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The efficiency of three-visit square surveys vs. one-visit line transects in censusing sparsely distributed birds in managed forest landscapes

TAPIO SOLONEN and JUKKA JOKIMÄKI

Summary

We conducted three-visit surveys of 1-km² plots and traditional Finnish single-visit line transects (considering only the 50 m wide main belt) to evaluate these methods in censusing of a predetermined set of 23 target species known to prefer old forests in three regions in Finland. The efficiency of the two methods was compared on the basis of the number of territories recorded per hour. An attempt was made to find indicators of the occurrence of suitable habitats for species preferring old forest in general, including the rarest ones, and so also largely indicating total diversity of forest bird fauna of the study area. The total number of pairs observed per hour and the abundance of sedentary bird species were significantly higher in the square surveys than in the main belt of the line transects. There were significant positive relationships between the densities of relatively abundant (density > 1.0 pairs km^{-2}) and less abundant target species. There emerged five common forest bird species that seemed to form a suitable set of indicators of the occurrence of habitats for birds preferring old forest in the northern boreal zone: Great Spotted Woodpecker *Dendrocopos major*, Mistle Thrush *Turdus viscivorus*, Willow Tit *Parus montanus*, Eurasian Treecreeper *Certhia familiaris*, and Eurasian Bullfinch *Pyrrhula pyrrhula*. We concluded that sedentary species preferring old forest are good candidates for indicators to characterize some threatened aspects of forest bird diversity.

Introduction

Sustainable development of forests requires the reconciliation of demands for biodiversity conservation and forestry. The European Union pledged to halt biodiversity loss by 2010. However, we still have inadequate systems to measure biodiversity change (Balmford *et al.* 2003, Green *et al.* 2005, Butler *et al.* 2007). Biodiversity assessment methods that are ecologically efficient and economical are rare (Lawton *et al.* 1998, Simberloff 1998, Carlson and Schmiegelow 2002, Similä *et al.* 2006, Brambilla *et al.* in press). Birds comprise one of the best-known groups of organisms, compact but diverse enough for various scientific and conservation purposes. From the conservation point of view, they of course have value in their own right, but on a larger scale, they may also be suitable as more general environmental indicators (Solonen 1984, Temple and Wiens 1989, Bibby 1999, Donald *et al.* 2001, Gregory *et al.* 2003, 2005). However, birds are so diverse a group that they cannot be monitored by a single universal method (e.g. Ralph and Scott 1981, Bibby *et al.* 1992, Gregory *et al.* 2004). So instead, a set of methods may be needed for a comprehensive monitoring programme. A good set of methods is a compromise between the requirements of cost efficiency by being as simple (easy to do) and as effective as possible.

Various forest bird species have declined in boreal forests of Scandinavia and Russia, as well as in coniferous forests elsewhere in Europe, due to habitat alterations caused by forestry and some of them have been considered threatened to a greater or lesser extent (Järvinen *et al.* 1977, Marchant *et al.* 1990, Väisänen *et al.* 1998, BirdLife International 2004, Reif *et al.* 2008, Ottvall *et al.* 2009). Line transects are in general suitable for censusing and monitoring most of the common forest birds that have relatively small home ranges (Koskimies and Väisänen 1991, Bibby *et al.* 1992, Gregory *et al.* 2004). Other methods are needed for sparsely distributed species, such as tetraonids (Lindén *et al.* 1996) and birds of prey (Saurola 2008). There are, however, many less numerous forest bird species that are not adequately sampled by the methods generally used in nationwide or regional monitoring programmes (Marchant *et al.* 1990, Väisänen *et al.* 1998, Ottvall *et al.* 2009). Therefore, an additional method is needed to detect effectively the abundance of these species.

Current bird census methods, such as line transects or point counts, have been developed to monitor population changes of common/abundant bird species in large areas (Koskimies and Väisänen 1991, Bibby *et al.* 1992). These two methods are efficient in collecting general data about species' densities and their trends. However, the basic versions of these methods, such as the traditional Finnish line transects used commonly in volunteer-based monitoring projects in Finland, are based on single visits (Koskimies and Väisänen 1991). A single-visit method detects about 60% of breeding pairs and 90% of species in forested areas in Finland (Järvinen and Lokki 1978; see also Kissling and Garton 2006), but there are large differences between species (e.g. Tiainen *et al.* 1980, von Haartman 1984, Hildén and Järvinen 1989). In addition, only a small proportion of observations collected on line transects (i.e. observations made within a 50-m wide main belt) or point counts (observations made within a 50-m radius) can be directly linked to corresponding habitat data. Normally about 15–25% of the observations on line transects are made in the 50-m wide main belt, and in areas of low bird density the proportion can be as low as 5% (http://www.fmnh.helsinki.fi/seurannat/linjalaskenta/index.htm). Koskimies and Väisänen (1991) suggested that the single survey should be conducted around midsummer. However, this kind of monitoring scheme does not necessarily give a reliable picture of sparsely distributed populations, in particular those of early-breeding residents (e.g. Rosenvald and Lõhmus 2007).

