison between two successive atlases

An essential assumption for the data is that the atlas methods must remain stable. However, in developing methodology between the two first atlas surveys in Finland, the number of basic categories of evidence of breeding for a species in a square was reduced from 17 to 9 (Väisänen 1989). Does this change disturb the use of breeding evidence as the dependent variable in the models? Although the breeding evidences were condensed into four main classes, and their ranks were used in more demanding tests, the renewal may have increased the statistical noise in the results to some extent (cf. changes in Table 2). It would have been wiser not to reduce the number of the original categories in the second atlas, even if the purpose made sense: the shorter codes were meant by the national atlas committee to be more logical and also to make the data input easier.

The other essential qualification for the data is that the research activity on different species remains reasonably stable between the atlas surveys. The deviation from this assumption biased the comparisons of the atlas results on raptors (Fig. 6), and the more the rarer bird was in question, because the large-scale monitoring of raptors began in 1982, shortly after the first bird atlas. A special case even among this group is the Golden Eagle, which has together with three other raptors been monitored from the beginning of the 1970s. The data on the Golden Eagle were uninformative in the analysis of covariance. The basic reason was that most of the breeding observations were made by the monitoring team at remote atlas squares in northern Finland, where the other atlas data were often poor. Thus, the research grades of the squares were not correlated with the breeding evidences of the Golden Eagle.

Besides the raptors, the atlas data on threatened birds forms another special case (38 species, 10 of which are raptors). The Conservation Committee published the catalogues of threatened flora and fauna in Finland in 1986, just when the second bird atlas survey was started. The Red Data Book notably increased the interest in threatened birds in the atlas studies. Accordingly, their distribution indices easily show unreasonable increases after the first atlas, because the threatened birds have been sought out more in the second atlas survey. Between the atlas surveys, the breeding places of some birds also became better known through various projects of BirdLife Finland, for example, those of the Red-throated Diver *Gavia stellata* and the Crane *Grus grus*. Totally, in 20–25% of the 248 species belonging to the Finnish avifauna the increase in research activity between the atlas surveys may have biased the distribution indices.

The problems presented in the introduction are fundamental in the exploitation of atlas data. This paper offers a solution on how to systematically and (fairly) objectively analyse changes in distribution between two bird atlas surveys. For those planning the data collection for second or later atlases, conservatism is suggested in methodological reforms, if the data will be used to study changes in distribution (cf. Gibbons et al. 1993; see also Gates et al. 1994, Gibbons et al. 1995).

It is also reasonable to store the basic data from each atlas into files as completely as possible. Thus, although the collection of the data for the first atlas survey would last for (unreasonably) many years, it would be of value to start the second atlas survey rather soon after publishing the results of the first atlas. If the year is recorded in observations, one can use it as a covariate in comparing the squares that have been studied in quite different times of the work on the two atlases, and thus analyse distribution changes of species.

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Selostus: **Lajien levinneisyysmuutokset lintuatlasten välillä, kun tutkimusteho-erot tasoitetaan**

Vuosina 1974–1979 ja 1986–1989 toteutetuissa Suomen lintuatlaksissa pyrittiin löytämään kaikki pesimälajit kultakin 10 km × 10 km:n suuruiselta yhtenäiskoordinaatiston ruudulta ja määrittämään, miten varmasti nämä lajit ruudulla pesivät. Atlasruudun selvitysaste kuvaa ruudun tutkimustehokkuutta eli sitä, kuinka hyvin retkeily kattoi ruudun eri osa-alueet ja maastotyypit, kuinka täydellinen havaittujen lajien luettelo on (arvioituun) todelliseen verrattuna ja kuinka luotettavia pesimisvarmuusindeksit ovat. Selvitysasteluokat ovat: 0 = ruudusta ei ole atlashavaintoja, 1 = ruudusta on satunnaistietoja, 2 = ruutu on tutkittu välttävästi, 3 = tyydyttävästi, 4 = hyvin tai 5 = erittäin hyvin.

Kuvassa 4 ovat kolmen yleisen lajin leppälinnun (A), punakylkirastaan (B) ja kulorastaan (C) pesimisvarmuudet kahden lintuatlaksen yhdistetyssä aineistossa Pohjois-Lapissa. Karttojen ympyrät tarkoittavat pienimmästä suurimpaan mahdollista, todennäköistä tai varmaa pesintää atlasruuduissa. Ruutujen selvitysasteet esitetään atlaskartoissa eri varjostuksilla: 1 = valkea, 2 = vaaleanharmaa, 3 = keskiharmaa ja 4–5 = tummanharmaa. Mitä tummempi pohjaväri on, sitä paremmin ruutu on tutkittu. Selvitysasteet helpottavat levinneisyyksien tulkintaa — esim. jonkin lajin puuttuminen valkoisilta ruuduilta voi johtua heikosta havainnoinnista, kun taas tummimmilla ruuduilla kyse on todennäköisemmin lajin todellisesta puuttumisesta alueelta.

Artikkelissa kerrotaan, kuinka ruutujen selvitysasteet on laskettu summaamalla lajien pesimisvarmuuskoodeja (1 = mahdollinen, 2 = todennäköinen ja 3 = varma pesintä) ensimmäisessä ja toisessa atlaksessa sekä niiden yhdistetyssä aineistossa. Selvitysasteista on hyötyä myös tutkittaessa sitä, muuttuiko kunkin lajin levinneisyys tilastollisesti merkitsevästi ensimmäisen ja toisen atlaksen välillä ja oliko muutos yhtä suuri Etelä- ja Pohjois-Suomessa. Analyysi perustuu pesimisvarmuuksien kovarianssianalyysiin, jossa ruutujen väliset tutkimustehoerot poistetaan. Menetelmistä on laaja suomenkielinen selostus tuoreessa kirjassa (Väisänen ym. 1998).

Levinneisyysindeksit muuttuivat tilastollisesti harhaisesti atlasten välillä 20–25 %:ssa Suomen 248 pesimälajista, koska erityisesti uhanalaisia lajeja ja petolintuja etsittiin suuremmalla innolla toisessa atlaksessa. Kuvasta 6 näkyy, kuinka petolintujen levinneisyydet laajenivat epäuskottavasti ensimmäisestä atlaksesta (vaaka-akseli) toiseen atlakseen (pystyakseli), ja erityisen selvästi harvinaisissa lajeissa. Katkoviiva kuvaa teoreettista 1:1 muutosta. Muiden tutkimusten perusteella tiedetään, että lajien 1–5 levinneisyydet todella laajenivat ja että lajit 6–12 taantuivat atlasten välillä.

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