In the present study, conducted in co-operation with BirdLife Finland and Metsähallitus (The Finnish Forest and Park Service, the manager of state-owned lands in Finland), we investigated a method suitable for censusing less abundant forest bird species that were difficult to sample adequately with other methods. Our goal was to find a method of obtaining, as easily and economically as possible, sufficient data on the occurrence of bird species that prefer old forests within managed forest landscapes. We compared the most commonly used bird census method in Finland (line transect) to the most promising simple alternative (square survey) in detecting a predetermined group of bird species. These target species mainly included species that preferred regionally rare habitat elements, in particular, old forests. They were also expected to indicate at least the potential occurrence of less abundant bird species of old forests that are not adequately sampled even by the present method. Therefore, they should also indicate some threatened aspects of total forest bird diversity. We collected data from three geographical areas, representing a wide latitudinal range of boreal forests, to assess whether the square survey is usable in the boreal zone as a whole, and which of the proposed indicator species might be suitable for different latitudes. We also briefly discuss the applicability of our findings in a wider context of European forest bird communities.

Material and methods

Study areas

The fieldwork was conducted within a ten-week period in April–July 2004, taking into account latitudinal differences in breeding times within the boreal zone (see Hämet-Ahti 1981) in Finland: 1) Meltaus (northern Finland, 66°N, 25°E), 2) Patvinsuo (eastern Finland, 63°N, 30°E), and 3) Seitseminen (southern Finland, 61°N, 23°E) (Figure 1). A set of 1 × 1 km study squares of the Finnish ordnance survey uniform grid system was established in each study area. The study squares were situated within larger, continuous forest areas for which there were detailed patch data available from Metsähallitus. The study squares represented the general forest environments of the districts concerned and were selected so that the total proportion of environments other than forests (such as fields and water) was as low as possible (approximately less than 10%). In this study, "old forests" largely represent mature and near mature stands (at least about 50 years old), the oldest and most natural ones in the study areas. Most stands were younger and largely commercially used.

As is probably usual in long-term monitoring projects not dependent on volunteers, the scope of the present pilot project was limited by the scarcity of financial resources. This obliged us to set efforts at an acceptable minimum, considering the nationwide coverage and sufficiency of the regional data. Therefore, we accepted a regional minimum of 10 squares expected to support several pairs of our target species in each region, according to the known general regional densities of the species (Väisänen *et al.* 1998). Thanks to some additional resources, seven extra squares were surveyed at Patvinsuo. This gave a total of 37 sampled study squares (Meltaus 10, Patvinsuo 17, Seitseminen 10).

Bird species

Because an accurate and comprehensive census of the total forest bird fauna needed for a detailed monitoring programme would be quite time-consuming and consequently expensive, we studied a predetermined group of less abundant forest bird species (Table 1) that were known to prefer old or mature forests. The selection of these target species was based on their habitat needs derived from von Haartman *et al.* (1963–1972), Väisänen *et al.* (1998), and the long experience of the authors. Most of the species selected clearly prefer the oldest age classes of forests, though many of them occur in younger forests as well (e.g. Väisänen *et al.* 1998, Kouki and Väänänen 2000,

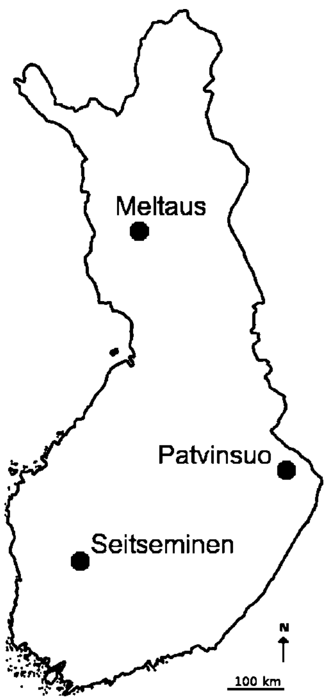

Figure 1. A schematic map showing the approximate location of the regional study areas (Meltaus, Patvinsuo, and Seitseminen) in Finland.

Mönkkönen *et al.* 2000, Jansson 2001, Virkkala and Rajasärkkä 2001). In addition to habitat preferences, the species should be abundant enough to gather an adequate dataset for analysis, they should live within a fairly restricted area, and they should be relatively easily detectable. For that reason, sparse, wide-ranging and nocturnal species such as birds of prey and owls were left out of the study. By excluding the census of common species in the study squares, the total effort could be directed more effectively to such sparsely distributed species that probably are more sensitive to habitat alterations than common species.

Monitoring the effects of specific habitat alteration is most revealing if birds are grouped by habitat-use strategies (e.g. Root 1967, Järvinen and Väisänen 1979). For the northern boreal forest ecosystem, sedentary bird species and hole-nesters might be suitable groups for evaluating the effect of forestry on biodiversity (Haapanen 1965, Järvinen *et al.* 1977, Helle 1985a, Jokimäki and Huhta 1996, Schmiegelow *et al.* 1997, Virkkala 2000). We therefore grouped the target species by migratory habit (sedentary and partially migratory *vs.* migratory) and nest site (hole-nesters *vs.* open-nesters) (Table 1).

Census methods

Fieldwork concentrated on accurate censusing of the target species (Table 1) with standard three-visit effort in the 1 × 1 km study squares. Plot-based censuses have been earlier applied by various authors (e.g. Palmgren 1930, von Haartman 1984). We chose to evaluate the three-visit plot survey due to its practicality and ease of application and because a similar innovative method (Pakkala and Väisänen 2000, 2001) was recently introduced for monitoring breeding birds in Finland. The study squares were surveyed for the target species in April–May, in the first half of June, and after mid-June. In each census, the study squares were investigated thoroughly, with about five hours spent

Table 1. Migratory habits and nest sites of the preselected target species. Mean densities (pairs km^{-2} ± SD) of each species in the 1 × 1 km study squares (n = 37) are also given.

Species	Migratory habit	Nest site	Pairs km^{-2}	SD
Dendrocopos major	Resident	Hole	2.4	1.6
Picoides tridactylus	Resident	Hole	0.2	0.3
Parus montanus	Resident	Hole	4.7	2.9
Parus cinctus	Resident	Hole	3.1	2.1 *
Parus cristatus	Resident	Hole	3.1	2.1 *
Parus caeruleus	Resident	Hole	0.7	0.1
Parus major	Resident	Hole	2.4	2.5
Certhia familiaris	Resident	Hole	0.9	1.2
Bonasa bonasia	Resident	Open	1.9	2.1
Lagopus lagopus	Resident	Open	0.3	0.5
Bombycilla garrulus	Resident	Open	1.0	1.3
Perisoreus infaustus	Resident	Open	0.3	0.5
Pyrrhula pyrrhula	Resident	Open	3.2	2.5
Jynx torquilla	Migratory	Hole	0.4	0.7
Troglodytes troglodytes	Migratory	Hole	0.2	0.7
Phoenicurus phoenicurus	Migratory	Hole	4.6	3.7
Ficedula parva	Migratory	Hole	0.2	0.4
Ficedula hypoleuca	Migratory	Hole	2.7	2.4
Turdus viscivorus	Migratory	Open	1.4	1.0
Phylloscopus trochiloides	Migratory	Open	0.2	0.3
Phylloscopus sibilatrix	Migratory	Open	0.2	0.0
Phylloscopus collybita	Migratory	Open	1.0	1.3
Emberiza rustica	Migratory	Open	0.8	1.1

*Here *Parus cinctus* of the northernmost region and *P. cristatus* of the other regions are combined.

per square. All records of the target species were plotted on a copy of the forest patch map, and attempts were made to estimate the number and location of their territories using available knowledge on their habits and habitats. The local groups of records or clearly separate single observations of resident individuals that expressed activities associated with breeding (such as song, warning, feeding) were interpreted as indicating territories, following broadly the general practices of the mapping method (e.g. Bibby *et al.* 1992). In general, the censuses also covered those parts of forest patches that were left outside the limits of the study squares.

For comparison, some traditional Finnish line transects with a 50-m wide main belt (Järvinen and Väisänen 1975) were conducted in the same general area as the study squares. In each region, the line transects were designed to overlap the set of study squares as far as possible. To link the observations to habitats as in the square surveys, only the data on the main belt that could be examined in sufficient detail were considered. Line transects were conducted in each of the study areas in suitable weather conditions and during the most active singing period of most of the species in the first half or around the middle of June, with a walking speed of about 1 km h^{-1} (Järvinen and Väisänen 1983, Järvinen *et al.* 1991). The observations were transferred to maps. In this way we gained knowledge especially on the occurrence and general densities of birds in the study areas. The total length of line transects covered 8.0 km in northern Finland (Meltaus), 12.0 km in eastern Finland (Patvinsuo), and 11.5 km in southern Finland (Seitseminen).

Because the unlimited survey belts of line transects do not allow detailed habitat analyses, we used only the main-belt data in the efficiency comparisons. Line transects did not cover the study plots exactly or comprehensively so the available data did not allow a sound comparison of census methods. Therefore, two kinds of indirect statistical comparisons were performed. Firstly, we compared the number of records of various sets of species per hour spent on the fieldwork. This was done on the assumption that data collected by each census method were derived from the same pool of potential observations. Due to spatial and quantitative differences in the data collected by different methods and spatial heterogeneity of environments, this was not exactly the case. Secondly, we compared the number of records per hour in relation to the density estimates based on the data gathered by each method. So the number of records should increase both with increasing time spent on the census work and with the density of territories.

Statistical methods

We used general linear modelling analyses (GLM; SPPS Inc. 2006) to study the effects of study area (region) and survey method (square *vs.* line transect) on the number of pairs observed per survey hour. In these analyses, study area and survey method were used as the main effects, and intercept as well as the interaction term (study area × survey method) were included in the models. At the species level, we firstly analysed whether the abundance of individual species differed between study areas. If the abundance of individual species did not differ between study areas (20 species in our case), we conducted an analysis of variance where the survey method was used as a main effect variable. We used the Bonferroni sequential correction for *P*-values to minimise table-wise errors in multiple tests (Rice 1989).

Relationships between the abundance of relatively common and less common target species (Table 1) were analysed by using the square survey data. A backward stepwise multiple regression (BSMR) analysis (dependent variables ln-transformed; F-to-remove 3.9) was conducted separately for the total pooled data and for the individual study areas (regions). In the present pooled dataset analyses, the abundance of the relatively abundant species was at least 50 pairs, whereas the abundance of less abundant ones was 4–10 pairs. In the regional level data sets, the abundance of relatively abundant species was at least 30 pairs, whereas the abundance of less abundant species was 4–10 pairs within a specific study area. The densities of the less abundant (at most 1.0 pairs km^{-2}) target species were dependent variables, while the densities of the other (more than 1.0 pairs km^{-2}) target species served as independent variables (see Table 1). Analyses were conducted using SigmaStat 3.1 statistical software (Systat 2004).

Our somewhat traditional statistical methods seemed to be suitable for demonstrating our ideas on indicator species in the present data. With more comprehensive or larger data sets more effective methods, such as mixed models and model averaging (Burnham and Anderson 2002) might be preferable.

Results

Comparison of census methods

Only the survey method affected the total number of pairs detected (Table 2). The total number of pairs per hour was significantly higher in the square surveys (range 0.093–0.126) than in the main belt of the line transects (0.045–0.078). The two-factor interaction term (study area × survey method) was not significant, indicating that the square survey was a more effective method in all study areas.

The abundance of resident species was significantly higher in the square surveys (0.098–0.109) than in the main belt of the line transects (0.051–0.082) (Table 2). The interaction term indicated that the square survey was the more effective method for detecting resident bird species in all study areas. The abundance of hole-nesters and open-nesters was nearly significantly higher in the square surveys than in the main belt of the line transects.

At the species level, the abundance of the Blue Tit *Parus caeruleus* ($F = 29.6$, $P = 0.011$, df = 2), Great Tit *Parus major* ($F = 12.96$, $P = 0.033$, df = 2) and Common Chiffchaff *Phylloscopus collybita* ($F = 19.13$, $P = 0.020$, df = 2) differed between study areas. Therefore, no further analyses were conducted on these species. The numbers of Great Spotted Woodpecker *Dendrocopos major* (0.155–0.030 in square surveys *vs.* 0.000–0.000 in line transects), Three-toed Woodpecker *Picoides tridactylus* (0.008–0.005 *vs.* 0.000–0.000), Mistle Thrush *Turdus viscivorus* (0.087–0.023 *vs.* 0.000–0.000), and Eurasian Bullfinch *Pyrrhula pyrrhula* (0.900–0.091 *vs.* 0.028–0.048 pairs

Table 2. The effects of study area (Meltaus, Patvinsuo, Seitseminen), survey method (three-visit square survey *vs.* one-visit main belt of line transect) and their interaction on the number of pairs of target species detected per hour according to the GLM analysis of variance.

	df	*F*	*P*
Total number of pairs			
Study area	2	0.102	0.903
Survey method	1	6.938	0.009
Study area × Survey method	2	0.564	0.570
Nest site categories			
Hole nesters			
Study area	2	0.043	0.958
Survey method	1	3.951	0.051
Study area × Survey method	2	0.333	0.718
Open nesters			
Study area	2	0.232	0.794
Survey method	1	3.965	0.052
Study area × Survey method	2	0.580	0.563
Migratory categories			
Resident species			
Study area	2	1.509	0.228
Survey method	1	4.641	0.035
Study area × Survey method	2	0.196	0.822
Migratory species			
Study area	2	1.157	0.322
Survey method	1	2.505	0.119
Study area × Survey method	2	0.435	0.649

detected per hour) were significantly higher in the square surveys than in the main belt of the line transects (Table 3). The effects of study method on 16 other target species were not significant ($P > 0.05$). When using sequential Bonferroni correction for the multiple tests, only the results of the Great Spotted Woodpecker and the Mistle Thrush were significant at the P-value 0.05.

Relationships between relatively common and less abundant target species

According to the pooled data analyses, a relatively high proportion (20–70%) of the variation of the abundance of the less common target species was explained by that of the relatively common species (Table 4). Mistle Thrush, Willow Tit *Parus montanus* and Eurasian Treecreeper *Certhia familiaris* contributed positively to the models of three less common species, whereas Great Spotted Woodpecker, Bohemian Waxwing *Bombycilla garrulus* and Common Redstart *Phoenicurus phoenicurus* had a similar effect in the models of one less common species (Table 4).

In regional analyses, the proportion of the variation in abundance of less common target species that was explained by the relatively common target species varied from 18% to 100% (Table 5). The Eurasian Bullfinch had a positive effect in the models of seven less common species, and Great Spotted Woodpecker, Bohemian Waxwing, European Pied Flycatcher *Ficedula hypoleuca*, Great Tit and Eurasian Treecreeper in the models of four less common species (Table 5). Species also showed various negative relationships. The species explaining the abundance of less common target species varied between study areas. The Eurasian Bullfinch was most often included in the list of the positive explanatory variables in Meltaus and Seitseminen, and Eurasian Treecreeper in Patvinsuo. Great Spotted Woodpecker was the only species included in the positive explanatory variable lists in all study areas.

The number of territories of the regionally less abundant target species (in total 4–10 territories per species) and the relatively abundant target species (in total about 30 territories or more) showed a positive correlation that was significant in two of the three study areas (Meltaus and Seitseminen; Figure 2). Due to the small sample size, all target species were included in these analyses to demonstrate the potential of the indicator species to perform in situations when the abundance of the least abundant species is not quantified satisfactorily.

Discussion

Census methods

The Finnish line transect survey method (Järvinen and Väisänen 1975, Koskimies and Väisänen 1991) is an easy and effective method for obtaining density estimates of common breeding birds in forest landscapes (e.g. Tiainen *et al.* 1980). However, the three-visit square survey method seemed to be more suitable for censusing various less abundant bird species in largely commercially used boreal forests. The suggested survey period for the single-visit line transect census in southern Finland is 1–17 June and in northern Finland 10–30 June (Koskimies and Väisänen 1991). However, many of the old-forest bird species, especially the resident ones, start their breeding activities (e.g. territorial singing) much earlier than the suggested survey periods

Table 3. The effects of survey method (three-visit square survey *vs.* one-visit main belt of line transect) on the number of individual species pairs detected per hour according to the GLM analysis of variance. Only species with significant results (before Bonferroni correction) are shown.

		df	*F*	*P*
Pyrrhula pyrrhula	Survey method	1	7.520	0.052
Dendrocopos major	Survey method	1	81.205	0.001
Picoides tridactylus	Survey method	1	8.174	0.046
Turdus viscivorus	Survey method	1	41.513	0.003

Table 4. The relationships between the abundance of less common and relatively common target species according to the pooled data set of different study areas. Total contributions include negative relationships with the following target species: [1]*B. garrulus*, [2]*Ph. collybita*, [3]*P. cristatus*, [4]*C. familiaris*. N = normality test failed, C = constant variance test failed. *F* and *P* of the variance analyses and adjusted coefficients of multiple determination (adj R^2 as percentages) are given.

Dependent	Independent	*F*	*P*	Adj R^2 %
L. lagopus	*P. phoenicurus*	10.8	0.002	
	B. garrulus	9.7	0.004	
	Total[4]	23.2	< 0.001	64.9
P. tridactylus	All eliminated			
J. torquilla	*T. viscivorus*	9.5	0.004	
	Total[3] N C	5.4	0.009	19.7
T. troglodytes	*C. familiaris*	16.6	< 0.001	
	Parus montanus	13.6	< 0.001	
	T. viscivorus	8.6	0.006	
	Total[1]	20.8	< 0.001	68.8
Ph. trochiloides	*Parus montanus*	20.4	< 0.001	
	C. familiaris	14.2	< 0.001	
	Total[1]	28.3	< 0.001	69.4
F. parva	*C. familiaris*	16.9	< 0.001	
	Parus montanus	12.0	0.002	
	T. viscivorus	8.6	0.006	
	Total[1]	22.4	< 0.001	70.4
P. infaustus	*B. bonasia*	27.8	< 0.001	
	D. major	7.1	0.012	
	Total[2, 3]	22.5	< 0.001	70.5

(von Haartman *et al.* 1963–1972). Therefore, midsummer single-visit surveys might probably underestimate the abundance of early breeding species. Because the three-visit study square method includes also a survey made early in the breeding season (April–May), this method should sample these species more effectively than midsummer line transects. Our results support this hypothesis, since square surveys detected more pairs per survey hour of old-forest bird species, especially resident ones, than could be collected by the main belt of the line transects.

It is possible to repeat line transects three times covering the whole breeding season. However, estimations of breeding density on line transect surveys are not based on defining territories and their boundaries as they are in square surveys. Line transects give relatively scanty information about direct relationships between bird species and their habitats because only observations made within the 50-m main belt can be linked directly to specific habitat patch and habitat variables. Interpretation of territories linked by habitat variables is more reliable based on the multiple records of individuals in square surveys than on the single-visit results of the main belt of line transects.

Indicator species

There were significant positive correlations between the densities of relatively abundant and less abundant old-forest bird species. In general, the total number of pairs of abundant old-forest bird species seemed to be quite a good indicator of the occurrence of less abundant species (cf. Canterbury *et al.* 2000, Su *et al.* 2004). These findings suggest that the occurrence of relatively abundant old-forest species can indicate some habitat features that are also important for less abundant old-forest bird species that are less easily censused and monitored effectively due to their low densities and that are probably more important from the conservation point of view.

The indicator species suitable for large-scale monitoring of old-forest birds should be relatively abundant and they should be detectable with reasonable effort. Their preferred characteristics

Table 5. The relationships between the abundance of less common and relatively common target species in different study areas. Total contributions include negative relationships with the following target species: [1]*B. bonasia*, [2]*D. major*, [3]*B. garrulus*, [4]*Ph. phoenicurus*, [5]*T. viscivorus*, [6]*Ph. collybita*, [7]*F. hypoleuca*, [8]*P. montanus*, [9]*C. familiaris*, and [10]*P. pyrrhula*. N = normality test failed, C = constant variance test failed. *F* and *P* of the variance analyses and adjusted coefficients of multiple determination (adj R^2 as percentages) are given.

Dependent	Independent	*F*	*P*	Adj R^2 %
Meltaus				
L. lagopus	*P. pyrrhula*	7.9	0.037	
	B. garrulus	4.5	0.088	
	Total[1, 8]	11.7	0.009	82.6
P. tridactylus	Total[1, 2, 4, 5, 10]	15.3	0.010	88.8
J. torquilla	*B. garrulus*	1639.2	< 0.001	
	P. pyrrhula	527.2	< 0.001	
	Parus montanus	26.5	0.014	
	F. hypoleuca	6110.0	< 0.001	
	Total[1, 4]	10000.0	< 0.001	99.9
P. infaustus	*B. bonasia*	13.7	0.014	
	D. major	11.1	0.021	
	P. pyrrhula	5.4	0.067	
	Total[3]	7.2	0.026	73.4
Patvinsuo				
L. lagopus	*E. rustica*	10.1	0.008	
	F. hypoleuca	5.0	0.045	
	Total N	3.7	0.035	40.3
P. tridactylus	*C. familiaris*	237.8	< 0.001	
	B. garrulus	15.3	0.003	
	D. major	10.3	0.009	
	P. major	7.4	0.022	
	Total[6, 7]	55.3	< 0.001	95.3
J. torquilla	*T. viscivorus* N C	4.4	0.053	17.7
T. troglodytes	*C. familiaris* N	34.6	< 0.001	67.7
Ph. trochiloides	*Ph. phoenicurus*	25.3	< 0.001	
	T. viscivorus	15.5	0.002	
	B. bonasia	8.7	0.013	
	Parus cristatus	4.1	0.067	
	Total[10]	10.6	< 0.001	75.1
F. parva	*C. familiaris* N	38.4	< 0.001	70.0
P. infaustus	*C. familiaris*	237.8	< 0.001	
	B. garrulus	15.3	0.003	
	D. major	10.3	0.009	
	P. major	7.4	0.022	
	Total[6, 7]	55.3	< 0.001	95.3
Seitseminen				
P. tridactylus	*Ph. collybita*	10.3	0.024	
	D. major	9.8	0.026	
	Total	7.3	0.025	73.8
J. torquilla	*P. pyrrhula*	85.7	0.003	
	Parus cristatus	43.1	0.007	
	Parus montanus	21.9	0.018	
	Total[6, 7, 9]	22.4	0.014	93.4
T. troglodytes	*F. hypoleuca*	29.2	0.012	
	P. pyrrhula	22.2	0.018	
	P. major	18.7	0.023	
	Total[2, 8, 9]	16.5	0.021	91.2
Ph. trochiloides	*P. pyrrhula* C	7.9	0.023	43.6

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Table 5. (*Continued*)

Dependent	Independent	F	P	Adj R^2 %
F. parva	*F. hypoleuca*	29.2	0.012	
	P. pyrrhula	22.2	0.018	
	P. major	18.7	0.023	
	Total[2, 8, 9]	16.5	0.021	91.2

include resident habits and the dependence on some primeval features of old forests. These requirements seem to be best fulfilled in small-sized sedentary species (see also Jansson 2001, Forslund 2003, Roberge and Angelstam 2006, Drever and Martin 2010). According to frequency as an explanatory factor (Tables 4 and 5), a suitable set of common primary indicators of old forests in northern Europe should include Great Spotted Woodpecker, Mistle Thrush, Willow Tit, Eurasian Treecreeper, and Eurasian Bullfinch. These species are commonly known to reflect the impact of forestry and the occurrence of old forests within the boreal zone (e.g. Haapanen 1966, Ekman 1979, Helle 1984, Kuitunen and Helle 1988, Haila *et al.* 1989, Raivio and Haila 1990, Virkkala *et al.* 1994, Edenius and Elmberg 1996, Väisänen *et al.* 1998).

We conducted our research in forest-dominated landscapes in Finland. Care must be taken when choosing more common species as surrogates of biodiversity in other areas, because of the differences in forest types as well as forest cover and ecological quality across Europe. For example, the Mistle Thrush is a common bird in Central European towns, whereas it is not urbanised in Finland (Jokimäki and Kaisanlahti-Jokimäki 1999). In northern Finland, even a small-scale seasonal urbanisation (at tourist destinations) might decrease the abundance of the Mistle Thrush (Jokimäki *et al.* 2007). Using Great Spotted Woodpecker and European Bullfinch as indicator species may entail the same kinds of problems. In addition, the abundance of the Great Spotted Woodpecker is highly dependent on fluctuating food abundance, i.e. seeds of coniferous trees (Väisänen *et al.* 1998). So it is obvious that species which are good indicators of habitat quality in one country are not necessarily suitable indicators in another (Lõhmus *et al.* 2005).

In a representative monitoring programme, it is useful to supplement the scanty data on rare species with data on regionally more common species. Due to their habitat preferences and general abundance, European Pied Flycatcher and Great Tit might be suitable additional indicator species in areas where their densities are not elevated artificially by provision of nest boxes. A diverse group of indicator species shows more clearly than a single species the factors affecting the diversity of forest bird assemblages. For instance, the density of sedentary and hole-nesting birds reliably indicates the effect of forest age (e.g. Haapanen 1965, Helle 1985a,b). Negative relationships between indicator and target species may be due to differences in general distribution or habitat requirements. They may also be due to some antagonistic behaviour such as competition and predation. On the other hand, positive relationships may be affected by similar habitat requirements and also by heterospecific attraction between species, in particular by resident species such as tits attracting migratory species to settle in certain habitat patches in northern boreal forests (Forsman *et al.* 1998, Mönkkönen and Forsman 2002).

Relationships between rare species and their indicators should be reviewed on a regular basis because trends in their respective populations may differ at different population densities. To avoid misinterpretation, there should be sets of various indicator species to be monitored. This would improve monitoring of rare species and the changes in relationships between indicators and their respective rare species could also provide valuable ecological information in their own right.

Monitoring bird diversity

Many large-scale monitoring programmes on birds seem to concentrate either on a large spectrum of common and abundant species (e.g. Baillie 1990, Marchant *et al.* 1990, Väisänen

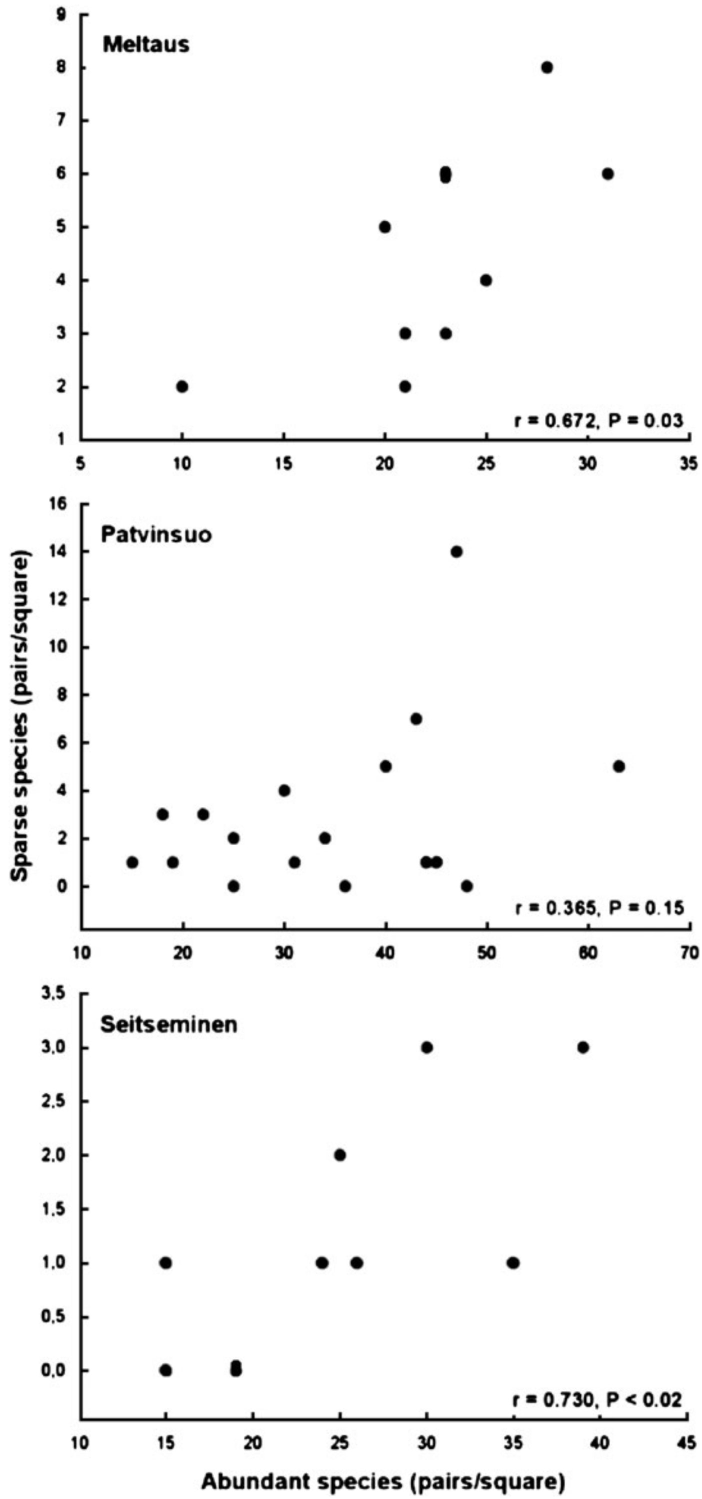

Figure 2. Relationship between the total densities of the common (abundant) and less common (sparse) target species in the survey squares (10–17 per locality) of different study areas. Pearson correlation coefficients (*r*) and their significance are given.

2006), or on some rare species of special conservation interest (e.g. Kovács *et al.* 2008, Saurola 2008). There are, however, various intermediate species which may be in need of monitoring but are missed in traditional monitoring programmes. The result is an inadequate knowledge of the diversity of bird assemblages. Our three-visit square survey method seemed to provide a promising, easy, and economic way to monitor such species of intermediate abundance within the boreal zone (cf. Edenius and Elmberg 1996, Kouki and Väänänen 2000). Probably it is also applicable in coniferous and montane forests of Central Europe (cf. Reif *et al.* 2008). With some local modifications, the method may have even wider international applicability.

Monitoring methods have to be selected according to habits, spatial requirements and abundance of the species to be monitored. Most of the abundant diurnal forest birds can be censused effectively in large areas by such methods as line transects or point counts (Ralph and Scott 1981, Koskimies and Väisänen 1991, Bibby *et al.* 1992). These methods are relatively simple and well-standardised, so are suitable for monitoring large areas but they still largely miss some nocturnal, skulking, wide-ranging and rare species. The less abundant species in general comprise the group of the most conservation interest. To gather relevant samples from these populations, various group- or species-specific methods may be used (Ralph and Scott 1981, Forsman and Solonen 1984, Gregory *et al.* 2004). Various less-abundant species sampled ineffectively or in small numbers by general (line, point) methods for large-scale monitoring of birds also merit special attention and should be monitored in larger numbers by some more effective method. Some relatively common species censused effectively by such a method may also provide an indicative tool for monitoring and predicting the fate of such rare and possibly threatened species that are ecologically similar but too rare to be monitored effectively even by methods suitable for rare species of intermediate abundance.

Conclusions

When building up a monitoring system for old-forest birds, the first step is to select a regionally representative group of indicator species. Based on our results, in addition to rare and threatened old-forest bird species, Great Spotted Woodpecker, Mistle Thrush, Willow Tit, Eurasian Treecreeper, and Eurasian Bullfinch seemed to form a suitable nationwide set of indicators of forest bird diversity in Finland, and they are probably applicable within a much wider range in the boreal zone. At the regional level, some other bird species might be included.

Our results indicate that the three-visit square survey is an effective method to collect data on the abundance of old-forest bird species and their habitat needs. Compared to the traditional Finnish line transect census, the three-visit square survey takes better account of the whole breeding period of forest birds, especially that of early-breeding residents, and allows observations to be linked more directly to habitat characteristics.

Our results show that for relatively rare old-forest species, three-visit square surveys provide more data per unit time than the main belt of single-visit line transects. Based on the description of the methods, to cover an area of 1 km^2 equally effectively, there should be an equal number of territories of the survey species in the main belt of a 20 h (20 km) line transect and in a 15 h survey of a 3-visit study square, when the observations of both methods cover the total area of 1 km^2 comprehensively.

We agree that the Finnish line transect method is suitable for gathering data and monitoring population trends of common forest bird species in a voluntary-based way from large geographical areas. However, to get more reliable habitat-specific data from less abundant species, the three-visit square survey method appears to provide an additional tool for monitoring forest bird assemblages more comprehensively. In practice, the target species as well as the size, number and location of study plots should be defined based on the regional habitat composition, landscape structure, and the approximate densities of the bird species to be considered. In addition, for the wider conservation of forest landscapes, voluntary-based monitoring programmes for rare and threatened bird species should include censuses designed for groups such as game birds and birds of prey.

Indicator species should be selected from a pool of species within a larger area, but within a certain vegetation zone where the habitat requirements among species do not differ appreciably. There should be as many indicator species as possible, in particular when sample size is small, to minimise the effects of stochastic variation. Both indicator and target species should have relatively even distribution throughout the area considered. They should have as similar habitat requirements as possible. There should be no (strong) antagonistic behaviour (competition, predation) between indicator and target species but indicator species should preferably show heterospecific attraction. We are looking forward to tests of the suitability of our method in other parts of the boreal zone as well as similar tests in other kinds of forests elsewhere.

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TAPIO SOLONEN*
Luontotutkimus Solonen Oy, Neitsytsaarentie 7b B 147, FI-00960 Helsinki, Finland.

JUKKA JOKIMÄKI
Rovaniemi Research Unit, Finnish Forest Research Insitute, P.O.Box 16, FI-96301 Rovaniemi, Finland; present address: Arctic Centre, University of Lapland, P.O.Box 122, FI-96101 Rovaniemi, Finland.

**Author for correspondence; e-mail: tapio.solonen@pp.inet.fi*

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